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The social space of complex systems

Rabea Morrison

Thesis submitted for the Degree of Doctor of Philosophy (Ph.D.),

School of Psychology,

Trinity College,

University of Dublin,

September 2013

DECLARATIONS

This thesis is submitted by the undersigned to Trinity College, University of Dublin, for examination for the degree of Ph.D.

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SUMMARY

The thesis aims to advance an understanding of how to address the complexity of socio-technical systems in a way that integrates diverse elements according to the functional logic that is at the core of the system. Questions are posed about how complex socio-technical systems deliver their outcomes, taking a special interest in the social space of these systems, and how based on this, relevant knowledge can be created systematically and utilised effectively.

Chapter 1 positions the thesis in pursuing this research agenda. It argues that the overall challenges facing the aviation industry carry the implication that Human Factors is required to complete its transition into a system science. This is necessary to address on the central role of people as part of systems that extend their reach into a global market. Knowledge and relationships are proposed as key assets in future systems and thus receive special attention in the approach that the thesis develops.

Chapter 2 systematically develops a problem statement using aircraft maintenance as an example system, building on a large body of previous research in that domain. It highlights the requirements for grounding the approach in the socio-technical reality of the system and consolidates a review of theories and approaches that promise leverage over the themes that are being identified. A framework is proposed that consolidates principles for addressing the complexity of the system and provides the baseline for organising the research around two rationales: knowledge structure and knowledge process. The chapter concludes with developing a dedicated multi-method design, the case study arc, which embeds the research within its target systems. This is implemented in the following two chapters, which report on its two interlinked case studies.

Chapter 3 implements the first of the two case studies in the context of the TATEM project, a technology development project that aimed to design innovative technology solutions based on IVHM with the view to deliver the capability for operating maintenance processes more efficiently and, thus, ensure reductions in direct maintenance costs. The chapter reports the conceptual consolidation of the framework and its iterative development into a model base that is deployed in a process that delivers the transformation of the socio-technical dimension of the maintenance operation into a to-be vision that operates TATEM technology solutions.

Chapter 4 introduces the HILAS case study which builds on the conceptual achievements of Chapter 3 and implements the proposed framework in an organisational improvement initiative. In this case study the emphasis shifts from conceptualising the knowledge structure (as expressed in the models of the framework) to more actively designing the knowledge process that deploys it and delivers outcomes that transform the system. In doing so, it advances the validation of Chapter 3 achievements and consolidates a functional level of description as an anchor for effective change.

Chapter 5 consolidates the findings of the case studies and advances a synthesis at a knowledge level. It argues that action that is effective in transforming a system is enabled by knowledge and consolidates the functional role of the social space within the system. Based on this, it advances an understanding of the integration of social and technical aspects in complex systems such as aircraft maintenance.

Chapter 6 derives the overall conclusions of the thesis. It summarise the core achievements of the thesis in a way that makes a case for their capacity to exert leverage and to create value which is then illustrated in its envisaged contributions to emerging SoS based enterprise models. This is the basis for concluding with a value proposition that is based on advancing Human Factors as a system science.

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LIST OF ABBREVIATIONS

5S	Sort, Set, Shine, Standardise, Sustain
AD	Airworthiness Directive
ADAMS	Human Factors in Aircraft Dispatch and Maintenance Systems
AMA	Aircraft Maintenance Assistant
AME	Aircraft Maintenance Engineer
AMM	Aircraft Maintenance Manual
AMO	Aircraft Maintenance Organisation – synonym with MRO
AMPOS	Aircraft Maintenance Procedure Optimisation System
ATOME	Airline Technologies for Operation and Maintenance Enhancement
BPM	Business Process Modelling
CBA	Cost Benefit Analysis
CEO	Chief Executive Officer
CI	Continuous Improvement
COO	Chief Operating Officer
CoP	Community Of Practice
DMAIC	Define, Measure, Analyse, Improve and Control
EASA	European Aviation Safety Agency
EE	Extended Entreprise
ERP	Enterprise Resource Planning
HBR	Harvard Business Review
HFES	Human Factors and Ergonomics Society
HILAS	Human Integration of the Lifecycle of Aviation Systems
HIT	Hangar Improvement Team
HVP	Hangar Availability Plan
IEA	International Ergonomics Association
ISO	International Organization for Standardization
IT	Information technology
IVHM	Integrated Vehicle Health Management
KPI	Key Performance Indicator
KSA	Knowledge Skills Abilities
KSM	Knowledge Space Model
KT	Knowledge transformation
LME	Line Maintenance engineer
MCC	Maintenance Control Centre
MEL	Minimum equipment list
MIS	Maintenance information system

MPD	Maintenance Planning Document
MRO	Maintenance and Repair Organisation – synonym with AMO
mx	Maintenance
NDT	Non destructive testing
NRC	Non Routine Card
OCC	Operations Control Centre
OEM	Original Equipment Manufacturer
OSA CBM	Open System Architecture for Condition Based Maintenance
PI	Performance Indicator
QN	Query Note
R/I	Removal/installation
SB	Service Bulletin
SLA	Service level agreement
SMS	Safety Management System
SoS	System of Systems
SRM	Structural repair manual
TA	Turn Around
TATEM	Technologies and Techniques for new Maintenance concepts
TBS	Troubleshooting
TQM	Total Quality Management
WIPIDO	Well intentioned people in dysfunctional organisations

1 CHAPTER 1: Introduction

1.1 Introduction

Across all types of industries, today's organisations can be described as socio-technical systems. No matter what the domain, technologies – from basic tools to full automation - are operated by people to deliver the aspired outcomes. Therefore, any scientific field concerned with the role of people in these organisations, such as Human Factors, faces the challenges of being a system science. It follows that issues cannot be adequately addressed in isolation, i.e. through the specific lens of a single discipline, approach or methodology, but the elements' interrelatedness inherent to a system requires an interdisciplinary approach. By the same token, the issues are multilayered, escalating from macro (top) to micro (bottom) and vice versa, requiring the consideration of the different system levels.

This chapter will argue that the field of Human Factors appreciates the relevance of systemic thinking and approaches to define their core questions but struggles with the implication of that, i.e. defining and positioning itself as a system science. Adopting a systemic perspective, Human Factors has to accommodate an expansion in focus from how people perform to addressing their performance as part of the overall system performance. Addressing socio-technical system issues means putting forward approaches that can conceptualise the social aspects of the quality of such performance in relation to the technical aspects of the system.

Emerging business models shape the future of operations and the literature indicates a general trend towards an expansion into System of Systems (SoS) which shifts the focus from local processes and their transformative transactions to relationships and knowledge as key assets for organisations. New products and services can only be delivered by a joint capability that cuts across the boundaries of organisations and their processes. This defines new requirements for constructive collaboration between different stakeholders. Features such as central control or a common understanding and culture shaped by shared experience and history, which shape the work in a single organisation (arguably with variable success) do not apply/apply differently to such a set up.

The overall question is how can a system science support these system and SoS scenarios?

The emerging challenges in the industry and how Human Factors is positioned to deal with them are further advanced in this chapter and provide background to the core question, which leads the research trajectory of the overall thesis.

1.1.1 Brief overview of Human Factors

The field of Human Factors is a diverse one. Multiple disciplines such as psychology, engineering, medical or management studies contribute to it, reflecting the complexity of how people and their actions influence their (work) environment and vice versa.

Originating in the time of WWII, Human Factors were established as a response to the observation of problems in production or execution which were not caused by technical faults (Roscoe 1997). The actions

of the human in response to the task defined by the technology were recognised as being relevant for delivering the aspired outcomes, such as safety or efficiency. Since the introduction of HF as a discipline the nature of work has continued to change. As the realities of people's work life have changed and become more complex in the advent of automation, interconnectivity, globalisations and such, Human Factors has continuously evolved and gradually expanded its scope during its relatively young existence.

With the advancements of technologies operated by people the set up of socio-technical systems has changed and thus also the interdependencies between tasks, people and information. Human Factors developed approaches and methodologies to respond to the salient issues of each generation of systems – from a cognitive task focus in increased automation to people and their competencies as a resource in increasingly global markets. The perspective of the human role in socio-technical systems has evolved in response to the dominant work life issues at the time, e.g. increased automation put a focus on HMI, and continues to do so. Over the past two decades Human Factors has extended its frameworks that centred on the individual into systemic approaches (e.g. Senge, 1990), moving from a notion of individual errors to researching how system deficiencies (better: vulnerabilities) contribute to adverse outcomes (e.g. Reason, 1997).

1.1.1.1 Systemic Human Factors definitions

Systemic Human Factors approaches take the emphasis off the individual and highlight the complex relationships between the different system elements, people being one of those, that together deliver its overall performance, e.g. safety, efficiency etc. There are several Human Factors definitions available, many of which focus on the individual which is representative of a (legacy) dominance of cognitive approaches in HF that originates in addressing increased automation at local interfaces as priority issues in HF over the past decades.

However, the most recent human factors definitions advocated by representative bodies such as Human Factors and Ergonomics Society (HFES) and international Ergonomics Association (IEA) adopt a system perspective, either implicitly or explicitly.

The definition of the Human Factors mandate of the HFES discusses the criticality of interfaces which implies a system notion. However, it not only falls short in explicitly stating this, but retreats to identifying Human Performance as the centre piece. "The Human Factors and Ergonomics Society is dedicated to the betterment of humankind through the scientific inquiry into and application of those principles that relate to the interface of humans with their natural, residential, recreational, and vocational environments and the procedures, practices, and design considerations that increase a human's performance and safety at those interfaces." (HFES, 2012) The recognition of the criticality of interfaces implies that performance is not limited to the make up of the person alone. However, the focus is then put on the human performance, which implies that it can be assessed in isolation of how other system elements behave and thus while not explicitly said, seems to resonate with a concept of Human Error.

A definition put forward by IEA (2010) overcomes these limitations and states "Human Factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."

Overall system performance is what Human Factors seeks to influence, by understanding how people interact with other elements of the system. It can be argued that between the performance and interface aspects these definitions also contain an implicit process angle. Performance is traditionally conceptualised and measured in terms of outputs which are delivered by processes. This is in line with general systems theory which argues that processes are at the core of a system and define the transformative actions that deliver system outcome.

1.1.1.2 Definition of Human Factors as a body of knowledge

In his discussion on how to communicate the Human Factors message Chapanis (1991) refers to Human Factors as being a body of knowledge. Different disciplines contribute different aspects to this body of knowledge. The question is how to apply this knowledge to achieve changes in the real world. Coming from an engineering and ergonomics view point,human performance is at the centre of his definition.

His definition focuses on the existing content and structure of the knowledge but neither defines how to build a knowledge base that is adequate (relevance) nor gives insights in how to utilise it (leverage).

The body of knowledge as defined by the scientific and research community accumulates the most prominent paradigms. This is reflected in a review article titled "Cumulative knowledge and HF progress" (Procter & Vu, 2010) which prioritises knowledge delivered by cognitive approaches to Human Factors, implying that what happens within the person is key to effectively doing HF. Even when the emerging relevance of social aspects is discussed and the authors conclude that this requires more attention the same paragraph promotes social cognition as a HF response.

Systemic Human Factors has not accumulated a large body of knowledge in the same way, or at least has not consolidated it in an accessible way. Besides the relatively recent engagement with the system perspective, possible reasons for this could include that boundaries are less clear when dealing with systemic issues, local manifestations of issues have a system origin, the intervention extends beyond a single focus, and change requirements are distributed.

This chapter will argue that approaching Human Factors from these two view points (system, i.e. elements and relations, and knowledge about it) provides a sustainable baseline to engage with emerging business trends that will fundamentally affect the way people work in and across organisations. However, the demonstration of system and knowledge as critical perspectives can only be achieved by implementing these two trajectories in an adequate manner.

Given the previous brief overview of where Human Factors is at in terms of defining itself as a field that wants to deploy its knowledge to impact socio-technical systems and their performance, the question is

what are the challenges that these systems are facing, now and more so in the future, and how far Human Factors areas of expertise are relevant to those.

1.1.2 Aviation as a changing industry

Today's business world is changing, yet again, affecting the people that work in organisations. As in most industries, the aviation industry is facing complex challenges, both external and internal:

- Rapidly, profoundly changing markets requiring resilience/ongoing innovation (e.g. operational concepts such as single sky; supply issues such as fuel; ever increasing demand on capacity both airspace and airport; cost)
- Technology innovation drive organisational change (onboard and offboard)
- Information capabilities with increasing transformation capability (e.g. IVHM, web0.2)
- Regulatory demands arising in response to system (non)functioning (e.g. SMS introduction in aviation)
- Demand from customers, i.e. Passengers (facilitated by more choice, better information, more rights)

It is in response to these challenges that organisations adapt and change continuously. Sometimes the required changes are minor, but often organisations deal with large scale changes. As Keen (1997, The Process Edge) states: "Change has become the norm, not the exception. The old principles of change management, which stressed incrementalism, are inadequate to respond to the waves of change that characterize almost every business environment" (p. 10). He goes on to cite the chairman of a company saying that incremental change is the right idea when the company is the world leader in its field, otherwise quantum-leap improvement is what is called for to stay competitive.

Responding to these challenges can be done reactively, investing to keep up with the minimum requirements or it can be taken as a unique opportunity for proactively designing step changes that go beyond legal requirements and local solutions and allow for sustaining competiveness into the future. Addressing the challenges an industry faces in an integrated way enables large scale change not only within one organisation or domain but meeting the challenges has the potential to transform how organisations across the aviation lifecycle work together to deliver products and services that ultimately benefit the ultimate customer, the passenger (and society). For realising the potential and maximising the benefits of such an integrated change agenda key stakeholders have to extend their focus beyond re-engineering their own organisation and immediate associations and address their responses to the emerging change requirements in a coordinated manner.

In the aviation industry, many key industries players pursue new business models that integrate strategic interests and pursue alliances and other business architecture that implement SoS more formally. Examples that reflect this trend include performance based contracts, extended enterprise, virtual enterprise, airline alliances etc.

The trend of business scenarios being driven by expansion into global markets can be observed in many industries. It is driven by the realisation that, in an integrated, connected business environment like today's, required products and services can only be delivered by a joint capability. The realisation of these

new business models is facilitated by technology innovation that enhances information integration capabilities which in turn enables goal orientated process integration across organisational boundaries.

1.1.3 What core dimensions are being discussed for understanding and leveraging change in this situation?

1.1.3.1 System

Adopting system science approaches, Human Factors moves from being a separate discipline in itself to a multidisciplinary approach that is embedded in all organisational and lifecycle functions. Following the IEA definition (2010) the system's performance is a core concern of future Human Factors.

1.1.3.1.1 Proposition

A **system** is broadly defined as a set of elements that are related in a meaningful way. The set of relationships that binds the entities establishes the system's structure and, thus, defines what the outcomes of particular constellations potentially are. A socio-technical system is people operating complex technologies within highly defined and regulated parameters, across different domains. As with any system it is designed to achieve objectives and its processes organise activities to deliver the relevant outcomes.

As expressed in the IEA definition (2010), Human Factors as a system science is concerned with pursuing ways to contribute to human well being and overall system performance. The reality of socio-technical systems is complex, people operate technologies with the view to deliver outcomes but this is not all that characterises the work situation. There are other influences that are only loosely based on or even go beyond the original system purpose, e.g. political dimensions of industrial relations, aspects of relations between people that are independent of the work situation, etc. However, at the core is the functional logic that is designed into the system structure and implemented in its processes.

The way a system performs is measured in outputs which are delivered by its processes. These implement the functional logic in activities. People are central in socio-technical systems because it is their actions that deliver the transformation required to produce desired outcomes.

The technical elements of the systems are usually well specified and described and subsequently, these aspects of the process benefit from well developed support. Social aspects are less clearly understood, if so more descriptive as independent entities rather than an integrated view on the different system properties (technical social information).

However, when it comes to operating technologies as part of processes in complex systems, it is the interaction and integration of the technical and social space in process activities that enables the system to effectively deliver its outputs. The variability and uncertainty that originate in the set of system interdependencies requires both technical tasks and social interaction to mitigate their effects on the process progression. While people are recognised as critical resources (or in recent discussion more specifically their relationships and knowledge capabilities) it is not well understood how the human and social dimensions deliver value within the functionally based process system.

1.1.3.1.1.1 System of systems (SoS)

Today's business world is changing, yet again, affecting the people that work in organisations. The trend of business scenarios being driven by expansion into a global market can be observed in most industries. As a result, Human Factors is faced with an expansion of the system notion, with the focus shifting from single systems such as individual organisations to system of systems (SoS).

It is difficult to find a succinct definition of SoS. DeLaurentis and Ayyalasomayajula (2009) make the general point that in defining new goals (e.g. shift in operational paradigm in ATC) systems are connected into systems of systems with multiple, heterogeneous actors with differing objectives dealing with more large-scale, socio-technical problems.

The aviation industry can be described as a SoS (e.g. Harris & Stanton, 2010) in which stakeholders in the aircraft lifecycle work together to deliver to the ultimate customer, the passenger. Harris and Stanton (2010) describe aviation as a SoS, following Maier's (1998) general characteristics: operational independence of elements; managerial independence of elements; evolutionary development; possessing emergent behaviour; having a geographical distribution of elements; and add that it is a legacy SoS, i.e. it happened into its current existence.

While the evolution of the aviation SoS may be a legacy, key industry players are taking an active interest in actively (re)designing and proactively managing it. In the aviation industry, many stakeholders pursue new business models that integrate strategic interests and pursue alliances and other business architectures that implement SoS more formally. Examples that reflect this trend include performance based contracts, extended enterprise, virtual enterprise, or airline alliances.

SoS is a useful term to describe the scope of the re-organisation of the industry that is driven by globalisation and expansions. With new enterprise frameworks being increasingly defined, it can be argued that what has been discussed as a SoS is transitioning into a system at a different level and scale. The extended enterprise framework as an example has the potential to integrate components of existing systems and their processes, implementing a functional logic that is designed to deliver outcomes that are of shared value. While this cuts across existing organisational boundaries the description of its features lends itself to considering it as a newly formed system.

The question underlying this argument is whether SoS as a rhetorical device has been adopted to express and emphasise the integrative forces, as outlined in the example of extended enterprise, or the residual diversity in such constellations, as emphasised by Harris and Stanton (2010). While not attempting to answer this question (yet), it can be pointed out that the new business models strengthen the network idea and are emphasising relationships as a critical functional component in these new configurations.

The emerging 'super'- systems have business, operational, technology and social dimensions. While there are formal architectures (for example, service orientated architectures) that account for and manage the functional integration of process and data interfaces, less emphasis is put on how to design and implement the social processes that enable the realisation of the production-focused process logic. In interactions, knowledge is created, transformed and transferred. While information systems integrate processes, social integration is required to elicit the relevant knowledge about new ways of working

together. Only together do they realise or enable effective implementation of processes that cut across currently existing organisational structures.

1.1.3.1.2 Human Factors challenge

The first step is having identified the scope of Human Factors as the system level - or emerging enterprise concepts that promise to make system of systems (SoS) accessible at a system level. While HF has the potential, it is not in a position yet, to proactively address issues at a system level in an effective and sustainable manner. Harris and Stanton (2010) conclude that HF has a strong basis but is too fragmented as a discipline to address system issues in an integrated way, yet. Taking stock of the capability of addressing the complex system of systems issues, they come to the conclusion: "For the majority [...], the discipline has essentially been building its applied science base, drawing heavily from experimental and social psychology, engineering and aerospace medicine, and providing bespoke solutions to localised problems. However, as a result it has also tended to become a somewhat fragmented discipline. While increasing levels of specialisation served to develop the science, it has also often mitigated against its coherent application." (Harris and Stanton, 2010, p. 147)

Discussing the future of HF, the IEA committee on Future of Ergonomics (Dul et al., 2012) attest a "great potential to contribute to the design of all kinds of systems with people" (p.1) but they acknowledge that, at strategic level, decision makers and experts in the systems are still to be convinced of the value proposition that HF delivers. This reflects that previous HF approaches have mostly delivered to local issues, often at the execution level, resulting in HF being regarded as a check list or add on service rather than a partner in proactively designing and changing the systems people work in. Cognitive approaches largely focus on dealing with local human responses, thus they are better suited to address issues of human performance rather than system performance. There are attempts to overcome this such as distributed decision making or social cognition, but they are limited by starting from the same premise, i.e. the locus of causation is mainly within people's heads, rather than incorporating the objective interdependencies that arise from the system.

Therefore, the current impact of HF in any industry is not at the level of the scope of the latest HF definition, i.e. system or SoS. How can this scope be realised? It requires understanding the nature of the industry and its challenges and innovative and multidisciplinary approaches that address them at an appropriate level. For contributing to system performance approaches are required that are based on a functional model of the system and can leverage this functional knowledge

"The fundamental key to both understanding how a system works and to being able to devise interventions to improve its functionality is a model of the system which incorporates the functional relationships between the elements of the system. What needs to be modelled is the real system – the objective dependencies and constraints operating in the real world independently of any one actor's intentions. Thus what is modelled is not simply a mental construction of the actors in the system but the actual material and social structure within which action takes place, including social relations, co-ordination actions, information and communication." (Morrison, Grommes and McDonald, 2009)

1.1.3.1.3 Question

How can Human Factors contribute to achieving a functional view of the actual operational situation in socio-technical systems; not a formal account of the prescribed system design, but the system as it is enacted, with both its social and technical aspects?

1.1.3.2 Relationships

1.1.3.2.1 Proposition

The way business is done today in a fully connected, largely virtual business world requires new ways of working together, including working together to respond to changes or to drive changes together. Post, Preston and Sachs (2002) discuss that enterprise concepts such as extended enterprise or similar views reflect the changing nature of doing business in 21 century and argue that this shifts the emphasis on relationships being key assets rather than focusing on the transactions themselves.

What are the main characteristics of new enterprise frameworks such as extended enterprise or virtual organisation? Organisations come together to define and deliver a product or service to the customer that could not be achieved individually. As part of this relationships are re-defined and new process interfaces are set up. These relationships differ in quality (e.g. contract, alliance, outsourcing etc) and timelines (e.g. temporary, long-term, once off).

Post, Preston and Sachs (2002) describe relationships as being key assets within enterprise frameworks such as extended enterprise. While transactions have an expiry attached to them, relationships outlive those. In the new enterprise frameworks, they become the platform for effectively defining the type of transactions that are optimal and deliver the basis for exchanging knowledge that designs a sustainable future for all partners.

Lane and Maxfield (1994) promote the concept of generative relationships. They consider this a key to strategically position an organisation to sustain competiveness in situation where adaptation in a complex business configuration is required. People interpret the world, i.e. how the system works, in interaction with other agents, within and outside their immediate organisation. These interactions are the basis for building generative relationships, which is a cornerstone for strategy under complexity. These relationships are discussed as the basis for new opportunities that can only emerge as part of joint activity.

"To realize generative potential, relationship participants must have the right permissions, time and space to talk; they must do work together; and that work must facilitate their coming to shared understandings about each others' competences and attributions of identity; and their relationship must be embedded in a network of other relationships that can amplify whatever possibilities emerge from their joint activities. Fostering generative relationships means managing people, projects and events so that these conditions are realized." (Lane and Maxfield, 1994, p.230)

While they do not explicitly mention it, Lane and Maxfield's (1994) argument resonates with the notion of social capital. Social capital argues that patterns of social relationships (as e.g. described in social

networks) have value. Adler and Kwon (2002) define social capital "roughly as the good-will that is engendered by the fabric of social relations and that can be mobilized to facilitate action"(p.17). Coleman (1988) discusses the benefits of 'appropriability', by which he means transferring the benefits of established relationships into new situations, for example, from friendship to work or between work contexts. However, there seems to be little insight into how those benefits are realised in a process system that delivers tangible outputs. Instead the focus is on HR functions that aim at the person, rather than on his or her role in the system.

1.1.3.2.2 Human Factors challenge

The social relations in a socio-technical system are largely a response to the functional logic, although not exclusively. People interact to collaborate and coordinate to realise their processes activities – at micro or macro level; exchanging information and knowledge about how the system works, with the view to contributing to the overall system performance and outcome.

While relationships and networks are well described in their own right and promoted as being critical to organisation's success in interconnected and complex business scenarios, there is work to be done to integrate them into the analysis of how systems function, more specifically, how the technical and social space effectively meet up in the operational process system. This understanding of the 'operational functional core' informs how internal processes can best support it and foster relationships that are strategically important.

New enterprise models span across organisational boundaries. Invoking the definition of a system as elements and relationships, one can argue that these new SoS are actually systems – in a simplified view, with each organisation or domain defining an element that is related to others in a specific way to enable the system to deliver the overall outcomes. Even though operational processes are inter-organisational in the future scenarios, it is still true that they implement the functional logic that is designed to achieve the goals. In an optimal situation, boundaries between organisations are broken up to the extent that systems are not only functionally defined for each purpose but actually fully implemented, in a fully integrated way. Even though this is not very likely, given the realities of, for example, IPR, industrial unions, cultural differences, language barriers and geographic complexity, it is a thought to be entertained when trying to identify key principles for designing these future systems.

1.1.3.2.3 Question

In order to verify the intuitively plausible claim that relations are a critical asset in new enterprise models and to support the design and implementation of these in an adequate way research has to address: How do social relations create value in its functional system context?

1.1.3.3 Knowledge

1.1.3.3.1 Proposition

Knowledge is being discussed as a key resource in addressing business challenges in the 21 century and securing competitive advantage in a business environment that is constantly changing (both quickly and radically). In new enterprise frameworks which share the defining characteristic of exploiting new

interconnectivity, information (but more so knowledge) is moving to the centre stage, not only as an organisational resource, but as the main currency within such network enterprise models. In these new scenarios, the complexity of the operation is increased by extending collaboration beyond organisational control. This increases the existing reliance on a shared understanding of all the salient characteristics of the operation, not only goals, transformation and outcomes but also of the value each stakeholder places on these different aspects.

Working through a serieus of case studies and examples, Lane and Maxfield (1994) argue that faced with rapid structural changes, the emphasis shifts to people interpreting and creating a new understanding – a cornerstone of effective strategising in the face of complexity. The emerging models include open innovation opportunities that one organisation would not have. But those have to be recognised by people in order to fulfil their potential.

If knowledge management (KM) is a central topic in an interdisciplinary approach then HF has to play a vital role given that it is people that hold knowledge about the socio-technical system of which they are a part. Issues concerning knowledge management in a single organisation escalate in a situation where knowledge is distributed across diverse stakeholders. It is argued that working towards a common goal is key to making the system work, but only a carefully managed process can enable partners to reach that common vision (e.g. Lane & Maxfield, 1994).

However, there is evidence that KM as it is being implemented today has failed to fully deliver its foreseen potential. Wickramasinghe (2003) reviews different case studies of major corporations that actively pursue a KM strategy and comes to the conclusion that organisational memory has been created but knowledge is not utilised effectively.

Following the discussion in this chapter, it is the functionality of the new system configuration that defines a core knowledge base. Defining relevant knowledge content a priori and making the effort of systematically collecting it, does not seem to be in the remit of KM theory. Knowledge creation is described but more in terms of aspirations, objectives, sometimes processes and activities. While it is correct to assume that people constantly create knowledge in a social context, the lack of direction can arguably be part of why the utilisation of knowledge falls short of expectations. If the knowledge base adheres to the principle of relevance, i.e. how the system that one aims to change actually works, then leveraging a situation by deploying it seems more likely to happen.

1.1.3.3.2 Human Factors challenge

Having identified functional knowledge about the system as a core resource that can enable targeted interventions at system level, the question is how well Human Factors is set up to address this. What knowledge does HF hold? What is its understanding of relevant knowledge?

1.1.3.3.2.1 Relevance of knowledge

Reviewing the existing body of knowledge in the field reveals an emphasis on cognitive approaches rather than system approaches (e.g. Procter and Vu, 2010). While the former approaches are still relevant to their specific purpose, new issues are emerging in the work situations of people. Thus, when the

aggregation of knowledge focuses on what was learnt in addressing existing issues, this limits the overall perspective on what knowledge is useful and does not well address future requirements. It defines the knowledge on the basis of what is known rather than on what has to be known, that is the system's functional logic that underpins its performance.

Harris and Stanton (2010) state that many HF solutions have addressed localised problems. It has been discussed how current business trends increase the complexity of the organisational systems and thus the interdependencies that underlie future challenges. Best practice knowledge of localised solutions (deploying existing HF theories, approaches, and methodologies) is not an adequate structure of knowledge for addressing the complexity of emerging system issues. HF has to be in a position to explore new challenges and engage with other disciplines in a joint effort.

A systemic view on Human Factors results in a different set of requirements for knowledge. A body of knowledge has to be defined from a functional perspective in response to issues and has to show how the system works. This defines a multidisciplinary agenda to drive research further, rather than reporting on what is been done which has little effect for new challenges.

Systemic Human Factors has not accumulated a large body of knowledge, or at least has not consolidated it in an accessible way. Besides the relatively recent engagement with the system perspective, possible reasons for this could include the following: boundaries are less clear when dealing with systemic issues, local manifestations of issues have a system origin, the intervention extends beyond a single focus, and change requirements are distributed.

1.1.3.3.2.2 Relevant knowledge as basis of leverage

The role of knowledge and how it is used is changing. Issues become more complex and distributed in expanding systems (or system of systems). Knowledge is therefore distributed and the existing reference points for interpreting what is happening are changing as a consequence of the restructuring of the socio-technical system in new enterprise frameworks. In this situation, integrating the knowledge into a relevant structure that makes sense to all stakeholders and is accessible to everyone is key to utilising it.

As discussed in the introduction, HF has evolved in response to the changing nature of people's work situations, continuously extending its scope. The introduction to a panel addressing "Teaching the Future Human Factors and Ergonomics Professionals to Solve Practical Problems" identifies three areas of expertise that are critical for practising future HF:

1. Problem solving

   The authors argue that problem solving is a core skill because HF problems are ill defined. The question is why are problems ill defined? The authors refer to Jonassen's (2004) assessment that these problems are not predictable, often dynamic, and tend to require a multidisciplinary approach.

2. Applying research to practice

The authors argue that there are several challenges but two main bottlenecks arise from the inadequacy of the research to address the problem or the failure to communicate.

3. Multidisciplinary team work

   Complex systems pose multi-faceted problems which require multi-disciplinary team work. This requires that "research must be undertaken with the big picture in mind. Much research is undertaken which addresses small aspects of a problem, with no thought as to how this piece fits into the overall picture. We must do a better job of consolidating the small pieces into a coherent picture" (p.685)

These three issues can be reformulated as knowledge challenges, i.e. how to create relevant knowledge and utilise it effectively.

1. Problem solving

   Having a relevant functional knowledge available in a systematic way, provides the platform to better define problems that are currently perceived as being ill defined. While not accounting for all variability, the functional logic of the system accounts for many aspects that result in a problem being complex.

2. Applying research to practice

   While a host of issues can be conjured that impact on this issue, a key pre-requisite of theory being successfully transferred into practice is the relevance of the theory for practical problems and its potential for interfacing with the points in the system where they can be leveraged, for example, the operational system, or supply chain. Selling these approaches depends on having the right content and methodology, but also being able to express it in terms that are familiar to the audience. The fact that relevant knowledge originates in the system and is integrated and transformed in collaboration with a scientific approach on same system, provides a shared reference point for both practitioner and 'theorist'.

3. Multidisciplinary team work

   This revisits the argument from the introduction. A system science has to integrate and transform diverse knowledge, both scientific and practical, in order to do justice to all aspects of the system and their interactions. The knowledge base is building on a mix of approaches.

1.1.3.3.3 Question

Postulating knowledge as a key resource for future organisations defines challenges for research to address concerning the nature of knowledge within its functional context and the definition of system processes that can utilise it. From the discussion, the question follows: How can a knowledge based approach leverage the change requirements in future systems?

1.1.3.4 Impact and value

Human Factors as a partner in the re-design of systems has to evolve in response to the changing situation. While traditional approaches are still valid for their respective questions they are not sufficient to address the emerging challenges that people are facing when operating their processes within the new system order.

While authors such as Post, Preston and Sachs (2002) or Lane and Maxfield (1994) specifically address and outline this new territory and the challenges that come with it, they do not elaborate on how those can be addressed. They advance arguments with a view of future potential and identify areas that have to be systematically covered by concepts put into practice, that is approaches that can be deployed to effect system performance. The topics outlined call for Human Factors involvement: People are part of the system and are core to relationships, knowledge and actions.

1.1.3.4.1 Strategy and impact

Lane and Maxfield (1994) discuss both making sense of the world (knowledge) and relationships as cornerstones for strategy under complexity. They argue that, faced with rapid structural changes, the emphasis shifts to people interpreting and creating a new understanding. This new knowledge is only achieved in interactions, utilising existing relationships for innovative responses. For an organization or network of organisations, strategy is the vehicle to deliver impact.

The concern with effectively engaging at a strategic level with the industry is mirrored by the authors (representing an IEA committee) who discuss "A strategy for human factors/ergonomics: developing the discipline and profession" (Dul et al, 2012). They argue that the value proposition of HF is clearer to people in the operation but not so much for stakeholders that are experts (e.g. designers) or stakeholders that take decisions (e.g. management). One distinction that can be drawn to characterise these two cohorts is around knowledge. While knowledge is key to any job, some are more knowledge extensive per definition: such as designers and decision makers.

If (in new business models) effective strategy is based on utilising knowledge and relationships (e.g. Lane and Maxfield, 1994, Post, Preston and Sachs, 2002, Adler and Kwon, 2002), then Human Factors has to address those who can use the knowledge through design or decision making.

It can be argued that existing approaches are not sufficient to escalate to that level because they have no capability of addressing the issues such as knowledge, relationships and system outcomes in an integrated way. In addition to addressing the details of local issues such as HMI, other approaches need to be scaled to a level that is linked to overall system performance.

Human Factors approaches are needed which can contribute to translating business scenarios into operational reality, by proactively designing the role of people. In operations that rely on people-mediated processes the analysis of their social structure demonstrates how well the functional production logic of the production is supported by its social counterpart.

System performance is not only about the delivery of outcomes but also concerns creating value for stakeholders. The discussion in this chapter has identified that in emerging enterprise models and their impact on the operation the social aspects of the socio-technical system are brought to the forefront. In conjunction with the role of knowledge, this opens up a new ways of discussing value.

1.1.3.4.2 Considerations of value

Value is a broad concept, used in different disciplines. In the context of system performance, the dominant discussion of value attaches it to the system outcome. With different people, groups and organisations having a stake in the outcomes that a system delivers the answer to the question of what constitutes value depends on the perspective. Cost is definitely a key driver and a reference system into which various indicators can be translated, for example, time. Other aspects that can be valued include customer satisfaction/retention, staff wellbeing amongst other things.

In the context of the thesis, the question of value has to be posed in the light of the changing business environment in which people operate and how that is addressed by systemic (HF) approaches to optimise the integration of people within the systems.

1.1.4 Research aims

In order to be able to address the complexity of these emerging business scenarios the participating organisations need to achieve a level of integration that has not been there before. The type of integration envisaged in this research relies on being able to advance a Human Factors approach that can support the delivery of the following functions:

- Ecologically valid understanding of system interdependencies;
- A model of the implementation of the functional logic in processes and their interfaces;
- Relationships built around common goals and objectives and managed proactively (to ensure qualities such as trust);
- Distributed and partially hidden knowledge proactively managed towards system objectives.

Addressing these broad requirements, the thesis research aims to advance an understanding of how to address the complexity of socio-technical systems in a way that integrates diverse elements according to the functional logic that is at the core of the system. It is based on understanding how complex socio-technical systems deliver their outcomes, taking a special interest in the social space of these systems, and how based on this, relevant knowledge can be created systematically and utilised effectively. Thus, the thesis aims to not only develop a methodological framework but moves its implementation beyond validation exercises in that it aims to deliver impact by deploying said framework, addressing actual challenges that organisations that are partners in this research are facing.

1.1.4.1 Preview of Framework

A systemic framework is devised that pursues the integration salient socio-technical dimensions of the aircraft maintenance system according to two main principles

- Structure: Content dimensions were organised in a structure in relation to a process core, integrating technology-based process functions and social processes of the system in a single framework
- Implementation: An iterative approach to knowledge creation and transformation was deployed using this framework of both conceptual structure and content.

While a broad perspective is taken, covering critical angles with an interdisciplinary mindset, the research does not aspire to be all-encompassing. It is accepted that it is impossible to achieve a complete and comprehensive account of all the social processes that occur within any particular operational system.

In order to manage this situation, the design of the research and its implementation was informed by two general principles: Relevance and Leverage. Relevance directs the attention to the factors which have a material bearing on the functionality of the system which is at the core of the framework. Leverage then directs attention to those factors which can be influenced by redesign of any of the mechanisms which govern the relevant functional processes. There is no point in concentrating too much attention on those factors which cannot effectively be changed – no matter how interesting they might be in theory.

It is important to stress that these principles should guide the manner in which the framework is applied. It is not an in depth investigation of all dimensions but targets insights into the system at a 'bigger picture' level. Following the implementation of the criteria, the features of this 'bigger picture' include being systematic, integrative, functionally focused and naturalistic and ecologically valid.

1.1.4.2 Potential for value proposition

The value proposition of such an approach is strongly linked to impact. A core function is around a knowledge business that can deliver effective change in operational systems in the real world, via system design or organisational change. This depends on having implementable solutions to how to generate meaningful, ecologically valid knowledge about how the system works and then how to use it effectively, while all the time learning and generating new knowledge about the system elements and relationships.

In so far as the common themes of relationships and knowledge are central to the industry trends discussed above, this gives to potential for Human Factors to address value in the following ways:

- In a socio-technical system, the technology capability is strongly associated with the value attached to the output, product or service. Advancing the understanding of how relationships and knowledge enable this capability within a process completes the value chain;
- Value creation depends on understanding the system, turning it into usable knowledge;
- Value creation depends on the appropriate relationships that foster knowledge;
- Knowledge is about doing which changes the state of affairs, and if directed appropriately, consequently increases the value.

2 CHAPTER 2: Background & Design

2.1 Introduction

Chapter 1 gave a summary of some of the key challenges that arise in operating complex systems and identified an opportunity for Human Factors to actively engage in delivering in a more integrated fashion to the creation of value for all stakeholders. In the light of emerging enterprise scenarios, questions that arise from limited insights into the functionality of the social aspects of a system are posed more starkly. Concepts such as relationships and knowledge which have been postulated as being core to ensuring competiveness of future systems are not sufficiently understood when described in isolation. For leveraging system performance, their social reality in the system has to be understood as a result of the functional interdependencies between technical and social elements of the system.

New enterprise models incorporate existing organisational systems and business functions and transform them along generic dimensions, such as business goals, process integration and collaboration. However, the effectiveness of transforming existing systems and implementing new models is limited by the extent to which the existing complexity is captured and unpacked into parameters that can be influenced. Reviewing the assessment of challenges that HF faces to fully establish itself as system science shows that there are many unresolved issues when it comes to accounting for the complexity of socio-technical systems, which weakens the baseline understanding for System of Systems (SoS) based frameworks.

The thesis attempts to advance the understanding of what underlies the complexity of socio-technical systems and devise an approach that demonstrates how it can be addressed. This is by no means a trivial task and whilst no model or framework can ever account for everything (Sterman, 2002) the aspiration is to make a significant step towards unpacking the complexity. The main criterion for significance here is usability in terms of effecting changes and practical impact, both of which relate back the principles of relevance and leverage introduced before.

For the purpose of the thesis, aircraft maintenance has been selected as candidate system for the research. One reason is that aircraft maintenance is a complex socio-technical system which is part of a wider system or SoS, the aviation industry. Aircraft maintenance as a domain delivers airworthy aircraft into the operation and thus is critical to delivering value to the ultimate customer, the passenger. It has close interfaces with the equipment manufacturing sector that defines the technology that is being maintained and the airline/ Flight operations sector that operates the aircrafts. Thus research in this area offered an inherent opportunity of considering the SoS when answering the questions posed here. Another reason for selecting the aircraft maintenance system is that an extensive body of in depth research over the past 20 years defined critical a priori knowledge about its properties as a socio-technical system (e.g. ADAMS project, ADAMS-2 project, AMPOS project). This gives access to data, information and knowledge about how aircraft maintenance as a system functions and as such provides an empirical entry point into its complexity.

Starting with an introduction to aircraft maintenance the chapter will provide an assessment of the socio-technical issues of the system (in the context of Chapter 1) and their conceptual equivalents in relevant

theories and methodologies. The outcome of the chapter is a theoretical position, implemented in a general methodological approach, which will be implemented in the following case studies (see Chapters 3 and 4).

2.2 Description of aircraft maintenance system

The overall aviation industry can be described as set of interrelated domains: From the design and manufacturing of the aircraft to its operation, including the provision of airworthy aircraft by maintenance to the ultimate scrapping and disposal of the aircraft technology. Together with flight operations, aircraft maintenance is core to operating the aircraft, supported by original equipment manufacturers (OEM) and aircraft integrators who deliver support in form of supply of parts, procedural information and specialist teams.

The aviation industry is a safety critical sector and thus highly regulated. The European Aviation Safety Agency (EASA) is the regulatory body that governs all aviation in Europe, including aircraft maintenance. Within the scope of EASA regulatory framework, different types of business models and organisational set ups are implemented for delivering the maintenance and overhaul of aircraft.

Liston (2005) gives a brief overview of the business situation for aircraft maintenance: "Some aircraft maintenance organisations exist as subsidiaries of an airline, while others are independent maintenance organisations which carry out maintenance on third-party aircraft (a third-party AMO [Aircraft Maintenance Organisation]). The aviation sector in general is characterised by a large amount of diversity in terms of the size and range of operations. In maintenance organisations this diversity ranges from maintenance organisations owned by large international carriers, repair and maintenance out-station facilities (overseas bases), through small regional and commuter airline-owned maintenance organisations, to the fixed-based third-party maintenance organisations who work on a contract basis (Drury, Prabhu, & Gramopadhye, 1990)." (p.21)

This picture is in the process of changing, not only for aircraft maintenance but for the industry as a whole. As discussed in Chapter 1 new enterprise frameworks and business models are emerging that have the potential to address the industry as a single system and which are actively pursued by key industry stakeholders. In order to be in a position to support this transition effectively and comprehensively, it requires a grounded understanding of the current systems and their relationships.

Reviewing the existing situation, Corrigan (2002) describes aircraft maintenance as a socio-technical system and identifies four functional areas which are generic to the different organisational implementations of the maintenance operations: (1) maintenance production system, (2) functions internal to the maintenance organisation, (3) regulations, and (4) external bodies. The following briefly summarises key aspects of those.

1. Maintenance production system

   The maintenance production system is at the core, delivering airworthy aircraft into the operation (on time). Its processes are facilitated or constrained by internal or external support and the regulatory requirements for a safe operation of any type of fleet. The maintenance work

is carried out either indoors, in a hangar set up, or outside on the ramp, e.g. as part of an aircraft turn around. 'Real time' direct support is provided by planning (e.g. live planner on the floor), engineering (e.g. query note (QN) process) and quality (e.g. safety audits) functions in the organisation.

2. Functions internal to the organisation

   Within an aircraft maintenance organisation or department, there are internal support functions that support the production, before, during and after the maintenance execution. These support functions include acquiring of contracts or defining commercially effective fleet maintenance schedule, planning the maintenance activities, resourcing their execution in the productions system and managing its financial aspects (external or internal).

3. Regulations

   As part of the safety critical aviation system aircraft maintenance is a highly regulated domain. Manuals for tasks are legally binding procedures and many aspects of the organisational set up that supports the maintenance execution are controlled, such as training, quality controls such as safety management systems, reporting schemes etc.

4. Other external bodies (external stakeholders)

   External bodies such as the manufacturer design the aircraft that is being maintained and define a maintenance schedule and manuals which formalise the maintenance requirements in terms of content (what), procedure (how) and timing (when). In addition they intersect with the maintenance when providing operation information update in form of service bulletins for the operation, expert teams for specific tasks, or as suppliers of parts.

2.2.1 Maintenance Production

In the maintenance system the production element is at the core, implementing the processes that deliver the expected outcomes: the airworthy aircraft that can be released back into flight operations. In doing so they are supported and constrained by the interdependencies that exist with the wider system, both internal and external support functions, as well as regulations.

Maintenance production activities are the implementation of the Aircraft Maintenance Programme (AMP), otherwise referred to as the Approved Maintenance Schedule (AMS) that is associated with every aircraft. "This document, approved by the national aviation authority, specifies the mandatory minimum maintenance program which an aircraft must follow during its life in service. It is drawn up by a Maintenance Review Board (MRB), comprising manufacturers, aviation authorities, airlines and maintenance organisations to ensure compliance with the maintenance needs of the aircraft" (Liston, 2005).

The formal maintenance requirements are implemented as organising principle in a check or work pack. Maintenance organisations or departments translate those maintenance requirements into a series of work packs, scheduled for a particular aircraft. Those include the tasks to be performed to satisfy the requirements and include information which outlines safety requirements, resource inputs, technical

steps and interrelated tasks. These work packs can be more or less work intensive, both in terms of type of tasks and overall number of tasks.

Descriptive terms such as line or base, light or heavy maintenance are used to highlight a general distinction between sets of tasks that are mandated and scheduled for periods during which the aircraft continues either to be on the operational flight plan roster, e.g. a turn around, or to be taken out of rotation for an extended period (days to weeks) while maintenance activities are performed. Both implement the same inputs such as maintenance tasks (with different emphasis) and their support, but they usually differ in terms of their timeline, the operational status of the aircraft, and the location, i.e. ramp versus hangar.

2.2.1.1 Check or work pack as organising principle

Maintenance activities that see the aircraft remaining on the operational roster are usually checks to ensure no maintenance requirements have arisen outside the schedule of maintenance interventions and usually cover the whole aircraft at a 'surface' level compared to in depth work organised around aircraft zones in a hangar based check. If such as surface review leads to a finding it gets attended to promptly if it is safety critical or if the opportunity presents itself, e.g. outcome of the last check of the day with an overnight at a fully equipped home base. Otherwise these items tend to be deferred (based on the Minimum Equipment list (MEL)) to be included into a schedule hangar based work pack or check. The burden of maintenance activities in a life of an aircraft is performed as part of these checks (ranging from A to D, indicating increasing complexity, in terms of number tasks and depth of intervention).

Liston (2005) has given a succinct overview of the check or work pack as an organising principle for implementing maintenance requirements:

"Checks can involve both scheduled and unscheduled tasks. Some tasks are based on cycles of time and can be scheduled for a check *before* they become overdue – these are termed 'hard-time' items. Scheduled tasks such as this might include replacement of parts which have ended their performance life or many of the inspection and testing tasks. Checks can also include tasks deferred from previous maintenance or may involve unscheduled items such as repairs on defect components which were previously logged by flight crews.

"Another source of unscheduled tasks is the inspection which occurs at the beginning of each check. A critical aspect of the workload on a check relates to recognising and identifying defects during the inspection and also during the maintenance itself. In particular there is pressure to identify critical defects that necessitate lengthy follow-up maintenance and additional logistical support early in the inspection process. Therefore there is usually a heavy inspection workload at the commencement of each check. Any defect items which are detected during the pre-check inspection generate Non-Routine Work Cards (NRCs) which are, essentially, task cards for unscheduled maintenance. These tasks are unplanned and cause many problems for the maintenance organisation; particularly in relation to the availability of parts and appropriately qualified personnel to carry out the maintenance. Only after the inspection activities and identification of defects can the planners and managers provide a more accurate estimate of the

expected maintenance workload, order replacement parts, assess manpower levels, assess additional technical support, and re-schedule maintenance items. [...]

"When each individual task is complete the technician 'signs off' the task card (depending on the types of tasks they are licensed to complete). Some safety-critical tasks require that a technician gets a colleague to inspect their work and supply a second signature for the job card. The job card is then returned to the aircraft's technical records. When all tasks in a check have been completed the check manager signs that all work has been completed correctly and that all the paperwork is in order. This means that the aircraft is released to service." (Liston, 2005, p.29)

The tasks are usually carried out by teams: in short term interventions it is usually a small team of two or three technicians that covers the whole aircraft, while in more extensive hangar based work packs teams are organised around aircraft zones. A central supervisor supports with technical advice and coordinated the tasks re-requisites and emerging issues in a situation where the aircraft remains operational (on the ramp or line) while in a hangar based scenario each zonal crew has a crew manger or supervisor. In addition to those there is another management level, i.e. line manger or check manager, who oversees the total check across zones or all A/C worked on in parallel on the line. These teams and their managers work in shifts, requiring a hand over, if tasks extend a single shift which they frequently do.

In addition to managing the sequential and parallel execution of maintenance tasks, the local operation is also dependent on inputs from other processes, both internal (e.g. planning, workshop, procurement) as well as external (e.g. information updates from OEM, customer decision on extra work). In order to work effectively on the ramp or in a hangar, these interdependences have to be managed effectively.

2.2.2 Aircraft maintenance as a socio-technical system

The aviation industry is a socio-technical system of systems (as are its subsystems). It is people operating complex technologies within highly defined and regulated parameters, across different domains. As with any system it is designed for a purpose, to achieve objectives and its processes organise activities to deliver the relevant outcomes. Merrion Webster Dictionary's definition of system is, among others," a regularly interacting or interdependent group of items forming a unified whole". It draws attention to the activity that implements the relationships. Socio-technical systems share certain characteristics: they have a purpose and associated goals, their technical and human/social elements and relations define the structure which delivers its functional purpose through processes. Process activities instantiate the functional logic and deliver outcomes which can be used to assess system performance.

The key elements of a socio-technical system are the people and technology they operate.

2.2.2.1 Thoughts on the technical

In aviation, the core technology that is operated is an aircraft. The aircraft is a complex technology system of which systems and sub-systems and their relationships are well documented in technical documentation such as design specifications which transitions towards instructive material in manuals or standard operating procedure (SOP). This information is mostly compiled during the design phase of an aircraft type and updated as a result of technology upgrades or based on operational feedback.

The technology defines the baseline parameters for the functional logic of the processes. It defines the set of technical tasks that are translated in activities that people perform. As a consequence, the emphasis is often placed on the technical space of the system: what is known about the objects, such as technology, and how to operate them. Support processes are designed in reference to this. In addition, the technical aspects of the system are more easily accessible. Even with complex technologies that require different expert involvement, their design and specifications are documented down to the last screw and algorithm, giving access to detailed information on the technical components of a socio-technical system.

The aircraft technology defines (a) the content and characteristics of the maintenance tasks and (b) what triggers them, e.g. 'hard times' such as date or defined number of flight cycles or condition based interventions. These constitute two main drivers of the functional logic of maintenance production.

Underlying logic: Flow x Interfaces

There are slightly different but overlapping classification systems to describe types of maintenance tasks, for example as used by Airbus and Boeing in their respective technical information. Each type of task has a certain functionality associated with it which defines its role in the organisation of a check or work pack. Research in Chapter 3 will show that tasks relate to each other in a workflow or process logic that has four major phases: set up, identification, rectification, testing. This is reflected in the check milestones, drawn up for larger checks.

The task types in each phase require their own set of inputs that are defined in the technical description and that are activated in sequence. There is a handover requirement from one task to the next that is realised in information based systems such as task sign off. A similar logic applies within each maintenance task: a series of steps is resourced, sometimes requiring an interim sign off, for example when another technician takes over at a shift hand over.

In addition to this, there are a few tasks with specific characteristics that define exceptional relationships with others in the sense that those can have an impact on the overall workflow, e.g. power off for a specific maintenance action limits the options of other tasks occurring in parallel.

The implementation of the flow of maintenance tasks has two sets of interfaces associated with: internal and external to the maintenance production system.

The nature of maintenance production sees tasks occurring in parallel in different areas of the aircraft. These parallel activities result in interdependencies such as shared access requirements, potential for interference, or requirements for resource sharing that have to be managed as part of the process. In addition to this, some of the inputs required are sourced locally, such as hangar equipment or allocation/distribution of personnel within a given shift, which adds internal resourcing interfaces into the flow.

More important in regard to resources and inputs, however, are the external interfaces. Support processes as described earlier include other functions internal to the maintenance organisation or maintenance department, such as planning, engineering or procurement as well as external support provided by the OEM or aircraft operator (external customer or flight operations department). These support functions deliver resources that are activated as input into maintenance production, covering the

three main areas of information, material and people and are largely based on the technical requirements of the maintenance tasks.

Uncertainty

The technology comes with its own sets of rules, specifying the maintenance requirements for the given technology system configuration. There are two types of triggers for maintenance action: 'hard times' (driven by a time criterion) and the actual condition of the technology.

The maintenance tasks that are based on hard times (flight hours, flight cycles and date/interval) define a large amount of the maintenance work to be performed. They are organised in a work pack or check and are scheduled and resourced in advance. However, there are additional maintenance requirements that introduce uncertainty to any maintenance plan: events occurring during the operation (e.g. failure messages) and 'pick ups' of maintenance issues when scheduled maintenance tasks such as checks, inspections or tests are performed.

These tasks cannot be scheduled in the strictest sense but, within the industry, there are general rules of thumb employed when planning for work pack execution: leaving anything between 20%-40% of the work effort unallocated to be dedicated to unscheduled maintenance tasks.

Management of these unscheduled items depend on the operational status of the aircraft as well as maintenance lead time. Pick ups are more common in a work pack of an aircraft grounded for maintenance since this is the time more extensive inspections and checks are performed, and systems are being accessed and assessed more thoroughly. Pick ups within a work pack execution are managed by Non Routine Cards (NRC) and their execution is included into the work pack whenever possible. If the time is too short, e.g. in overnight, or resources are not available, they are added to the deferred items, if allowable as per MEL. Events during the operation of an aircraft are managed in close collaboration with the Operation Control Centre (OCC). Commercial and operational parameters influence the decision to shift the item, if allowable, to the deferred defect list or to ground aircraft for immediate maintenance action.

The complexity of a work pack is added to by the introduction of unscheduled items that create a whole set of additional interdependencies which have a shorter time scale for planning and implementing.

Baranzini (2009) has shown that socio-technical system can work without perfect conditions and still function well. He coins the term "Friedlander's argument" to describe a seemingly paradoxical organisational situation in which less resources are provided than the overall process system requires. The rationale is that in an economically viable scenario support to operational processes are provided, but at a level below total saturation. While local outcomes may be less than optimal as a result of this approach, the expectation is that the overall performance is maintained at an acceptable level by effective coordination of the shared resources. Baranzini (2009) has shown that this paradox exists in aircraft maintenance as an organisation. While this assessment applied to aircraft maintenance as an organisation, it is exacerbated by the element of uncertainty that is introduced by the nature of the work (e.g. unscheduled events and 'pick ups').

2.2.2.2 Thoughts on the social

The technical system components provide the reference point for human involvement, including skills, competence and related aspects. Research into the effects of increased automation or HMI design has provided a baseline for understanding the technical dimensions of tasks that are performed by people.

Liston (2005) discusses the technological advancements in the design of aircraft that have not only changed the tasks of the crew flying it but also have changed aspects of aircraft maintenance. However, he concludes: "Despite these advances (and the concomitant benefits) aircraft still require regular maintenance from human operators. The nature of this maintenance may be changing however: technological advances mean that maintenance is moving towards a model of operations which is more focused on avionics and the use of computers than the 'torque wrenches and elbow grease' model of the past. Notwithstanding these changes the task of maintaining aircraft [performed by people] still plays an important role in guaranteeing the safety of the aviation industry. "(pp. 20)

It emphasises that aircraft maintenance remains a people-mediated process. Maintenance tasks are reliant on people, both individually and as crews, planning, managing and executing them and cannot be automated in the same way that some flight operations tasks have. While key task characteristics are defined by technology, they are executed in an operational context in which people make sense not only of tasks in isolation but part of processes.

A process account based on technical information is not a comprehensive account of all that goes on in an operational situation. It is a privileged description that prioritises the steps and dependencies necessary to move or transform the product towards the operational goal. In between these technically driven steps is a lot of activity that enables, facilitates, accompanies and sometimes frustrates the movement from one process step (or phase) to another. More effort is required to understand the social space that enables or constrains the technical activities. As part of the system people perform tasks, but they do much more than the technical activities specified by the technology system.

McDonald, Ward and Morrison (2012) argue: "People are central to system functioning; they have an important, often taken for granted, role co-ordinating processes, as well as task-related roles. Information technology has dramatically extended the reach of this co-ordination role, enabling the transformation, not just of an organization, but of systems-of-systems – for example the many components that make up the aviation system. Complex system interactions are implicated when things go wrong." (p.1)

The functional logic as it is instantiated in the sequence of tasks (flow) and their interdependencies with each other as well as external entities (interfaces) does not account for all activity that realises the operational process. In addition to the technical steps, there are coordination activities in the process that are key to managing the flow as well as inputs at interfaces (e.g. Malone and Crowston, 1994, Baranzini, 2009). Coordination is a main means for people to mediate that the technical tasks are effectively implemented and supported and, thus, ensuring the best possible outcome is achieved in any given situation.

Given the uncertainty in the maintenance system that originates in unscheduled tasks and the distribution of informal knowledge, for example undocumented coordination requirements, the coordination of less

than optimally supported interdependencies holds a key to a safe and efficient operation. McDonald, Corrigan and Ward (2002) identified a pattern of well-intentioned people in dysfunctional systems (WIPIDO) in the maintenance industry. They adopt a systemic perspective when they argue that the technician at the sharp end of the operation often compensates for the deficiencies in the organisational system in order to perform the job at hand in a safe and efficient manner. Based on their understanding of how the system works (or not), experienced staff actively pursue ways to effectively manage the delicate balance of safety and efficiency in a less than optimal situation.

Coordination activities have a functional role in the process which is discussed in the literature (e.g. Malone and Crowston, 1994, Baranzini, 2009), but these interactions are also a gateway into the social space of the system. Coordination is instantiated by people interacting, either directly or indirectly, exchanging information and sharing their understanding of the situation. Some of these interactions are formally accounted for e.g. management meetings or shift hand over procedures, but a lot of the regular social patterns are not captured systematically in the context of a socio-technical system and thus not recognised in their contribution to creating value and subsequently not well supported (e.g. Ward, 2005).

The social structure of a socio-technical system is largely established through repetitive patterns of social interactions (both formal and informal) that are occurring in response to the functional logic the system was designed to instantiate. The types of interactions that are enabled by structure and quality of people's relationships facilitate or limit the effectivity of process actions and as a consequence influence the variance in process performance. Ward (2005) has demonstrated that the quality of social relations is critical to understanding the performance of the overall system. The level of trust or mistrust that is the result of the quality of people's interactions and relationships does not only affect performance at a local level but also enables or constrains the overall system's ability to deliver.

People work together towards a common goal and in doing so and achieving it, they benefit from a shared understanding that is built on shared experience and ongoing exchange of their respective knowledge about the system. Given the complexity of socio-technical systems, the critical knowledge is distributed and partially hidden, in informal practices or by the virtue of being tacit. The extent to which people are able to access, transform and utilise knowledge about how the system works has an effect on how well their processes perform and deliver the ultimate outcome.

This is even more important in a situation that by nature involves uncertainty: people rely on their knowledge and interpretation of the situation to decide on the best way forward. When exchanging information and coordinating interdependencies are becoming more important in the face of uncertainty, the further emphasis is put in the requirement to understand how social relations are conducive to this. If critical knowledge cannot be effectively used, the system's opportunities to perform well are limited.

The concept of WIPIDO (McDonald, Corrigan and Ward, 2002) as discussed above is an illustration of how knowledge about a system, especially an imperfect one, can counteract adverse outcomes. At the same time it also highlights that informal practices, local knowledge and a disconnect between local activities and system design contribute to preventing this critical knowledge from being accessed and used systematically. Staff in organisations are not deliberately creating this situation, rather it is a symptom of

the existing incapability to address and manage technical and social dimensions of the system in an integrated manner. As argued before, social processes are the basis for knowledge exchange, both creating and transforming knowledge in response to the functional process.

Knowledge about the system resides in the social space. People have a (partial) understanding of how the system functions that exceeds formal accounts and utilises the tacit knowledge acquired in doing their work and their access to informal practices that emerge in response to the system context in which they perform their tasks. Tacit knowledge is generated through action and while it poses challenges in terms of accessing it, it is critical to implement formal work descriptions. Brown and Duguid (1998) argue that an organization's core competency is more than the explicit knowledge of ``know-what''; it requires the more tacit ``know-how'' to put it into practice.

In social interactions, people exchange knowledge and make explicit their hidden assumptions about the system, even if only through their actions. The shared tacit and explicit knowledge that evolves in these interactions creates values and meanings that subsequently guide people's actions.

The implication is that a lack of adequate approaches to understand and manage the role of different types of functional knowledge in socio-technical systems is fostering cycles of hidden knowledge which create relative stability. If that system is confronted with requirements or an opportunity for change (as presented in Chapter 1), or worse, that system fails, the capacity for implementing changes in response is limited.

2.2.3 Conclusions: What are the challenges to be addressed?

The main Human Factors challenges for the future is to follow through the aspiration of affecting overall system performance and put in place systemic approaches that can deliver this in an integrated way. For this, it has to move beyond its existing knowledge base that can be argued to have been largely built up by addressing local issues (as outlined by McDonald, Ward and Morrison, 2012) to investing the effort in systemically building up system knowledge – a complex conceptual and research task that requires a multi-disciplinary, multi-dimensional and multi-level take on it.

As a consequence, building such a framework will use key principles of various approaches, rather than exploring all their detailed nuances. The first stepping stone is to demonstrate the feasibility of Human Factors as a system science. In later iterations, details can be added. However, it can also be argued that due to the complexity of socio-technical systems, it could be preferable, i.e. effective, to design a generic framework that detailed methodologies can systematically be linked into within a new overall conceptual take in socio-technical systems and what makes them work. This seems to be supported by some of the findings in this thesis.

Following Chapter 1, the overview of the complexity of the aircraft maintenance system has furthered the positioning of the thesis in the nexus of the technical and the social space of a socio-technical system. While the functional logic originates in the technical properties of the system and provides the baseline for system activities, it cannot be implemented without social processes complementing those.

The proposition developed in chapter 1 that technical and social aspects of such a system cannot be understood in isolation has been further explored and strengthened by the review of the aircraft maintenance system. The discussion of its technical and social aspects (as identified in empirical research) shows that in order to support overall system performance which is being postulated as a HF aim in the IEA definition, it requires approaches that can integrate both.

In summary, the discussion of socio-technical issues in aircraft maintenance shows that there are four key dimensions which are interrelated within a functional system and contribute to its complexity.

Task logic

The technology defines the core of functional logic of the system. In aircraft maintenance the requirements for maintenance that are defined by technology specification and characteristics such as reliability. These are translated into tasks, which, when implemented in a workflow, enable the transformation of the aircraft technology towards the ultimate system outcome, the delivery of an airworthy aircraft. The task characteristics define external demands such as resource requirements and can pose challenges such as their inherent complexity. In addition to this, they relate to each other, such as exchanging inputs and outputs of interfering with each other while running in parallel.

This results in a set of dependencies, both between maintenance tasks and associated support functions. The extent to which those can be effectively managed and satisfied defines the quality of outcomes both locally as well as aggregated across system levels.

Uncertainty

Uncertainty is a defining feature of the aircraft maintenance system. As a result of the functional logic that originates in the technology system, some work can be planned, while some tasks cannot. The resulting uncertainty is exacerbated by strategic business decisions that put additional strains on realising the dependencies defined by the tasks. An example is Friedlander's argument which can be summarised as total support across operational processes and their thousands of tasks is not economically viable for an operational system. This was illustrated by a failed improvement initiative in one of the partner companies. Although the results of implemented changes were positive and staff happy, 'the perfect check' was discontinued because it was not cost effective to be rolled out company wide. While the check at the centre of the initiative worked well, it took resources out of the wider system and increased uncertainty for other checks. Therefore, even if the technology systems improve and their status becomes more predictable further (as it continues to do), there will always be residual uncertainty for the foreseeable future and beyond.

Given this situation, it raises questions about how uncertainty is addressed in the system. One can argue that uncertainty results in a pattern of sub-optimal functioning. There is no full control over the operational situation which limits the effectiveness of rational planning approaches that are purely maintenance task and technology based (e.g. Baranzini, 2009).

In response to these patterns, functional requirements arise that are satisfied by social processes.

Dealing with uncertainty effectively requires a sufficiently shared understanding of the logic that underlies the maintenance activities and how it affects the operational situation. This is achieved in social interactions which are implemented as coordination activities within the technology based workflow. Understanding dependencies allows for optimising within uncertainty, to prioritise and facilitate. One could argue that while the technical system creates the baseline for uncertainty, the human system manages it.

Knowledge

Formal practices are largely based on rational plans. These plans are limited in how they account for the uncertainty and its management (e.g. illustrated in use of rule of thumb leaving 20-40% of effort within a check unallocated for unscheduled items). While one could make an argument for revisiting them in the light of uncertainty, and in aircraft maintenance checks this certainly takes place, the operational urgency for adapting to changing circumstances calls for alternatives.

The sub optimal functioning that is inherent in aircraft maintenance demands informal practices and partially shared tacit understanding. Only then can the system maintain its relative stability and perform to an acceptable standard. This phenomenon has been described previously by McDonald, Corrigan and Ward (2002) in their theory of well intentioned people in dysfunctional organisations (WIPIDO).

As result, knowledge about all that is going on in the operational situation is hidden in these informal practices and tacit knowledge acquired as part of people's daily work. The challenge is not only to elicit this hidden knowledge but to do so in a way that makes it useful, i.e. systematic and structured.

Relationships

The informal practices centre on achieving a common picture of the configuration and status of the interdependencies and implementing the resulting requirements. How system dependencies are managed (in coordination activities) instantiates patterns of social practices. In contrast to coordination that supports the formal practices (such as shift hand over procedures) the basis for implementing informal practices is some form of mutual adjustment which presupposes a relationship (rather than a procedure) as the basis of cooperation.

Thus, those patterns articulate the social relationships between stakeholders in the system processes and are key in forming the social structure of the organisation. A caricature of optimal system functioning would be as follows: If all was in place people could slot into the workflow as resources according to procedure without requiring any social relations to make the system work.

However imperfect knowledge is in the current systems, its utilisation is further mediated by opportunities for interaction. These are key to transferring knowledge and transforming it into a more powerful resource for the organisation. The social structure of an organisation is instantiated in relationships which vary in their quality and as a consequence constrain or enable opportunities for exchange. In an environment where business targets shift and processes change accordingly, knowing the system's underlying logic unlocks the potential to support any transaction that are required to stay competitive.

Conclusion

The technology based functional logic creates uncertainty (exacerbated by economic strategies such as in Friedlander's argument) which in turn requires additional functions for the system to work. Those functions are enabled by the social elements of the system and their processes. A key set of processes is around the use of knowledge in the system, exchanged in interactions for coordination function and enabled or constrained by the quality of relationships. This shows how knowledge is functional when dealing with complex system interdependencies, and thus establishes a knowledge level as a core characteristic of any framework that targets complex socio-technical systems.

The fact that social processes are key to effectively dealing with knowledge (from creation to transformation) gives a new appreciation of the social elements in the system. The social structure that is established by patterns of practices, both formally as well as informally is therefore not just a by-product but defines a response to requirements for system functions that exceed technology specifications.

Arguably, this demonstrates the interpenetration of social and technical aspects of a socio-technical system and raises questions about their interdependence. This fact is postulated but rarely demonstrated in a single framework as the following review of theories and methodologies will show.

The systemic approach developed in this thesis sets out to incorporate those aspects and operationalise them. Demonstrating the effectivity of such an approach for specific application contexts provides a basis for changing a system in response to the emerging enterprise requirements discussed in Chapter 1 and to deliver a means to substantiate the claims postulated in regard to the criticality of relationships and knowledge in future business scenarios.

The questions posed about the role of functional task logic, uncertainty, knowledge and relationships and their interaction in delivering system performance at an acceptable level of quality, efficiency or safety necessitate an approach that is not limited by prioritising a single perspective. Therefore both literature and methodology has to adopt a diverse approach, driven by what is useful in moving towards a demonstration of an integrated approach to complex socio-technical issues.

2.3 Background to the thesis research

The outline of the complex issues in aircraft maintenance reinforces the conclusion of Chapter 1 that systemic Human Factors approaches need to adopt an interdisciplinary perspective.

The previous section has outlined the issues of aircraft maintenance on account of it being a socio-technical system. Trist (1981) recounts the origins of the socio-technical research paradigm and traces the development of the concept back to the realisation that separate approaches to the social and technical systems were inadequate to address the emerging issues. He continues the arguments saying that the interdependencies between social and technical aspects consequently called for them being grounded and integrated in a system notion.

He defined socio-technical organisations as being reliant on their resources and materials to produce outcomes. This is a core feature of aircraft maintenance, and the aviation industry in general, revolving around aircraft systems and their associated technologies and services.

He further argues that studies have to be carried out at different system levels, from micro to macro, which are interrelated: suggesting at least three: the work system itself, the organisational system and its societal or macro-social context. Reflecting back on the discussion in Chapter 1 that are concerned with the changing realities in SoS based business models, it seems important to take on board Trist's conclusion that while his interest in socio-technical questions arose at the higher level it was only by conducting research in the work system that insights into the higher levels could be gained.

In summary, when targeting socio-technical system performance, systemic HF approaches have to consider technology, people and information aspects, independently as well as in their interactions, at multiple system levels.

The socio-technical nature of the system is implicit in the IEA definition, and many scholars would agree that their approach aim to address that reality, although they do not necessarily explicitly define the social and technical aspects. In safety critical industries such as aviation, the system notion has gained prominence in addressing Human Factors concerns such as attempting to explain unacceptable performance. An example is Reason's approach to investigation which argues that a complex set of factors within the system contribute to the incidents and accident that occur when operating a technology (e.g. Reason, 1997). It allows moving the attention from the sharp end, e.g. the AME that executed a maintenance task, to opening up an inquiry about the sequence of action at different system levels that preceded it. While Reasons's approach strengthens the role of systemic precursors for safety failures, it requires the data from actual events to derive to conclusions.

Having reviewed the main features of aircraft maintenance as a socio-technical system, four themes have emerged: task logic based on technology, uncertainty, knowledge and relationships. The following gives an overview of how the challenges and questions resulting from the discussion of these are addressed in relevant theories and approaches across various disciplines and thus is the first step in positioning the thesis research in its theoretical context.

2.3.1 Functional baseline

For any approach targeting system performance, a useful level for approaching the issue is the process. It implements the functional logic that is at the core of the system, which is both imposed by the technology design and complemented by addressing residual uncertainty. In a system the process is the means that delivers the outcome that in turn is used to measure performance. It does so by instantiating technical and social aspects of the system in actions and how the functional logic and uncertainty reflects these, making these dimensions tangible and accessible. The process provides a shared reference point for both, that they share by virtue of being elements of the same system. Following the earlier argument of their interpenetration within an integrated functional logic, it is the actual process and its practices that can give access to the complexity.

In aircraft maintenance, the work pack or check with its internal and external interdependencies, i.e. interfacing with wider system processes, is an instantiation of the socio-technical process. To understand system performance, the operational core is a valid starting point. It can be argued that in aircraft maintenance all other processes in the systems are designed to contribute to ultimate delivery of

airworthy aircraft. That outcome represents the main business value, with other goals being defined to add to that or optimise it. More general business goals such as making a profit are tied to the operation in that it is the means to earn the money and can only continue to do so if it can be set up in a cost effective way. In that sense, achieving the central goal of delivering airworthy aircraft to the customer has to be achieved in certain ways: safely, cost effective, within regulation, but nevertheless remains the driving force in the organisation.

2.3.1.1 *Business process modelling or transformative view of workflow*

A process can be defined as follows: An activity or set of activities using resources, and managed in order to enable the transformation of inputs into outputs, can be considered a process (ISO9001:2008). This definition succinctly summarises the main aspects that are present in many other definitions o of a process, i.e. resources, transformation, output. The transformative view on processes originates in the engineering discipline and is widely accepted - as reflected in the business process literature (e.g. Davenport, 1993, Rummler and Brache, 1995).

Business process modelling is based on the above definition. It provides a description of the activities that are at the heart of a company. The rationale is to understand how outputs are produced and through this understanding increase control over the organisation's performance and productivity. When modelling processes, the key perspective is that of a workflow. It describes a series of activities, many of which are sequential, but also allows for deviation at key decision points. Additional information is collected (and, in software applications, attached to process map as metadata) around parameters such as resources, responsible roles and PIs, data models for which are defined by the pragmatic implementation of the process definition.

The basic idea is that a workflow that delivers the transformation implies a certain amount of linearity, (even though not exclusively), and sees value as being added with each transformative action.

BPM is less concerned with the organisational structure which allocates responsibilities and assigns decision making. Instead it provides a horizontal view on the organisation that accounts for the operational activities that are enacted on a daily basis. Arguably, at the time, adopting a process view on organisations represents "a revolutionary change in perspective: it amounts to turning the organisation on its head or at least on its side." (Davenport, 1993).

Adopting a process perspective added to management and organisational studies; spanning the white space that is left in organisational charts, extending business functions and roles by assigning responsibilities and decision making to activities (Rummler & Brache, 1995).

For these reasons, process modelling provides an entry point into organising the maintenance tasks into a flow of activities that take the aircraft through a series of transformations to deliver it back into flight operations in an airworthy state. A process framework allows for implementing the tasks according to their function in the overall check, such as inspection or rectification, and maps their resources requirements and relationships with each other, e.g. sequential or parallel.

2.3.1.1.1 Lean thinking

Lean initiatives are a prominent example of approaches that use business process modelling methodologies (e.g. Womack and Jones, 2003). Lean philosophy originated in the manufacturing sector and targets wasteful activities in the organisation. Examples of process modelling implementation include value stream mapping which focuses very much on time aspects (e.g. lead time) and associated cost savings, and is an integral part of lean approaches such as Six Sigma. Lean thinking has its origin in the manufacturing sector (e.g. Womack, Jones and Roos, 1990). Manufacturing processes lend themselves to the transformative view since they are mostly sequential, implementing the functional logic of an assembly line where one step delivers the input into the next, and have well defined resource requirements.

Given this background, there is strong focus on the activities that deliver outcomes while people who perform those are reduced to actors that are represented as swimming lanes or only feature in the background data models, being assigned to tasks. In socio-technical systems, where people are key to not only enacting technical process activities but also manage the progression of these, there is a requirement to extend this beyond annotating actor and human resources.

This does not imply reverting back to organisational charts which contain some of the relevant information but considers the possibility of social interactions instantiating activities that are at the core of system functioning, but not systematically accounted for in the traditional take on workflows.

In contrast to the features of manufacturing processes, processes in aircraft maintenance are characterised by parallel activities and, rather than starting the process with a clear definition, a full picture of resource requirements usually only emerges well into the process. The nature of the work being characterized by work packs that have multiple dependencies within the wider system and face varying degrees of uncertainty, its successful operation requires extensive coordination by people.

2.3.1.2 *Processes as coordination of work*

Alternative definitions of process replace the transformative view on activities by focusing on the goals and objectives that account for why the activities are happening in the first place. They highlight the relationships between tasks, as a set of interrelated activities (sequential or more complex). This opens up the territory for a coordination based view on processes.

2.3.1.2.1 Coordination around value proposition to customer

Approaches in this area originated in communication studies and conceptualise processes on the basis of communication actions (Winograd and Flores, 1986; Taylor and Van Every, 2000 as cited in Goldkuhl and Lind, 2008). Goldkuhl and Lind (2008) state that the transformative view is replaced by the following "Business processes arise through requests, offers, agreements and commitments and other communicative acts. " (p.763). The authors summarise the difference between the two process views as follows: "..., a business process can (in this coordination view) be described as moving from customer requirements to customer satisfaction. The process can be called an assignment process (a customer-to-customer process). This means that it is a process where the customer gives an assignment to the supplier

and the supplier performs what the assignment expresses. In the transformation view the process goes from raw material to finished products delivered to a customer. This is a way to compare the two business process views; the starting point and the end point." (p. 766)

Although this is not discussed by the authors, the different conceptualisation of process outcomes represents different interests and priorities, which implies slightly different takes on value. The transformative view tends to associate value more directly with the core product or service. The coordinative view discusses value in reference to the customer; with customer satisfaction as the ultimate goal. Taken to the extreme this could bankrupt an organisation by delivering a perfect product or service at the cost of their profits. In contrast, taking value stream mapping to an extreme customer relation services such as taking the time out of the operation to iteratively update the customer could be considered wasteful in that they interrupt the process that delivers the product. In practice, however, both approaches operated on more moderate ground, with lean thinking specifically including the customer as part of the value stream.

The main challenge with the coordinative view as described is that there remains a physical world that has to be altered, such as the aircraft status of which is transformed. While it opens up new territory for engaging with process modelling, it reduces the aspects that make the transformative view valuable. Goldkuhl and Lind (2008) come to the conclusion that both perspectives on processes are not mutually exclusive but keep that argument at business level and do not offer insights into how to advance the integration as part of process modelling. This, however, is a pre-requisite to advance an understanding of how the system functional logic is implemented in processes and consequently allow insights into how to affect process performance.

2.3.1.2.2 Coordination theory: Managing dependencies between task

Coordination Theory introduced by Crowston and colleagues (e.g. Malone and Crowston, 1994, Crowston and Osborn, 1999, Crowston, Rubleske and Howison, 2004) advances this integration within a task based framework and considers the roles coordination plays in transformation processes. Their definition of coordination puts it at the core of process functioning: "Coordination manages dependencies between tasks" (Malone and Crowston, 1994). The authors argue that this approach is novel in that it links dependencies to tasks not units or people and opens up the process description to be extended into the functional process. "Coordination Theory suggests identifying the dependencies between the tasks the different group members are carrying out and the coordination mechanisms the group use to coordinate their work [...]."(Crowston, Rubleske and Howison, 2005, p.2)

Conceptualising the dependencies being task based addresses challenges described for aircraft maintenance processes and positions coordination into the functional logic of the process. The three different types of coordination processes reflect the reality in aircraft maintenance where resources are shared and their use has to be managed in order to optimise outcomes (see also Baranzini's Friedlander argument): flow, interface and fit. Flow is delivering resources sequentially, interface refers to resources delivered by parallel activities and fit described multiple origins of a resource.

They argue that the coordination methods with which the three different types of resource based dependencies are deliver are generic across different processes and organisations, e.g. first come first served or a line manager decision to allocate a shared resource.

While they do not address the role that coordination has in implementing social dimensions, they acknowledge that there are other human and social mechanisms that coordination relies on. Crowston, Rubleske and Howison (2004) reflect this issue saying that "It should be noted that in developing this framework, Malone and Crowston (1994) describe coordination mechanisms as relying on other necessary group functions, such as decision making, communications and development of shared understandings and collective sensemaking."(p.7)

Previous sections discussed the functional logic of the aircraft maintenance system which underlies the dependencies. Therefore, by virtue of its being socio-technical those can be both technical and social, given that the system is made up from both elements. To advance an understanding of how system processes that implement the functional logic in activities that are designed to deliver the dependencies, social aspects require explicit attention.

2.3.1.3 Resilience engineering

Resilience engineering offers a framework for posing questions about interdependencies at a system level. A definition of resilience engineering and its objectives is offered by Hollnagel (2012): "Resilience Engineering looks for ways to enhance the ability at all levels of organisations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures".

Four key principles inform resilience engineering approaches (Hollnagel, 2012).The following briefly introduces them and discuss each of their significance to being able to address the challenges in aircraft maintenance.

The Principle of **Equivalence of Successes and Failures** states that successes and failures have the same origins rather then being of different nature. From the point of this thesis, the origin can be seen as instantiations of the same underlying system logic which can be deconstructed into dependencies as described above. Resilience engineering acknowledges that people and organisations have to adjust to a given situation without having optimal resources, including information and time.

This is expressed in the second principle: **Approximate Adjustments.** It acknowledges the discrepancy between formal and informal practices that results from dealing with the complexity of the system, as discussed in the overview of the aircraft maintenance system. It argues that "Individuals, groups, and organisations normally adjust their performance to meet existing conditions (resources, demands, opportunities, conflicts, interruptions). Because resources (time, manpower, information, etc.) always are finite, such adjustments will invariably be approximate rather than exact." (Hollnagel, 2012a) This echoes the previously discussed findings of the role that people have in managing the performance of chronically

under-resourced systems (Baranzini, 2009). As a result performance varies which can lead to both things going right or wrong.

The principles of **Emergence** and of **functional resonance** both make an argument that system performance cannot be fully predicted, as illustrated in the following quotes: "Both failures and normal performance are emergent rather than resultant phenomena, because neither can be attributed to or explained only by referring to the (mal)functions of specific components or parts." and "The resonance analogy emphasises that this is a dynamic phenomenon, hence not attributable to a simple combination of causal links. Functional resonance is the detectable signal that emerges from the unintended interaction of the normal variabilities of many signals."
This poses a challenge to the thesis proposition: it has been argued based on empirical in-depth research that the complexity of a socio-technical system can be organised in a way that makes it accessible for intervention, both reactively and proactive. While there may well be instances where the complexity eludes a full analysis, resilience engineering does not offer a functional architecture that can identify the limitations of managing complexity.

In summary, resilience engineering offers a useful framework to consolidate key aspects that have been identified as being critical for the thesis proposition and pose questions. However, it falls short in providing all the answers. Adopting a systemic view that assumes that the same underlying logic is responsible for both good and bad system performance, it goes on to acknowledge the realities of the operation (e.g. finite resources, inherent uncertainty, informal practices, mitigating by approximation). The concepts of emergence and functional resonance, however, cannot be easily adopted to advance an understanding of the underlying logic. They show the limitation in dealing with complexity and variance rather than offering methods to access what is understood about the complexity, which is what people base their approximations on.

A key observation from research in aircraft maintenance is that complex systems, and even when they are dysfunctional, continue to perform well (e.g. Baranzini, 2009; McDonald, Corrigan and Ward, 2002). At the core of that is the capability of people to gain insights into the underlying logic as they experience it in their daily work, develop a shared understanding of it and base actions on it. While not perfect this allows for optimisation within given constraints that are resulting from complexity and uncertainty being system features.

2.3.2 The social space

In this sections, approaches are discussed that focus on the social aspects of the system and how people create and knowledge.

2.3.2.1 Communities of Practice (CoP)

Communities of practice are established around a shared domain or interest which is the reason for the members to interact in the first place which establishes them as a group (community). What differentiates CoP from other groups is the fact the members are practitioners and through their interaction they progressively develop shared practices (e.g. Wenger, 1998, 2006, Brown and Duguid, 1998, 2000).

Wenger (2006) gives a summary of "the structure of a CoP as consisting of three interrelated terms: 'mutual engagement, 'joint enterprise' and 'shared repertoire' (Wenger 1998, pp. 72–73).

- Mutual Engagement: Firstly, through participation in the community, members establish norms and build collaborative relationships; this is termed mutual engagement. These relationships are the ties that bind the members of the community together as a social entity.
- Joint Enterprise: Secondly, through their interactions, they create a shared understanding of what binds them together; this is termed the joint enterprise. The joint enterprise is (re)negotiated by its members and is sometimes referred to as the 'domain' of the community.
- Shared Repertoire: Finally, as part of its practice, the community produces a set of communal resources, which is termed their shared repertoire; this is used in the pursuit of their joint enterprise and can include both literal and symbolic meanings."

CoP show that people who engage regularly around a shared interests such as work, together develop a better understanding of their practices and how those are effective. This is not always a conscious act. An example Wenger (2006) cites is nurses regularly meeting for lunch, exchanging stories about their work day and through this develop a shared repertoire or practices of how to care for patients.

As a conceptual approach CoP provides an entry point to informal practices and tacit knowledge that people have. Recurring patterns of activities, both formal and informal, are translated into a shared repertoire that encapsulates people's understanding of the logic of operation.

In the overview of aircraft maintenance it has been argued that, in order to effectively navigate the complexity of the system and its inherent uncertainty, people rely on coordination. The extent to which this is effectively implemented is mediated by how the actors share an understanding of the underlying interdependencies.

Membership in a CoP is traditionally not defined by the organisational structure, but by common interest and shared practices. People select themselves as members (Wenger & Snyder, 2000). CoP can cross departments and organisations and promises the potential as a vehicle for knowledge diffusions and transfer. In an ideal world, this is driven by a genuine shared interest.

However, research evaluating change initiatives in aircraft maintenance implies that CoP boundaries are often defined by the existing relationships in an organisation or industry (Ward, 2005). People who share an interest are locked in relationships that are defined by qualities such as trust. This social reality mediates who joins, what is shared and how far shared understanding is achieved. Transferring the concepts of CoP to an organisational context, Brown and Duguid (2001) make a similar point when they observe that people in apparently similar jobs fail to effectively communicate as they have developed different sets of practices and thus a different knowledge base. The authors conclude that " [...]while the idea of community may comfortingly suggest that organizations are significantly culturally homogeneous, practice, as we have noted, uncomfortingly suggests they are to a significant degree divided, driven by

practice even as that practice provides participants with their particular kind of organizational identity. Indeed, if regarded as a community at all, any but the smallest organization should probably be regarded as a "community of communities of practice" (p.203)

Even in a situation where relationships were amenable to the core CoP concepts, allowing encompassing all who share an interest, CoP offers little insight in how the knowledge and shared understanding they hold can be structured and directed towards effective use.

Wenger (2006) discusses the roles of CoP in knowledge management which many companies are invested in since knowledge is regarded the key resource for competitive advancement in an increasingly technologically supported professional world. While CoP delivering critical functions such as access to informal knowledge, linking of learning and performance, ownership of tacit knowledge, support this argument, the question that remains what is the process for utilising the knowledge systematically. Wenger and Snyder (2000) themselves raise the issue that: "The organic, spontaneous and informal nature of communities of practice makes them resistant to supervision and interference."(p.140)

In a professional context the operational outcome is the criterion for assessing performance and this knowledge has to be judged in reference to how it enables it. Therefore the key to unlocking the knowledge potential of these groups is to bring it to bear into the process that delivers the outcomes and integrate it into a framework that can be shared.

2.3.2.2 Effective team work

Hackman's (e.g. 2000, 2002) work on effective team is an approach that actively organises social structure. He proposes a set of conditions that establish and support groups of people as a team and allow for effective team work. In the context of this thesis, teams can be regarded as one instantiation of the social structure that is created in response to the functional logic that the technology imposes.

Baranzini (2009) has demonstrated that teams operate at different levels in the maintenance system and that their interactions are instrumental delivering effective coordination that mediates sub-optimal conditions.

In contrast to CoP, Hackman (e.g. 2000, 2002) is less concerned with socially based knowledge functions, but emphasises the structural aspects of people working together. Hackman, Wageman, Ruddy and Ray (2000) argue that real groups are pre-requites for effectively working together and he defines those as having boundaries within which there are differentiated roles that are interdependent. For those groups of people to effectively collaborate, he defined a set of enabling conditions. Firstly, it requires a compelling direction: "Direction is critical to energize the team, get it properly orientated towards its objectives and engage the full range of members' talents" (Hackman, 2002, pp.56). This allows for people to orientate their work appropriately and thus becomes consequential for the organisation and its customer. Secondly, an enabling structure and supporting context is critical for the effectiveness of teams. Hackman (2002) argues for the right balance between overly structured approaches and self-managing teams.

Lastly, expert coaching "can promote team effectiveness by helping team members learn to work interdependently and manage themselves" (Hackman, 2002, p.60). However, it cannot counteract flaws in the first two conditions.

These conditions enable teams to be effective in reference to their tasks in the process. Hackman, Wageman, Ruddy and Ray (2000) proposed three "process criteria" for assessing effective team work: effort, talent or knowledge, and strategies for the given context.

2.3.2.3 Quality of relationships: Trust

While the concepts of CoP have highlighted the role of social interaction in sharing practices and knowledge in an informal setting (e.g. Wenger, 1998, Browns and Duguid, 1998, 2001), Hackman's approach to team effectiveness emphasises the structural aspects (e.g. Hackman, 2002, Hackman, Wageman, Ruddy and Ray, 2000). A third perspective on relationships is adopted by Ward (2005). She highlights the quality of relationships as being a critical factor in effective collaboration, especially in the context of change. Performing a meta- analysis on three change case studies in aircraft maintenance Ward (2005) derives a set of dimensions that either foster trust in relationships in organisational settings, or have the reverse effect. The following are adverse to creating or fostering trust:

- Gap between formal versus normal
- Incompatible goals
- Performance requirement
- No open communication
- History of mistrust

In contrast, trust can be fostered by establishing the following:

- Belief in future
- Genuine support
- Personal relationships

As discussed earlier in the chapter, the uncertainty that is a feature of aircraft maintenance as a system is managed by social functions such as coordination. The quality of relationships defines the opportunities or constraints for social interactions in the process.

2.3.3 Knowledge Management

Following from the discussion of the social structures such as CoP that enable shared understanding that is crucial to drive actions in complex systems that are characterised by uncertainty, the question arises how to access the knowledge and how to ensure its usefulness.

In the knowledge management literature two main processes can be distinguished: knowledge creation and knowledge transfer (e.g. Grover and Davenport, 2001). The knowledge management literature is a diverse field: addressing diverse knowledge functions at different levels and from different perspectives depending on the disciplines focus, e.g. role of IT, role of organisation, role of individual, role of business strategy etc.

The two main processes can be further unpacked.

- Knowledge creation or acquisition: Here different taxonomies for knowledge are proposed, the most prominent one around tacit and explicit (e.g. Polanyi, 1966, Nonaka, 1994) and strategies put forward for fostering different types of knowledge.
- Knowledge storage/retention: Here the focus is on capturing the knowledge that is created or acquired in way that makes it widely accessible and retains its context for it to be useful. Today, information technology has a prominent role here.
- Knowledge transfer: Having the knowledge accessible in one way or the other is a pre-requisite for transfer. There are two main types of transfer (a) across organisational units (b) from one situation or context to another, which are discussed in an interlinked way to varying degrees.
- Knowledge application: How to ensure effective utilisation of the knowledge is the least developed part in the process. One could argue that once the other three are in place, using the knowledge will happen as logical consequence. However, the gap between expectation and knowledge management benefits indicates that this assumption is flawed (e.g. Wickramasinghe, 2003)

A prominent approach in the knowledge management literature is offered by Nonaka (e.g. 1998, 2002). In its original application context this knowledge was used to drive product innovation. However, the core principles resonate with the situation in aircraft maintenance for the following reasons: he specifically addressees the relationships of tacit and explicit knowledge and thus offers a means to systematically access the currently hidden knowledge; he strongly argues the case of knowledge being a social process and takes to actively designing its social setting (e.g. requisite variety and BA); he argues that the knowledge spiral spans from micro to macro, and thus integrates a representation of a system and its levels.

Tacit knowledge represents the fact that, in Polanyi's phrase: "We can know more than we can tell" (Polanyi, 1966, p. 4) and includes 'know how' based on experience. In his SECI model Nonaka proposes four conversion modes, integrating tacit and explicit knowledge, in order to explain how knowledge is created and argues that this cycle is implemented in an iterative process, spanning micro to macro. The four conversion modes are: socialisation (tacit – tacit), externalisation (tacit – explicit), combination (explicit – explicit) and internalisation (explicit – tacit).

The process that Nonaka (e.g. 1998, 2002) designed for creating knowledge in the SECI cycle is built around the following principles: requisite variety, redundancy and social setting (BA).

"The work of Nonaka (2002) on new product development [..] is one of the few models which directly studies the innovation process of using operational and technical experience as a source of new product ideas. Tacit knowledge has a very important role in this process. Tacit knowledge is acquired through direct 'hands-on' experience. In [Nonaka's] model the organisational process for sharing tacit knowledge is through self-organising teams which are cross-functional, spanning organisational boundaries, in which leading members will have had multiple job functions, and which may include people from outside the organisation. Thus such teams have the "requisite variety" to synthesise different experiences in the

knowledge conversion process of 'externalisation' – transforming tacit to explicit knowledge. Preconditions for this knowledge creation are the building of mutual trust and the development of a shared implicit perspective which can then be articulated through continuous dialogues. The ground rules for such dialogues encourage the free and candid expression of ideas, creating room for revision and constructive criticism, and ensuring the continuity of the whole process. Redundancy of experience is critical to this process. It enables the sharing of implicit, tacit knowledge across divergent organisational roles and allows people to "enter into another person's area and give advice". Redundancy also determines the degree to which shared created perspectives are diffused, and is important in the crystallisation of new knowledge." (TATEM D6102, 2006)

Nonaka's approach shares features with CoP in that both emphasise the social nature of knowledge processes and addresses the critical role of tacit knowledge. It complements CoP in that it defines knowledge conversion mechanisms and principles that actively implement a process. However, both approaches do not address the structure of the knowledge or its context and thus do not link it to the functional logic it is meant to say and do something about. From an organisational point of view, the value of knowledge as a resource depends on being able to utilise it, preferably in a targeted way. This seems to be a bottleneck in current approaches. Wickramasinghe (2003) describes three case studies of corporate firms that early on engage in the knowledge business and although having progressed their knowledge management capabilities, at its centre is an organisational memory rather than an active knowledge process - this is where most of organisations fall short.

2.3.4 Effecting change

At the core of the thesis is the aim to effect change in organisations, not only reactively but to develop a framework that can be an integral part of understanding how to design future socio-technical systems. Chapter 1 has outlined industry trends that create a new reality in which people work and identified the need for Human Factors to advance its transition into system science that can be a partner in the transformation, adding to the creation of new value.

The change management literature is not going to be discussed here in detail. The reasoning behind this decision is that a review of the change management literature showed that its discussions do not adopt a functional perspective as promoted in this thesis and therefore, while providing a backdrop for the research, there can be no direct application or advancement of specific approaches or methodologies.

In lieu of utilising or advancing specific existing approaches and methodologies reported in the literature the thesis is built on a strong conceptual foundation, incorporating insights from a large body of empirical work. This provides the basis from which the requirements for addressing change in a functional approach are derived.

In a critical assessment of change management initiatives, McDonald (2008) concludes that there is little empirical evidence for effective change management. Without denying that multiple reasons contribute to change management case studies facing challenges when it comes to empirically link outcomes to interventions , the argumentation in this thesis offers yet another perspective. A relative lack of empirical evidence can be seen as a reflection of the absence of functionally focused approaches in current research

avenues in the area; arguably, in the face of the complexity of change, a functional view is crucial to navigate and account for causal relationships amongst the system elements and their effect on outcomes. In the functionally driven approach proposed in the thesis change is regarded in terms of supporting functional transformation, linking the discussion closer to a socio-technical perspective on system processes and a value proposition that anchors the transformation logic empirically. From this standpoint, the extensive discourse in the area of change management is not directly applicable here. Instead the thesis defines an approach based on a priori knowledge, relevant theoretical concepts from different disciplines and a rigorous methodological trajectory – all designed to address the issues that have been systematized in so far, in Chapter 1 and here.

For contextualising the change dimension in the thesis, McDonald's review of a longitudinal study conducted by Pettigrew and Whipp (1991, cited in McDonald 2008) is used. The study identified five factors which "are environmental assessment, leading change, linking strategic and operational change, human resources as assets and liabilities and coherence. One of the core themes running through this study is the connectedness of these different factors, in particular the linkage between organisational change strategy and competitive advantage." (pp.65)

"The first factor – environmental assessment – establishes the basic conditions for Pettigrew and Whipp's model: these stem from the fact that organisations are open systems which operate within a competitive environment. The argument is that competition and strategic change are intimately linked and inseparable processes. [...] The ability to garner and integrate information for this assessment from across the organisation (from planning, marketing, operations, etc.) makes a critical difference between firms. This is far from a formal planning exercise, but can be called a process of strategic 'sense-making' of the environment." (p.68)

This sets the scene for the other factors: linking strategic and operational change addresses the implementation of strategic intent in operational processes and is discussed in a way that highlights that leverage is gained by understanding the system basis for operations. A core message in regard to the factors of Human Resources and leading change is the critical role of knowledge and its use in social processes. The function is to use existing knowledge about the system, including the knowledge that is hidden, and drive its integration and utilisation in the light of both change objectives (environmental assessment) and constraints (coherence). "Coherence, the final factor, essentially concerns the extent to which the different elements of the strategy pursued not only relate to each other but effectively address the challenges in the firm's competitive environment. The issue of coherence is important because organisational change is a disordered, opportunistic, chance-influenced, dynamic political process. The notion of coherence relates to the "ability to hold the organisation together while simultaneously reshaping it" (p. 266)." (McDonald, 2008, p.69)

This short summary highlights that the five factors can provide a backdrop relevant to the issues outlined for aircraft maintenance as a socio-technical system and this can provide a framework of change that the thesis refers to.

2.4 Proposed framework

The problem statement at the beginning of this chapter which organises the complex issues that people experience in their work in aircraft maintenance goes beyond emphasising the importance of both social and technical aspects of the system, but also outlines their intimate relationships in managing system performance. The formal system descriptions such as technology design and business logic translate into important building blocks of the system, but do not add up to account for all that is going on in the operational situation. It is the implementation of both technical and social aspects in an integrated response to the inherent uncertainty that has to be accounted for to allow leveraging the situation.

Contrasting the conclusions of the review of the empirical base in aircraft maintenance research with existing theoretical approaches in the previously identified key areas pose the following challenges:

- Theoretical approaches tend adopt a specific focus, either socially or functionally based, and usually pursue one line of inquiry, relying on the method most pertinent to it. This hampers the effective integration between social and technical aspects of the system that is called for in this thesis. An example is the way CoP deal with processes. Brown and Duguid (2000) contrast the notion of process with practices and thus disconnect the functional transformative logic that it encapsulates (if only partially) from the socially based inquiry into practices. Business process models are reduced to function as a boundary object that can facilitate exchange between CoPs, but no further consideration is given to their structure or content. Thus, the added functional value that these represent is not exploited in the CoP approach.
- Modelling socio-technical systems in a way that allows appreciating how their complexity and uncertainty is managed in order to consistently deliver system outcomes requires the explicit integration of both social and technical aspects to account for the functional nature of the overall system. Patterns of activities, both formal and informal, make the system logic accessible and express interdependencies. Aiming to impact on system performance arguably puts the process at the core, as it delivers the outcomes which provide a baseline for performance assessments. In contrast to traditional business mapping approaches, the implementation of social functions in activities has to receive attention in its own regard. An integrated view on formal and informal patterns of activities and how they are enabled in the organisation (both socially and technically) defines parameters of a model that configures social and technical aspects to deliver an account of what is going on in an operational situation. This gives insights into their interdependence and allows for optimising their management and delivery.
- Knowledge about how technical and social aspects are functional in a system can be organised in such as model. Having a conceptual structure for knowledge extends the discussed approaches and allows anchoring the analysis of events as well as proactive interventions in the system. Interventions can target socio-technical functions in a way that that affects outcomes, and, as such, system performance.
- Currently this knowledge is not systematised, but hidden locally in informal practices and tacit knowledge. It is used in the existing social structures such as CoP but the effect cannot be directed properly. Leverage from an organisational point of view is based on having sufficiently

comprehensive and relevant knowledge, as consolidated in the proposed structure, but ultimately impact is delivered by bringing it to bear at the system level and in the processes where transformations are necessary. This requires an active process which integrates social interactions into the transformation chain that delivers the expected outcome: a consensus solution based on a system picture.

In order to answer to these challenges the conceptual framework at the core of the thesis needs to be designed to deliver the following:

- Extend the functional logic that is defined by the core technologies and represented in formal descriptions of the system into a framework that accounts for and integrates core social dimensions that are relevant to the system functioning and thus delivers a fuller account of drivers of operational activity.
- Use this comprehensive framework to
  - elicit knowledge that is tacit and/or that represents informal practices/patterns of activities from diverse stakeholders
  - integrate previously distributed and non-accessible knowledge
- Make this body of relevant knowledge available for use in different areas, such as system engineering or organizational change initiatives, in a systematic knowledge process which key output is the transformation of current knowledge into a to-be version of how a social-technical system could function in the future.

The review of aircraft maintenance as a socio-technical system defines the platform for developing such a framework. Details of the empirical research that enabled the development and deployment of it are presented in Chapters 3 and 4 of this thesis. The following gives an overview of key principles and assumptions in order to ground both the selection of methodologies in the next section as well as the detailed results and their discussion in later chapters.

2.4.1 Features of KSM framework

In order to address the call in Chapter 1 for advancing Human Factors as a system science the implication of a socio-technical nature of the system has to be brought to the fore.

The thesis proposes a framework that originally was labelled the Knowledge Space Model, reflecting the critical role of knowledge in leveraging system transformation. The knowledge about the system that is currently partially hidden in informal practices and tacit knowledge as well distributed across the system holds the key to understanding the socio-technically based functional logic of the actual system. It is access to this logic that promises to effect change by transforming knowledge in a targeted way and design ways of basing action upon the new knowledge.

The KSM framework adopts a system view, looking at socio-technical elements and their relations to understand how human performance as a system feature is shaped. It considers Human Factors as built into the system, i.e. factors that affect the human and its performance as actors in system processes can be modelled in terms of key system dimensions.

The development and deployment of the framework is the subject of Chapters 3 and 4 which report on the empirical work that was conducted as part of the thesis research. Here an overview of the key assumptions and principles is given which provides a context for the methodological choices and their implementation in the empirical studies.

In general, the framework adopts a systemic orientation, addressing elements and their relations at different levels. Relevance and leverage as defined in Chapter 1 are driving the conceptual consolidation and application in each step.

Positioned within this context, the following gives an overview of key assumptions and principles:

- Operational systems operate in nexus of the technical and social spaces which interrelations are mediated by information and knowledge. Their process system is delivering the outcomes in the operational situation and as such are appropriate as key reference when understanding all that is at work in a socio-technical system
- The process system at the core of the framework is extrapolated from the patterns of activity, both formal and informal, at different system levels. The process instantiates the functionality of technical and social elements of the system in a functional logic that enables or constrains people's actions.
- An ecologically valid representation of activities rather than representation of a formal or prescriptive view on the operation is presented in the framework. Recurring patterns of activities are the baseline, some of which can be easily expressed by the people operating the system; others are embedded in the way of doing things which requires observation and extracting and transforming (tacit) knowledge.
- A conceptual structure organises key dimensions which can account for most of the variability observed in system outcomes. In essence, all models are wrong (Sterman, 2002), i.e. they cannot cover all possible variability, however, if they allow for leverage this is largely inconsequential.
- Process activity is approached from a socio-technical point, incorporating both technically based activities as well as interactions functionality of which in the process is socially based. Related representations of social relations and the utilisation of information are mapped, anchored in the process activity perspective.
- The three perspectives allow for interrogating the role of activities in the process while at the same time opening up an assessment how these are supported or constrained by the social system as expressed in the social structure and its processes and the technical system, where an emphasis is put on information technology as a direct interface between aircraft technologies and people.
- The core functional logic is distilled in a series of states that organise process dependencies and anchors the knowledge transformation scope. The conceptual model is the basis for a series of steps in a knowledge process that iterates the same set of core concepts from description of knowledge content to its transformation into solutions or future vision, depending on the application context.

Having a conceptual structure as the proposed framework enables the following

a) Knowledge structure: An integrated description and analysis of operational reality, delivering change recommendations for the system in a way that is transparent and sustainable; providing dedicated tools and methods for doing so.
b) Knowledge process: Facilitates a systematic knowledge process that realises the implementation of this structure to guide knowledge creation, transfer and application in operational and organisational processes at a micro and macro level
c) Added value: It creates the basis for leveraging g the role of people as part of the system's value chain and thus enables doing Human Factors in a way that positions its value proposition into the business logic

2.4.2 Conclusions

The proposed framework (a) defines a structure for knowledge that is ecologically valid and, while process based, is inclusive of the key dimensions that underlie the criticality of the human role in socio-technical systems and (b) provides a heuristic anchor for knowledge activities that enable interventions that systematically and effectively draw upon this new knowledge base.

The methodologies to be selected for the thesis have to be integrated in response to this trajectory and enable an active, in-depth engagement with the target system.

The presentation of findings in developing and deploying the proposed framework in Chapters 3 and 4 is organised around this structure. It should be noted that the distinction between the two in representing the empirical research is not an absolute one. Capturing knowledge and populating models is the starting point of a knowledge process, however, as it uses the structure to define content, it is reported in the first of two sections in each study: the knowledge structure. The research reported in the second section: knowledge process, in each study, has a different focus. Here the focus shifts from representing relevant content to creating capacity for action. Both rely on knowledge transformation, as both are socially based, integrating the knowledge held by different stakeholders.

2.5 Methodology

In the beginning of this chapter the complexity of aircraft maintenance as a socio-technical system has been organised around four themes. Based on this, the remainder of the chapter is reviewing what the implications are for positioning the research in an interdisciplinary landscape, both in terms of concepts and methodologies.

The empirical research that implements the questions posed in this thesis has to be designed in a way that builds on the existing knowledge and allows for insights into the complex interactions of technical, social and knowledge aspects that contribute to how a socio-technical system performs as a whole.

Adding to this complexity is the fact that, by nature of the operation, insights into many of the relevant aspects are hidden in informal practices and tacit knowledge. Therefore, methods have to be able to elicit this type of knowledge without compromising it, but at the same time also provide the means to integrate it with existing explicit knowledge and test assumptions about their relationships.

Taking all of this into account, the design of the research and its associated methodologies is led by the outcome that this thesis aspires to deliver, which is developing an approach that can effectively deal with the complexity, as outlined. Summarising the core proposition of the thesis, it aims to develop a conceptual framework integrating diverse dimensions by exploiting multidisciplinary approaches, and its utilisation in a process that demonstrates how people and their actions and interactions contribute to value creation in a socio-technical system. Advancing such an approach is not only driven by prospect of theoretical gain, but equally by the conviction that this is key to creating the ultimate value by being able to more effectively leveraged change.

In order to understand how to transform the operational process system through which organisations conduct their business, it is necessary to develop an understanding of their social context – developing a rich picture, or thick description of the whole socio-technical situation.

This has to meet a number of requirements. It needs to be

- Grounded: addressing the normal operational activities of every day life, including informal and unofficial ways of working.
- Systemic: seen in the context of the organisational systems and processes which constrain and influence activity – a functional perspective.
- Dynamic: Concerned with activity over time and processes of stability and change.
- Meaningful: Encompassing the way in which people make sense of or understand their activity in its systemic context.

The framework as sketched out in the previous section adheres to these principles. Addressing the issues outlined for aircraft maintenance, it advances the social aspects and integrates the social with the technical aspects to demonstrate their complementary functionality. From a methodological point of view, the framework is designed to capture and analyse operational reality in a systematic and ecologically valid way. It encapsulates and transforms knowledge about the system, systematically covering the critical space – in terms of both organisational structure as well as conceptual dimensions. It drives the knowledge base through a series of iterations which, as part of a socially based process, leads into doing things differently.

The research trajectory can be described as a process that was designed and implemented to deliver exactly that (a conceptual framework that allows leverage over system performance). The logic of this overall research process informed the decisions in relation to design and methodology and led to the conclusion that it was appropriate to design a **case study arc,** i.e. two interrelated cases that instantiate the two key rationales or phases of the research trajectory – the conceptual design of an approach and its utilisation in an industry context.

Having preconceptions of the nature of socio-technical systems such as aircraft maintenance is not contrary to qualitative research in case studies. Yin (2009) explicitly states that a case study "benefits from the prior development of theoretical propositions to guide data collections and analysis." (p18)

The complexity of the system as outlined before led to an interdisciplinary review of theoretical concepts and approaches, and consequently, a framework such as required cannot be realised within one methodological paradigm. The design has to allow for a mix of methods to address the interdisciplinary nature of relevant dimensions, and their exploration at different system levels, all targeted to wards the thesis objective.

The two methodological paradigms that were integrated to deliver the thesis research are ethnographic approaches and action research. Both are concerned with ecologically valid understanding of the target system, but differ in the type of knowledge they can elicit. While ethnography delivers an in depth understanding of existing situation without deliberate interference, action research actively manipulated the situation and gains insights by doing so.

The following sections will outline the reasoning behind the decisions (see "Overview of research trajectory") and introduce the high level design of the research presented in the thesis (see "The (HF) research case: Case study arc"). In Chapter 3 and Chapter 4 the more detailed account of the empirical research conducted will extend on this in the light of their respective roles in the overall research case that this thesis is arguing.

2.5.1 Overview of research trajectory

The research in this thesis is driven by considerations of relevance and leverage. Having established that the issues, are complex due to the varied forces at work in a system, the thesis set out to confront the complexity of a well explored socio-technical system, aircraft maintenance, which is an ideal candidate as it is also part of a well described larger system or system of systems, the aviation industry.

The aspiration of the thesis is not to account for all possible variance that can be observed in a system, but to progress the integration of key technical and social aspects which are often discussed in isolation regarding their functionality in the system and thus advance not only the understanding of how socio-technical systems work but also open up the opportunity for targeted interventions, giving leverage.

The implementation of the research can be characterised as two interrelated rationales that in sequence deliver the overall outcome of the thesis. They represent a succession of theoretical advances that see the relevant knowledge organised into a framework, defining a knowledge structure (Rationale 1), which allows for the knowledge being used to leverage system performance, in a knowledge process (Rationale 2).

Rationale 1

The thesis started out with the proposition that in order to better understand how people contribute to making complex systems work, the distributed knowledge about technical and social dimensions had to be elicited and integrated within a process activity baseline. In contrast to a more explorative nature that is a characteristic of many case studies, the research in this thesis was built on a priori knowledge that was accumulated in an extensive action research programme in aircraft maintenance. The review of this existing research provided an initial overview of the salient issues in the existing systems that resulted from aircraft maintenance being a socio-technical system that operates people mediated processes.

The aim of phase 1 was to design an approach that systematically complemented functional accounts of socio-technical system that are technology based with the social dimensions whose contributions to the overall system performance is equally critical, but which are not sufficiently investigated in how they realise their functionality.

An initial framework was proposed that integrated salient socio-technical dimensions of the aircraft maintenance systems according to two main principles

- Content dimensions were organised in a structure in relation to a process core, integrating functional and social aspects of the system in a single framework.
- An iterative approach to knowledge creation and transformation was developed within this framework for both the conceptual structure and the content.

In phase 1 the focus was put on the functional logic of the aircraft maintenance system as experienced by a diverse set of operational and management staff, in contrast to available formal accounts that favour the technical perspective. It represented a consolidation of the certainties of the system's logic that people faced in their daily work but which were largely hidden in informal practices and tacit knowledge, while the issue of uncertainty was addressed indirectly in the conceptual redesign of the role of coordination as integral part of the process activities.

As the focus was on developing the approach and populating it with distributed knowledge, case study 1 drew on ethnography to investigate in depth, using observations and other appropriate means such as interviews, documentation review, focus groups to collect data.

Research in case study #1 advanced the modelling approach for the process core including its analytical iteration (e.g. states, gates and dependencies) and further specified the social processes in regard to their functional interface with the process (e.g. coordination activities). A mix of methods was deployed to investigate the elements and their relationships as outlined in the framework and to deliver the in-depth understanding of how those are enacted/realised in the aircraft maintenance system. This resulted in extending the a priori knowledge base and refining and advancing key propositions of the approach. The conceptual advancements achieved in phase 1 were consolidated in an updated version of the framework that was deployed in the second phase.

Rationale 2

The development of the conceptual framework was the pre-requisite for the second set of research activities which saw its utilisation to leverage change in two different aviation based contexts: (a) the interface between design process and operational system and (b) an organisational improvement initiative in partnership with the customer.

The extent to which the utilisation of the framework as part of a knowledge process delivered outcomes that affected change in response to the challenges each application posed, simultaneously served as a step towards validating the framework, i.e. as validation of relevance of knowledge structure and content.

While the initial focus was on an in-depth investigation to systemise knowledge about how the system functions along key socio-technical dimensions, the research activities here were aimed to utilise it to

change the given situation. This required a shift in focus from ethnographic methods that largely delivered the understanding of the system's functional baseline to an action research programme for realising its potential for change. Within the action research agenda it was possible to design an active process that iteratively addressed the role of relationships in utilising knowledge and how it affected the management of uncertainty inherent to the maintenance system.

The action research agenda and strategy was formulated in collaboration with different project stakeholders to align the relevant aspects of their respective agendas and to establish what the proposed approach delivered for each project (that were the research context for two case studies presented in Chapter 3 and Chapter 4). Pursuing this approach promised to deliver an outcome that was valued by all stakeholders – a shared understanding of how the system could work differently, systematically organised and represented to drive necessary implementation actions.

In case study #1, this agenda was cut short for several reasons, including the challenges that the researchers faced to integrate a systemic Human Factors approach into a technology driven project design. However, it was implemented in a series of workshops that utilised the framework to converge project partners' understanding of operating the technologies and transformed it into a vision of how emerging technology capabilities could be translated into a future maintenance operation.

Having learned from case study #1, the second case study transferred the process into the organisational domain, implementing it as part of an improvement initiative, jointly driven by maintenance organisation and customer.

Research in case study #2 applied the framework and extended research by linking the process based coordination functions into the broader social concepts of the analysis and by formalising the role of knowledge.

Case study #2 more fully embraced the second rationale of the research trajectory and therefore has a stronger emphasis on the action research paradigm, as reflected in the focus on implementation and the role of social processes in it. Data collection methods were varied, focusing even more on interactions and exchange with participants (e.g. workshops, interviews, participatory process mapping, training elements etc).

2.5.2 The (HF) research case: A case study arc

The themes that emerged when reviewing challenges faced by industry in chapter 1 were further explored and operationalised at the beginning of this chapter, focusing on the system of aircraft maintenance as an example. The previous section summarised the research trajectory and process that was implemented in response to the research agenda consolidating the issues. In consideration of these, high level characteristics requirements can be identified for the research design and the methodologies that are appropriate to address the questions being raised in the thesis.

Seale (1999) argues: "Methodological discussions of the quality of research [...] benefit the quality of research by encouraging a degree of awareness about the methodological implications of particular decisions made during the course of a project. Intense methodological awareness, if engaged in too

seriously, can create anxieties that hinder practice, but if taken in small doses can help to guard against more obvious errors." Rather than propagating that methodological considerations are less relevant in qualitative research, this reinforces the point that methodological decisions have to be grounded in and justified by the nature and objectives of the research. Designing a study and selecting a methodology or mix of methodologies is done to serve a purpose, i.e. deliver a research agenda and answer its research questions, rather than fuelling partially emotive argumentations about the superiority of research paradigms, approaches and methodologies.

In the context of this thesis, the emerging requirements for design and methodologies include the following:

- The research trajectory is implemented across different projects
- The issues raised are complex, touching on different disciplines
- Integration of several methods to sustain appropriate engagement with various dimensions and levels
- In depth engagement to uncover partially hidden knowledge about how the system works
- Theoretical framework and a priori knowledge are accommodated in the design approach

In response to these requirements, the case study approach was selected as a framework for the research. Yin (2009) consolidates available definitions and discussions of the case study methodology in defining it twofold:

1. Its scope: A case study is an empirical enquiry that investigates a contemporary phenomenon in depth and within its context
2. Its (data) strategy: "The case study inquiry
    - Copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
    - Relies on multiple sources of evidence, with data needing to converge in a triangulating fashions, and as another result
    - Benefits from the prior development of theoretical propositions to guide data collections and analysis." (p18)

A case "can be whatever "bounded system" (to use Louis Smith's term) is of interest" according to Stake (1987)." An institution, a program, a responsibility, a collection, or a population can be the case." (p.) In this thesis two research programmes defined the interconnected cases – both aspiring to the development and implementation of a systemic approach to the people centred re-design of operational systems.

Their respective research objectives can be summarised as follows: Case study 1 defined a programme that developed and utilised the framework to investigate the impact on the operation of technology innovation driven by the aircraft manufacturing sector. Case study 2 built on those conceptual achievements and deployed the framework to design and implement an organisational improvement initiative.

2.5.2.1 Constructing a case study arc

The research trajectory of the thesis is build around relevance and leverage. Conceptually, they can be regarded as complementary in that relevance is a pre-requisite for leverage (as discussed in Chapter 1). Turning this proposition on its head, one can argue that while leverage goes beyond relevance in creating impact through intervention, the effects can only be fully understood on the basis of established relevance.

From a design point of view, both have to be instantiated in the research, and while they have independent qualities, the research designed to gain insights into them is intimately interrelated.

Yin (2009) states that "case study research comprises an all-encompassing method – covering the logic of design, data collection techniques, and specific approaches to data analysis." (p.18). Here the logic of design (and related techniques and approaches) requires a case study arc that is dedicated to implementing the overall research trajectory across cases. Implementing a research agenda around relevance and leverage for the first time requires extensive work (as previewed in the section "Overview of research trajectory") and implies two rationales which can be best accommodated in more than one case. The proposed two stepped approach also allows for additional validation iterations, using different participant sampled and application context. Once established and demonstrated, there is always the option of condensing it into a single programme with a shorter timeframe.

Though the two case studies were part of two separate projects, each with specific research objectives and tasks, from a theoretical point of view they successively advanced the framework proposed in this thesis. Together they implement the Human Factors research case of this thesis.

The case study approach delivers an adequate structure for managing a systematic research trajectory, but at the same time allows for iteratively refining the particulars of the implementation in response to emerging outcomes of the in-depth investigation ("progressive focussing" Parlett & Hamilton, 1976).

The inherent complexity of socio-technical systems requires an in-depth analysis to understand what makes them work and what the key dimensions are that deliver relevance and leverage when intervening. In contrast to many case studies that are explorative in nature and build up a rich picture from the bottom up, this thesis uses a case study methodology to combine a top down approach, i.e. proposing a conceptual structure, with progressively building up a rich picture of the cases, integrating key stakeholders' understanding of how the system works (bottom up).

The same applies to any intervention designed on a conceptual basis. Shifting the focus from the in-depth investigation to designing interventions to advance the potential for effectively exploiting the new knowledge base requires a similarly iterative approach.

Johannson (2003) discusses the pragmatic nature of case studies and cites Patton (1990, p.39): "Rather than believing that one must choose to align with one paradigm or the other, I advocate a paradigm of choices. A paradigm of choices rejects methodological orthodoxy in favour of *methodological appropriateness* as the primary criterion for judging methodological quality".

This allows for implementing a research agenda in a multi-case arc that utilises multiple methodologies to advance its cause.

2.5.2.2 Multi-method approach as part of interdisciplinary strategy

Due to the variety of dimensions that influence the performance of a complex system, any approach has to be multidisciplinary and agile in its utilisation of the associated diverse methodologies.

Every theory has its preferred method. As a consequence, systemic research is faced with the challenge that methodologies are often designed to address a single dimension or a partial view of a system issue. Therefore, it requires a combination of methods to adequately address complex problems in their system context.

Hackman's (2012) comparison of ethnography and action research summarises their adequacy in delivering to the objectives within the case study arc of the thesis. "Ethnographic studies and action research have complementary virtues and limitations. Ethnographies provide rich and detailed descriptive accounts of what transpires in groups but leave unaddressed the gap between what exists and what might be done to change or improve group behavior or performance. Action research, by contrast, focuses explicitly on implementing and assessing constructive change but runs the risk of becoming so problem-specific and system-specific that it can be difficult to extract from what was done and found any general propositions about group behaviour."(p.434).

Implementing the overall trajectory, both cases incorporate elements of multiple methods, namely qualitative approaches associated with case study including ethnographic approaches and action research, which in turn inform the research activities, interactions and data collection in these cases.

2.5.2.2.1 Ethnography

Ethnographic approaches focus on social and cultural processes. They deliver an in-depth description of every day life and practices and insights into shared meanings and values that are held by people in a given setting, e.g. work place, and ultimately aim to extract cultural constructions of the world people live in.

Hoey (2012) states that "Ethnographers generate understandings of culture through representation of what we call an *emic* perspective, or what might be described as the "'insider's point of view." The emphasis in this representation is thus on allowing critical categories and meanings to *emerge* from the ethnographic encounter rather than imposing these from existing models. An *etic* perspective, by contrast, refers to a more distant, analytical orientation to experience."

Access to the insider perceptive is gained by observation, predominantly by participant observations, which was not an option in this thesis as aircraft maintenance is a highly regulated safety critical industry. Social meanings and activities as they occur in their natural setting are captured in this approach.

Ethnographic research has been critical to establishing the a priori knowledge base this thesis is utilising. While this is integrated in an emerging framework that guides the overall research trajectory, aspects of it require additional in-depth research to validate and further explore and refine. In instances where a requirement was identified to extend the a priori knowledge base, ethnographic approaches informed the

research conducted in response. This was particularly relevant in regard to rationale 1 of the research trajectory which focused on the iterative development of the framework.

Ethnographic research gives ecologically valid insights into the current way of doing things. It uncovers knowledge held by people, explicitly but more importantly, implicitly, about regular patterns they experience. In that respect it is best suited to access aspects of a case that can be characterised as being regular or certain. In phase 1 (based on a priori knowledge) this allowed to establish the recurring patterns of system functioning and explore them in detail. Once those had been established and consolidated in a framework, its deployment to leverage change in operational system required another methodological approach.

2.5.2.2.2 Action research

Action research, as defined by Peter Reason and Hilary Bradbury (2001), is: "a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview [...]. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities." (2001, p. 1, as cited in Brydon-Miller, Greenwood and Maguire, 2003)

Action research seeks insights into complex issues in a practical context by intervening – doing things inevitably introduces changes to the situation and allows iteratively testing hypothesis and learning from the outcomes. "Robin McTaggart reflects this commitment to action in describing the difference between action research and other forms of inquiry, 'the crucial difference lies in the commitment of action researchers to bring about change as part of the research act. Fundamental to action research is the idea that the social world can only be understood by trying to change it.'"(cited in Brydon-Miller, Greenwood and Maguire, 2003, p.15)

Action research positions itself for addressing systemic issues in that it acknowledges its preoccupation with complexity as well as the fact that answers are not held by a single perspective, researcher or not. "As Victor Friedman put it, it helps to have 'a preference for learning from experience and especially from engaging uncertainty/complexity'. You have to be willing to be wrong, to trust that other people know their own lives and their own interests better than you do." (Brydon-Miller, Greenwood and Maguire, 2003, p.21) However, it leaves open how to systematically engage with the complexity. This is reflected by Brydon-Miller, Greenwood and Maguire (2003) in saying that action research is "often doing great good in a local situation but then failing to extend beyond that local context" (p.25)

Action research has been the dominant paradigm for implementing the second rationale of the research. Together with organisational staff the newly acquired insight in how the system works (i.e. conceptual framework) was used in a process designed to reduce uncertainty. "A key value shared by action researchers, then, is this abiding respect for people's knowledge and for their ability to understand and address the issues confronting them and their communities." (Brydon-Miller, Greenwood and Maguire, 2003, p.14).

"Many of us cite Kurt Lewin, who once observed, 'there is nothing so practical as a good theory' (1951, p. 169), as a major influence on our work."(Brydon-Miller, Greenwood and Maguire, 2003, p.15) The framework developed in the thesis qualifies as a theoretical approach that is used as a reference system for the research agenda. "But action research goes beyond the notion that theory can inform practice, to a recognition that theory can and should be generated through practice, and, as the earlier discussion of values would suggest, that theory is really only useful insofar as it is put in the service of a practice focused on achieving positive social change."(Brydon-Miller, Greenwood and Maguire, 2003, p.15) One can argue that this statement paraphrases the concept of leverage that is guiding the second phase of the research and thus further the choice of paradigm.

2.5.2.3 Uncovering in-depth system knowledge

Another argument for a case study approach being appropriate for the research undertaken here is the fact that by its very nature it is designed to elicit knowledge. The qualitative in-depth, multi method approaches allow for accessing hidden and tacit knowledge and to converge a shared understanding of the case from different stakeholders perspectives.

Stake (1978) discusses the tacit knowledge dimension as part of a case study: "Tacit knowledge includes a multitude of unexpressible associations which give rise to new meanings, new ideas, and new applications of the old" (p.6)

Within the case study framework both ethnography and action research address the issue of knowledge, in complementary ways. While ethnography uncovers existing knowledge in great detail, an action research agenda - if devised in combination with ethnography – can use this knowledge and manipulates the situation to affect change that delivers new insights.

"Naturalistic generalizations develop within a person as a product of experience. They derive from the tacit knowledge of how things are, why they are, how people feel about them, and how these things are likely to be later or in other places with which this person is familiar. They seldom take the form of predictions but lead regularly to expectation. They guide action, in fact they are inseparable from action (Kemmis,1974)." (Stake, 1978, p.6)

Beyond eliciting relevant knowledge, the combination of both paradigms also allows for adopting a meta perspective of how knowledge works in the system, from generation over distribution to use.

2.5.3 Considerations of validity

This section discusses concept of validity in qualitative research that are relevant to the design case outlined before and which will be instantiated in validation activities reported in the case studies in Chapters 3 and 4.

2.5.3.1.1 Rigor & "Trustworthiness"

Morse, Barrett, Mayan, Olson and Spiers (2002) propose that a common denominator in judging quality is the rigor in the qualitative research or its "trustworthiness" (e.g. Guba & Lincoln, 1981; Lincoln & Guba, 1985; Guba & Lincoln, 1982, cited in Morse, Barrett, Mayan, Olson and Spiers, 2002), which they propose

to build into the qualitative study rather than using the concept for an evaluation of the product. The authors argue that "Contrary to current practices, rigor does not rely on special procedures external to the research process itself. "(p.6)

The design of the case study arc to implement the two phases of the conceptual research trajectory addresses the criterion of rigor. Both phases are built around the use of the same conceptual dimensions which enables an iterative validation in different application contexts.

To ensure rigor as a criterion Morse, Barrett, Mayan, Olson and Spiers (2002) promote verification strategies that are used as part of the research process. *"Verification* is the process of checking, confirming, making sure, and being certain. In qualitative research, verification refers to the mechanisms used during the process of research to incrementally contribute to ensuring reliability and validity and, thus, the rigor of a study. These mechanisms are woven into every step of the inquiry to construct a solid product (Creswell, 1997; Kvale, 1989) [...]" (Morse, Barrett, Mayan, Olson and Spiers, 2002, p.9)

The proposed verifications methods include

- methodological coherence
- sample must be appropriate
- collecting and analyzing data concurrently
- thinking theoretically
- theory development

The design that supports the realization of the research trajectory adheres to these: The trajectory starts off with advancing conceptual knowledge and developing a theoretical framework which provides a baseline for further research activities. A dedicated multi-method approach has been designed to deliver the research agenda in a coherent way. These methods were chosen for their ability to capture different types of information and knowledge that are critical for each phase, building up the content iteratively. In aircraft maintenance, as in any socio-technical system, the critical knowledge is distributed. Using the system structure to identify key stakeholders ensures the sample appropriateness. This does not only drive general requirements for the overall research process, but also for specific interventions such as knowledge transformation activities.

2.5.3.1.2 Types of validity

Responding to the quantitative paradigm, validity has been discussed in terms of how to achieve it, i.e. in term of procedures, criteria and standards, within the different types of qualitatively orientated research approaches. Maxwell (1992) argues that "... defining types of validity in terms of procedures, an approach generally labeled instrumentalist or positivist, is not the only approach available. The most prevalent alternative is a realist conception of validity that sees the validity of an account as inherent, not in the procedures used to produce or validate it, but in its relationship to those things that it is intended to be an account of." (p. 281).

Maxwell (1992) proposes five different types of validity in the qualitative research paradigm:

1. Descriptive validity (e.g. capture what everyone says correctly, capture everything relevant?)

2. Interpretative validity (e.g. consensus/integration into one big picture)
3. Theoretical validity (e.g. framework – concepts/building blocks and how they fit together)
4. Generalisation (e.g. within community/outside community)
5. Evaluative validity (e.g. deploying evaluative framework)

This classification is can be translated into a process that facilitates a progression of understanding of the subject/object of the research. This is implemented in the design choices in the thesis as outlined in the previous sections of this chapter.

2.5.3.1.3 Triangulation

The term triangulation originates in geography and land surveying and is used as a metaphor in the research process. Patton (1999) states: "The logic of triangulation is based on the premise that no single method ever adequately solves the problem of rival explanations. Because each method reveals different aspects of empirical reality, multiple methods of data collection and analysis provide more grist for the research mill." (p.1192)

Denzin (1978, cited in Mathison, 1988) outlines four types of triangulation: "(a) data triangulation including time, space, and person, (b) investigator triangulation, (c) theory triangulation, and (d) methodological triangulation (pp. 294-307)"

Seale (1999) states that "triangulation exercises can add to the credibility of a particular account as a part of a fallibilistic research strategy in which evidence is sought for central claims."(p. 474) He argues that triangulation arose in a realist paradigm, inspired by the geographical approach to positioning, i.e. identifying a fixed point, but has since also been adopted by constructivist paradigms. While the realist approach is in line with the origin of the concept in geography and considers its goal to converge in a fixed point that reflects a shared reality, constructivists see triangulation as a means to uncovering different realities as constructed by different individual or groups ("indefinite triangulation" Cicourel, 1974, as cited in Seale 1999).

Linking triangulation to the discussion of rigor, the former position makes use of triangulation as a mechanism in the verification strategy of sample selection in order to achieve saturation that indicates the research territory has been sufficiently covered.

In this thesis the main triangulation strategies deployed are the data and methodological triangulation. Data is collected at different times, locations and a variety of key stakeholders, including redundancies of roles. The multi-method approach designed to implement the research trajectory uses ethnography and action research to approach the same set of socio-technical issues.

These three perspectives on validity in qualitative research have been used to inform the design and conduct of the research in this thesis. Given the complexity of the subject and the long-term trajectory of action based research (integrated into two four year project), they seemed to be appropriate for managing the complexity and support the progression of the case study, conceptually and in terms of content.

3 Chapter 3: The TATEM case study

3.1 Introduction to research rationale

Reason and Hobbs (2003) comment on the challenging nature of aircraft maintenance by saying:

> "If some evil genius were given the job of creating an activity guaranteed to produce an abundance of errors, he or she would probably come up with something that involved the frequent removal and replacement of large numbers of varied components, often carried out in cramped and poorly lit spaces with less-than-adequate tools, and usually under severe time pressure. There could also be some additional refinements. Thus, it could be arranged that the people who wrote the manuals and procedures rarely if ever carried out the activity under real-life conditions. It could also be decreed that those who started a job need not necessarily be the ones required to finish it. A further twist might be that a number of different groups work on the same item of equipment either simultaneously or sequentially, or both together" (p.1).

Although it does not say so explicitly, this quote illustrates that it is not so much the maintenance task in itself that makes aircraft maintenance a challenging job to work, but that the challenges arise from its set up in the process of the maintenance production system and its interfaces with the wider organisational system. It captures the conditions within which maintenance is performed on the hangar floor or apron, including a reference to inputs designed externally such as manuals as well as the intra-organisational challenge of matching staff roster and task schedule; both being examples for problematic working conditions originating outside the operation. This illustration of the nature of maintenance highlights many of the dimensions that contribute to the problems manifesting themselves in the operation and have been reviewed in more detail in Chapter 2.

Chapter 2 has explored the dynamic of aircraft maintenance and argued that the challenges of a situation as complex as described above are amplified by the existence of formal systems that are designed in (partial) ignorance of how people proactively manage this complexity as part of their operational practices.

Uncertainty that is inherent to a complex system such as maintenance leads to sub-optimal functioning. The effects of this are mediated by patterns of activity that are not random or idiosyncratic but a systematic, regularly recurring response to the experience of uncertainty. However, as those are rarely recognised in formal accounts of the system and thus are treated as violations or deviations if the sub-optimal cannot be mitigated any longer and any of those informal practices are discovered in a resulting investigation.

In line with resilience engineering, this thesis adopts the view point that success and failure are expressions of the same underlying operational logic that is expressed in both formal and informal practices, and argues that effort needs to be spent to work through the given complexity and uncertainty

and extract those regular patterns of action and interactions that can shed light on how the system really works.

Therefore, the concept of error in the quote above requires clarification. While the notion of error is traditionally associated with people at the sharp end, executing operational tasks, most recent literature agrees that this often is merely a symptom of a dysfunctionality occurring in the wider system (e.g. Reason, 1997). Adopting a systemic approach shifts the focus from individual performance to assessing how the outcomes of maintenance processes are delivered and how different configurations of the maintenance system overall account for variance in their quality.

The systemic perspective defines an anchor for how to deconstruct the complexity of the system and develop and approach that can deliver relevant knowledge into a process that envisages future system transformation or delivers positive changes in the existing situation. From an aircraft system design point of view, including the associated information based services, the quote points to the crux of the matter in the relationship between design process and operation: designers have currently a limited understanding of 'real life operation'.

Intertwined reasons for the unavailability of these critical real life insights include the following; requirements processes are not able to access this knowledge, even if it can secure strong end-user participation, as it is hidden (informal and tacit) and thus difficult to share even if people wanted to (which again is mediated by agendas, e.g. legal accountability, data protection , competition in services etc), and there are no dedicated approaches that target this type of knowledge and thus could act as broker of knowledge . This makes critical knowledge about how technology is operated in reality not only difficult to access, but creates a more profound gap: designers basing decision on a false sense of accuracy of available knowledge, not realising what they are missing out on. However, these decisions have an impact on operational concepts and the implementation of next generation technology capabilities can shape the formal system for decades to come. One can argue that, that the situation as described perpetuates the uncertainty for the operation, maintaining or even increasing the disconnect of formal systems and operational reality.

To overcome this predicament, an approach is needed that systematises key dimensions of system functioning and the role of people in it , addressing the argument of complexity outlined in Chapter 2, and that, thus, creates a knowledge base of real operational life. Having this, allows indentifying opportunities in which the approach can productively intersect with the design process and support aligning technology capabilities and operational impact expectations.

3.1.1 Overview of TATEM design scope

The aircraft maintenance system is the backdrop for the TATEM project, a large integrated project in the 6th framework, in which the research presented in this chapter was conducted.

TATEM aimed to demonstrate how new maintenance concepts that are enabled by new technology capabilities can achieve a direct maintenance cost reduction of 20% or more. Achievement of this goal was realised by TATEM technologies seeking to transform the effectiveness of the maintenance processes underlying the consistent delivery of airworthy aircraft to flight operations.

In order to create a basis for achieving these objectives, the project was designed with a strong focus on developing Integrated Vehicle Health Management (IVHM) technologies for different aircraft systems which were developed in response to scenarios and top level requirements. The project was designed around a traditional v-cycle – leading from requirements to specification – implementation – verification to validation – with a strong focus on technology, as reflected in budget and person months. While there was additional consideration for the people element of the system, it was introduced separately as a stand-alone work package. Within the overall technology development trajectory (i.e. scenarios – requirements – development - demonstration), a separate work package called Ground Crew support was tasked to consider the impact on the operator, mostly at the point of execution. The work strands included: process orientated information (6200), mobile task support (6300), proactive maintenance planning (6400), and embedded training (6500). Main participants in these strands were mostly representing the manufacturing sector and thus formal knowledge about the operation that was also remote, rather than insights into the real life conditions as referred to in the initial quote (Reason and Hobbs). The tasks of the maintenance providers that were involved were small and defined as general review of technology development.

Although there were dependencies, the direction of these was of HF to respond to emerging technology rather than integrating it as an equal partner in the design of a better operation. As a consequence WP6000 was centred on ground execution (including task support, presentation of information and HMI design) with some consideration of training for the staff on the floor or ramp. All of which are important but not close to being sufficient for design for operations.

In the light of this assessment, the scope of the research presented here was defined wider that the core of the Ground Crew support work package that was focusing on individual task support and lower level decision making at the maintenance execution level. Addressing the operational complexity that Chapter 2 raised, the research was extended into the system context in which the specific project questions were situated. It instantiated a shift in focus from people as users and concerns with HMI design (which remained valid questions) to developing a methodology to assess how operational processes were to be transformed, not only at the point of technology insertion (e.g. task execution) but also in their relationships within other system functions .

While other Human Factors partners in the project took on the responsibilities around task support, information presentation and general HMI design, TCD led tasks focused on the maintenance operation as a system and how new information capabilities, enabled by IVHM technology, change the way its processes function to deliver an improved outcome. A special concern was given to the role of people in mediating this process transformation.

In both articulating and addressing these aspects the resulting research contribution to the project was designed to create a means to escalate from the application of emerging technology capabilities in the maintenance execution to systematically address assumptions about the operational space that links them to top level project objectives.

Technology innovation has the potential to transform the socio-technical system such as the maintenance operation. New technology never simply delivers an operational outcome – that outcome is the result of the impact of the implementation of that technology on an operational system. As discussed before, designers rarely have privileged access to the detailed and valid knowledge of how operational systems really work on a day to day basis. This is not least because such knowledge is normally not formalised or written down; rather it is tacit knowledge acquired through the experience of those who, in a variety of roles, make the operational system work. Formal documentation of the process, for example in maintenance manuals, does not adequately represent the complexity of how operational systems actually function (see also resilience argument of approximate action for further support, Hollnagel, 2012a).

Generally speaking, impact is tied to the technologies' effectivity in delivering system transformation that create the expected outcomes. Therefore, it is intimately linked to having a sufficiently comprehensive understanding of the target, here the maintenance operation. Understanding the processes of aircraft maintenance, as they normally function, is critical to understanding how the project technologies can deliver the operability goal which is the top level requirement of the project.

The research in TATEM built on an extensive body of action research in aircraft maintenance that had been conducted over 15 years, focusing on the role of people in navigating and managing its complexity (e.g. ADAMS project, ADAMS-2 project, AMPOS) and used the knowledge accumulated there as a platform to build on. It provided a rich picture of the maintenance operation and gave systematic insights for what makes this such a complex system to deal with.

Deconstructing the complexity and re-building the knowledge obtained in doing so in an accessible approach provided that basis to address the TATEM questions and create a vision of how new technology can be instrumental in leveraging issues in the current maintenance system.

3.1.2 Positioning the design scope in thesis: research questions

As outlined the earlier chapters, the maintenance operation can be described as a complex set of tasks coordinated by people. The technical tasks are defined by the aircraft technologies and so are the rules that trigger them (these are defined as part of the certification process, based on assessments including technology system specifications and test bed performance). The resulting maintenance requirements for each aircraft see tasks being into work packs and their scheduling of tasks organised around the functional logic of how the process transforms inputs into outputs. Supported by the rest of the organisation the operational process system is at the core, delivering the ultimate outcome, an airworthy aircraft, back into the operation. While the functional logic as defined by the aircraft technology is central to the operational processes, it does not determine the operational situation entirely. Economically driven consideration exacerbate residual uncertainty and create a situation that relies on people functions such as coordination, competence and team work to energise the process as a flow of activities and ensure that outcomes are delivered. Thus, it is these that have to be factored in to the design for operability.

Aircraft maintenance is part of a safety critical industry and as such, the operation is highly regulated. The design process not only delivers the technology itself but also the parameters in which it is operated and maintained, formally prescribing tasks to ensure quality and safety. Manuals outline the procedures that

describe how tasks are meant to be performed in the process, and are supplemented by several "libraries" of task related information (e.g. Illustrated Parts catalogue) as well as regular updates (e.g. service bulletins or airworthiness directive). This wealth of information gives the false impression that people have access to a full account of how the job is done. (e.g. McDonald, Corrigan and Ward, 2002) have shown that the process activities that people perform every day cannot be reduced to the formal accounts of maintenance actions. Those additional activities within a process are not arbitrary but instantiate recurring patterns in response to the basis functional logic defined by operating the technology. While procedures give some basic functional requirements they fall short of providing an adequate account of how the work is done (or should actually be done).

It is these additional activities which allow the process progression. Without them the transformation of the technology, i.e. broken aircraft to 'release into service', would not occur. The ability of designing and deploying technology capability to address both, formally prescribed and operationally necessitated activities, is the basis for achieving the TATEM objectives related to operational KPIs such as increased availability.

Some of the operationally motivated practices are outlined in organisational documentation (such as Maintenance Organisation Exposition (MOE)), an example being the shift hand over procedure. Most of them, however, are informal practices enacted and shared by a group of professionals in their daily work practices. Therefore, knowledge about them is either not accessible due to reasons outlined before, such as knowledge being distributed across local settings, often tacit and hidden outside formal system.

With thousands of work cards (each representing one or more tasks) as a realistic, probable number for a single aircraft overhaul, it is not surprising that aircraft maintenance is a resource intensive operation. There are many systems and subsystems that require attention to ensure the safe and reliable operation of the aircraft. Also, grounding an aircraft is costly, so the use of maintenance-related downtime has to optimised which usually means doing as many tasks as necessary, as parallel as possible, with potential gaps in the schedule being filled with opportunistic work. While there are scheduled items that are planned for in terms of resources (e.g. staff, parts, equipment) and impact on the overall work pack (e.g. power off), there is always unscheduled work. As a result of opening up and inspecting the status of the aircraft in base (and to a lesser extent in line) maintenance or events occurring during the flight before the aircraft is received for line maintenance (in turn around or overnight). In combination with the business strategy for resourcing and support provision, this defines a baseline of uncertainty in the operation. The fact that the operation deals with more than one aircraft, namely a fleet or as an independent MRO several customer aircrafts puts an additional strain on the resources. In such a business scenario, it is not cost efficient for an organisation to always have all possibilities fully resourced. The consequence for the operation is that resources are always suboptimal requiring people to constantly react, adjust, and fire-fight (Baranzini, 2009).

Critical to the ability to 'fire-fight' (i.e. reactively allocating resources to enable dealing with unforeseen problems) is the interactions between process owners and other stakeholders which enables the technical process to progress, despite or, more correctly, especially in dire circumstances. In mostly informal

practices as discussed above, the same activities are enacted repeatedly in which information is exchanged, goals are agreed, priorities negotiated across the process system. These activities are an integral part of operational processes and cannot be reduced to a separate account of management functions. Every technician on the hangar flow performs these on a regular basis, even if they would often fail to describe them as part of their job.

In a situation where formal support systems systematically fail or fall short in meeting the operational expectations, people rely on their relationships to coordinate optimising the process within the given constraints, usually in an informal, mutually adjusting way. The degrees of freedom of these activities are limited by their respective social capital, i.e. potential for progress is limited by the relationships people have. There are intrinsic limits to this since the 'fire fighting' is local to the operational domain, with little access or leverage about the remote (in time and space) support processes such as planning or set up functions such as contracts.

In summary, put together the formal and informal recurring patterns of activities instantiate the underlying mechanisms that make the system work. While these define the logic of how the system works in the real world, knowledge about them is only partially accessible. It is distributed across the system, with different stakeholders having mainly local knowledge, possibly with some insights in other parts of the organisation, e.g. through staff transfers, working relationships etc. While people usually have a detailed understanding of what impacts in their work (especially in recurring patterns), the insight in how this cascades down or escalates up outside their processes varies greatly.

The unavailability of critical knowledge, packaged coherently, does not only pose a challenge to the operations themselves, but the problematic extends into the wider system and even system of system, i.e. lifecycle. The TATEM technologies and their information capability on the face of it offer an opportunity to reduce uncertainty and support managing the process in an integrated way. However, this potential is only fully realised when the starting point is an analysis as provided here that gives a fuller account of what enables the operation to produce its outcomes. Maximising the value of the operational system outcomes does not only rely on optimising the operation itself but enabling transformations that are delivered by external triggers such as new technology designs, regulatory requirements, or business models, all of which should have an interest on building on a comprehensive account of operational reality. Only then can they hope to insert profound and sustainable changes into the operation and effect outcomes in a way that realises value for all stakeholders.

In the design process, many human factors methods are centred in human performance. This reflects the pre-occupation with cognitive process that has driven HF research and methods for a long period, as discussed in Chapter 1. While addressing the role of people as technology users in a local sense remains valid, the transition to systemic HF as argued for by representative bodies of the discipline and the aspiration to deliver large scale impact (see Chapter 1) requires a new generation of approaches. Approach that are addressing the complexity of socio-technical systems have to be integrated into the design cycle to deliver the potential of large scale technology innovations such as IVHM.

This discussion highlights that aircraft maintenance as a socio-technical system is defined by a complex set of dimensions. Moving away from a fragmented view, the system has to be understood as it actually works in order to get leverage

- **Research Question 1**: What needs to be known about the role of people in a socio-technical system to advance the understanding of how it delivers its outcomes through processes? (Structure of knowledge)

Within the project the research presented in this chapter was conducted in, the context for gathering this type of knowledge was to feed a system engineering process delivering innovative technologies into the maintenance operation.

As argued before, technology innovation has the potential to transform the socio-technical system such as the maintenance operation. However, new technology never simply delivers an operational outcome – that outcome is the result of the impact of the implementation of that technology on an operational system. When considering the operational system, technology development often puts a strong emphasis in the interface with the end user. As a result, the notion of usability aspects tend to focus on presentation and interaction issues instead of systematically assessing how the new information will be used in the process and not only change its local, internal logic but also they way it depends on other processes it interfaces with. While outputs are delivered at one level, the overall operational system is contributing to their delivery as well as their quality, as discussed in Chapter 2.

The TATEM work programme lays out a project structure that was built around a traditional technology development trajectory which assumes a technical view of processes and therefore was not set up to fully appreciate the role that people play in managing the actual complexity of the operation. Thus, the way the role of people in operational issues was represented in the project centered on task and decision support and their associated HMI issues.

As discussed in regard to the first question in this chapter, a full account of the real operation is rather difficult to obtain, even for the people involved in it. Outsiders to the operation such as designers rarely have privileged access to the detailed and valid knowledge of how operational systems really work on a day to day basis. As outline before, this is not due to lack of interest or appreciation of relevance of operational inputs into design, but limited availability and access. This raises questions about the quality of the inputs into the design process and consequently about the adequacy of its outputs. The information that is a readily available input into the design process is formal documentation of the process, for example in maintenance manuals, which does not adequately represent all that goes on in the operational situation that is meant to receive the technology.

In a situation where the current operational system is only partially understood, the outcome of a process designing technology with the aim to change operational practices cannot fulfill its potential. Even with technology innovation addressing the accessible version of operational practices, it is destined to fall short of its expectations because of the influences of those factors that are unaccounted for but nevertheless are at work in any chosen operational scenario.

This challenge is not overcome by answering the first research question that seeks to make the relevant knowledge available in a systematic way, but is only resolved by complementing the new body of knowledge with a process that can utilize it effectively, i.e. how to utilize and implement it in a way that improves the operational validity of design choices, not only in retrospect, once prototypes are built but from the beginning of the technology conception. The v-cycle and OSA CBM were the design methodologies of choice in the project and defined the project system engineering processes that any new approach would have to be inserted into.

Generally speaking, requirements are the key input into the design process and preview the vision of a future solution. Requirements can be organized in different types and are derived from different sources, including own experience, SOA literature, documentation review and collaboration with operators. They are formulated in response to a problem statement or as-is situation that is to be transformed. As such they can be regarded as representing demands that reflect what an operation depends on to operate. At this point, it has been discussed at length that this is not solely determined by the technology that is operated, but equally defined by the social functions that are necessitated by the techno-economic set up to manage the uncertainty in the system. Without a systematic framework it is left to the designer (possibly in iterations with experts) to structure, prioritize and select the requirements that will be addressed by the technology.

Within the TATEM context, understanding the processes of aircraft maintenance, as people make them work on a daily basis, is critical to understanding how the project technologies can deliver the operability goal which is the top level requirement of the project.

Following from this, the second research question of the chapter is posed:

- **Research question 2**: How can the relevant knowledge be captured and effectively utilised in system design? (Knowledge process)

Following an overview that positions the case study developed in this chapter in the overall case study arc and its core methodologies, the remainder of the chapter is organised in two sections, with each one addressing one of the research questions posed.

3.2 Case study arc: TATEM case

The TATEM case study is the first part of the case study arc introduced in chapter 2. It is building on extensive empirical research in aircraft maintenance and further explores its issues as a socio-technical system. The core is the development of a framework that defines a knowledge structure which functions as repository, analysis heuristics and guides changes. It consolidated concepts about the socio-technical system that is aircraft maintenance and organises them in a way that integrates them in terms of their functionality.

The development of such framework then allows testing assumptions about the current system and trying its application in directing transformation into a technology enabled to be version, i.e. assessing the potential of technology induced changes in the process that benefits operational outcomes.

3.2.1 Ethnography

The main focus was an in depth exploration of the inherent systemic properties of aircraft maintenance which build on existing knowledge created by ethnographically based research in the field (e.g. Corrigan, 2002, Liston, 2005, Ward, 2005, Baranzini, 2009), and further explored how these dimensions and their interactions contribute to delivering system outcomes. Therefore, it was appropriate to make extensive use of ethnographic methods to ensure that the outcome of this first phase a delivered

- Ecologically valid description of aircraft maintenance
- Integration of both knowledge that is formally organised and that which is hidden in informal practices and/or build up by the experience of doing the job (tacit knowledge)
- Selecting knowledge that is relevant based on its role in system process activity

In developing the knowledge consolidated within the framework (both around conceptual dimensions as well as capturing content into it), several iterations of in depth investigation were deployed. Those deployed different data collections methods such as interviews, observations, document review in interactions with various sets of key system stakeholders to ensure in depth exploration along the identified dimensions and the validity of the content.

3.2.2 Action research

The action research paradigm informed the research in that the researcher propagated that the operational benefits were regarded as being of value to all stakeholders, including operators and OEM, and as such best achieved in a collaborative research process that aimed to deliver, if not a full implementation, at least a preview of operational changes. As part of the research and internal project dissemination activities in the project, the role of collaboration within a shared research process became clearer and its promotion and facilitation based on the emerging framework eventually led to the Knowledge transformation workshops (KTWS).

However, the progression towards this action research driven event can be described as an uphill struggle which itself gave valuable insights into the barriers to implementing a knowledge process that can make effective use of critical knowledge. In the TATEM project the issues that were faced included

- A recognition that information from operator is critical to demonstrating the operational benefits that technologies promised was not complemented by a clear concept of what has to be known about: It was driven by a data management strategy which suffered from the inherent limitation that available data is largely a representation of the formal system, rather than the full picture. A "getting data from operators is sufficient to address the issues" attitude that initially prevailed within project had consequences for the opportunities for action research based collaboration.
- While the R&D project context allowed for some degrees of freedom in the collaboration, the motivation for participating was still defined by the exploitation potential and thus by the internal agenda of the organisations. These internal agendas in combination with 'suspicion' that originated in the existing business relationships constrain the opportunities for action research based collaboration.

- The overall project design and technical perspective was more about designing than doing, especially with the view that TATEM was dealing with future, not yet available technologies and concepts.

in that sense, the KTWS can be seen as a snapshot action research agenda that, together with the steps that were required to make it happen, highlighted important aspects about instantiating a knowledge process (as part of a project remit). The insights gained informed the approach to the second case study.

3.2.2.1 Considerations of validity

This case study has been positioned within a case study arc which design has taken considerations of validity, bit in terms of process and content. In line with the overall case study arc, the research within this case study has been implemented as an iterative research process, with key concepts traceable to previous research, and has demonstrated new conclusions and knowledge in the area, deploying transparent data collection methods. Its features include verification mechanisms, incorporated iteratively in the research activities, such as different stakeholders' input into data collection; several data collection methods were selected, allowing for triangulation within the case study; iterations of content and conceptual validation with several stakeholders and generalisation of results by achieving productive transfer of concepts and content across different groups and application contexts.

The different types of validity as proposed by Maxwell (1992) were progressively achieved in building up a comprehensive understanding of the case study, progressing from populating the framework with descriptive data to deploying it to deliver a 'to be' model of the process.

The starting point was a set of dimensions identified as being relevant to understanding the system functioning. So the study was designed around those, developing an initial set of conceptual building blocks to approach the complexity of the maintenance operation and guided data collection. By progressing the analysis of the data and iterating the review within the stakeholder the final structure emerges out of progressive research.

The final validation of concepts and content was achieved in the workshops setting, which saw the largest group to date, including participants that had not been involved in the development of the framework or its contents and also demonstrated that the framework has the capability to deliver to its objectives: enabling a to-be version of the model building on the content representing knowledge of the as-is situation.

3.3 Section 1: Knowledge structure

Socio-technical systems such as maintenance can be defined as people operating technologies, with information mediating in between. In order to support the redesign of such systems, e.g. by inserting innovative technology capabilities, both technical and human/social dimensions of operational activity have to be considered and supported. Therefore, leveraging the situation depends on having adequate knowledge about them.

The research question addresses in this section of the chapter is **Research Question 1**: What needs to be known about the role of people in a socio-technical system to advance the understanding of how it delivers its outcomes through processes? (Structure of knowledge)

3.3.1 Background

Chapter 2 has described the complex dynamics of a socio-technical system such has aircraft maintenance and identified theoretical approaches and methodologies that are instructive in regard to the themes that emerged. These span various bodies of work in different disciplines to deliver new insights and explain aspects of the socio-technical functioning. Earlier chapters have given an overview and positioned the overall thesis trajectory. The following is not meant to repeat this, but to highlight those aspects that informed the research in this particular case study.

3.3.1.1 Communities of practice

CoP have been introduced in Chapter 2 as socially focused theory about how people mange and use their knowledge to act, as individuals or as a group. A key theoretical assumption put forward by the leading authors (e.g. Wenger, 1998, Brown and Duguid, 1998) states that these groups are not defined by the organisational structure and processes but emerge out of common practice and transcend boundaries.

Applying the principles that define CoP, one can argue that those apply to groups that are defined by organisational structure and processes, such as the different aircraft maintenance teams and management groups. The CoP framework is a useful approach to understand the role of local knowledge in complex systems. The way aircraft maintenance is structured defines interdependent crews that work together along the check process, to deliver the ultimate outcome, i.e. airworthy aircraft. Practices are shared to deliver a common goal, making the process work and safely and efficiently deliver an airworthy aircraft. How people perceive their role in the process and its phases mediates their action and constitutes practices, many of them being informal as discussed before.

The fact that people are members in different teams enables cross boundary knowledge transfer. Regarding these teams as CoP opens up the opportunity to actively design the membership to increase transfer of knowledge between teams, benefiting the overall check, or even between hangars.

The maintenance operation can be regarded as a set of different CoPs which are organised around zones, check, roles such as inspectors, base maintenance, line maintenance, check planning and others (as such they have large overlap with established organisational units which is in line with Wenger and Snyder, 2000). All of them share practices and knowledge about how the operation works, but while some of it is transferred within the operation itself through multiple memberships, a bottleneck arises when it comes to sharing with external stakeholders such as customer, support staff or designer.

3.3.1.2 Process modelling

The operational activities that can be organised in processes are at the core as they are the means to deliver the operational outcomes. Those are the ultimate targets when transforming the system, be it by means of technology innovation as in TATEM or as part of any organisational change initiative. Process

modelling has been discussed in chapter 2, reviewing two perspectives: transformative and coordinative. Goldkuhl and Lind (2008) summarise the difference between the two process views as follows: "..., a business process can (in this coordination view) be described as moving from customer requirements to customer satisfaction. [...]In the transformation view the process goes from raw material to finished products delivered to a customer. This is a way to compare the two business process views; the starting point and the end point." (p. 766)

Both perspectives have arguments in favour of them. The transformation of inputs into outputs is critical for delivering the outcome, either product or service, which both represent a different state of affairs compared to the start of the process. However, the coordinative view has its merits, too. Especially in a system like aircraft maintenance that has people-mediated process at its core, those cannot be neglected. The complex interdependencies in the maintenance system affect the effectiveness of transformative activities which is mediated by coordination.

Therefore, like Goldkuhl and Lind (2008), the author of this thesis would like to argue that those are not mutually exclusive views but rather require integration. The transformation capability of the process remains critical for changing an initial state into an outcome that has value attached to it. Arguing from the existing research in aircraft maintenance (e.g. Baranzini,2009), the resulting transformation based functional logic is delivered by coordination that manages the related uncertainty; which in turn extends the functional logic of a process.

While value is attached to outcomes, the value creating activities include both transformative and collaborative process activities. The challenge of appreciating their contributions and managing the realisation of value is that it requires an approach to implement their integration and to show how both are interlinked.

Coordination theory (e.g. Crowston, 1999, Malone and Crowston, 1994) advanced a platform for this by conceptualising coordination as managing interdependencies between tasks (which from a traditional process modelling perspective, are aligned with transformative actions) rather than people or roles or business units. This highlighted the functions that coordination has as part of the transformative view on the process. It is based on conceptualising dependencies in terms of resources, following the classical transformative approach (Malone and Crowston, 1994)

From a thesis point of view, the definition of coordination as managing dependencies between tasks opens up a new perspective on the process. The demand for not only resources in the traditional sense that is dictated by the transformative logic is extended by requiring also the appropriateness of the overall operational situation, including social processes and knowledge. Therefore, while transformation is at the core of the functional logic of the process, said logic can be better described in terms of resulting interdependencies. Abstracting from the technical detail of the task sequence, the underlying functional logic can be expressed in interdependencies along a series of major phases. This gives access to a level of analysis and explanation that can drive interventions that target functions rathe than the symptoms of their sub-optimal realisation and thus has the potential to realise leverage over a complex operational situation.

As discussed in Chapter 2, process modelling is a pragmatic approach that can be tailored to the needs and objectives of its application context. Therefore, the appropriateness of different levels of process understanding can vary: for example, while detailed process maps and task analysis support HMI design, the high level view on the process logic that is proposed as a key level here is meant to leverage system re-design and value considerations.

3.3.1.3 Critical human and social dimensions in the maintenance system

An extensive body of research in action research based project in the maintenance operation emphasised the fact that maintenance can be described as a people mediated process and as such identified the following concepts as being salient: Competence, social relations & trust, team work & coordination (e.g. Liston, 2005, Ward, 2007, Baranzini, 2009). It also highlighted the relevance of systemic properties within each and proposed new theoretical perspectives on the dimensions that are key to a socio-technical system's performance. Those look at "traditional"/ established concepts such as competence and team work but move away from an individual-centric perspective to identifying the system mechanisms that are central to understanding the human role in these systems. They conceptualise system mechanisms that affect the human performance when the person reproduces and transforms the system he/she is part of through his/her work activities.

In summary, previous research has adopted a systemic perspective in the role of people in making aircraft maintenance work. Corrigan (2002) described the maintenance operation as a socio-technical system and highlighted the critical role of the wider support systems, both within and outside the organisation. This socio-technical system can work without perfect conditions and still function well as demonstrated by Baranzini (2009) and discussed in the "Friedlander Argument". System functioning in suboptimal conditions is mitigated by coordination in different types of teams (Baranzini, 2009). In this context, competence is better understood in terms of operational setting and system performance parameters rather than individual characteristics (Liston, 2005). In addition to the role of teams in coordinating the maintenance production system, Ward (2007) showed that the quality of social relations is critical to understanding the performance of the overall system. It does not only affect performance at a local level but also defines key characteristics and qualities of the social space that facilitates or constrains the functional logic or maintenance production.

This research gives valuable insights into the social and human dimensions that contribute to making the maintenance system work: coordination in process teams, competence, and quality of relationships (trust). In order to leverage the complexity of the aircraft maintenance operation as outlined in chapter 2, the emerging human and social dimensions need to be integrated into a dedicated framework that shows their role on the process system. In order to keep its deployment manageable, such an approach has to use concepts at an appropriately high level, with enough substance and merit to identify the vulnerabilities (or opportunities) in the system. Having identified a critical constellation, the derivation of solutions and planning of interventions can utilise the relevant sets of theories and methodologies in more detail to allow more in-depth insights.

3.3.2 Methodology

Addressing the complexity of socio-technical system as outlined in Chapter 2, the research has to confront multi-faceted challenges that originate from dealing with varied dimensions (technical, social, knowledge) and their relationships that define the functional baseline for the system and the fact that knowledge about these is distributed in the system while, largely, also being hidden in informal practices and tacit elements.

This defines requirements for the design and methodology. The overall approach was based on qualitative methodologies which are appropriate because they allow for

- Naturalistic view, ecologically valid
- Exploring complex issues
- Detailed, in depth analysis of what happens
- Utilising people's knowledge of their situation
- Designs that enable combining methodologies

The operational reality as it is experienced by people when they perform their respective activities in the process was a core subject for the first phase of the research trajectory. Ethnographic research methods give access to in depth insights into actual practices while a dedicated process modelling approach provides a structure to organise and consolidate the captured knowledge around activities.

3.3.2.1 Ethnographic methods

The thesis puts forward the idea that a dedicated view on the social structure that enables processes adds to understanding the functional logic of activity in socio-technical systems. Therefore, ethnographic methods are selected. Ethnographic approaches give access to groups of people, their interactions and how those shape how they understand their world. Ethnographic methods build up a rich picture of people's experiences and give access to their system of meanings. In the thesis the human and social aspects are driving the extension of a functional logic of processes that is often solely technologically defined.

The main methodology or ethnography, participant observation, was not possible to implement since aircraft maintenance is a safety critical operation that is highly legislated. However, the researcher spent time in the organisation that extended scheduled activities such as interviews or workshops. Besides scheduled observations, there were many opportunities for opportunistic interactions, e.g. lunch breaks, running into ad hoc meetings in the corridor, which gave additional insights people's work life.

The core methodologies that are discussed in more detail later included observations, interviews, documentation review, workshops and focus groups.

The outcomes of the ethnographic research were used to further concepts and consolidate the framework and to populate it with content in its several iterations.

3.3.2.2 KSM modelling methodologies

Process mapping methodologies are pragmatic but by standardising elements and relations in a common language gives access to some of the assumptions underneath. They provide an anchoring point of the activity in a functional sequence. A process is transformation of resources in to outcomes. The formal functional logic can be described in the standard process modelling assumptions. Here, this functional logic is extended to include dimensions such as social or human, knowledge about which is hidden in the current system and thus accessing it requires an approach such as ethnography.

As an integral part of the KSM framework, the model is organized around the operational process system, which incorporates rich layers of knowledge about the regular patterns of actions and interactions with which people respond their work situation. The modeling starts with a representation of the system as it is; but, through the application of the methodology and the knowledge transformation process, it is developed to represent the future process, incorporating the new technology or organisational changes, depending on the application context.

3.3.2.2.1 Process at the core

As discussed earlier, the process system is at the core of the framework. The system outputs are the critical deliverable in an organisation and thus an indicator of how well the system works. In distinction to the BPM approach, the process baseline developed here is not only implementing the functional logic of the technical activities but takes into account what else enables processes to be realised.

In order to organise this, process maps are the anchor for additional perspectives on the system activities, such as stakeholder diagrams which show key relationships that underlie the coordination activities and are created based on patterns of interactions around the process and an information perspective which highlights the flow of information that is a key building block in creating shared knowledge.

The main principles for the process system models include

- Extension beyond activity view into three perspectives: Information and stakeholder perspective are anchored in functional activity view, i.e. core support function view
- Systemic perspective
    - Process activities and their associated people and information perspective are described at different system levels
    - Stakeholders extend the notion of process actors and reflect the shared responsibility for overall system performance
    - Localisation of blockers/facilitators in a process extends into a critical path following interdependencies with the wider system
- The models are based on normal practice, including people interactions and information exchange, that encapsulate the knowledge of how a system works (compared to what is prescribed)
- The description of activities is generic and organised in a series of main phases that are defined by critical points in the process

- Coordination is integrated into the activity description in a way that shows its role in facilitating the required transformations
- Extending the notion of value by proposing that human and social functions are delivered in a way that creates value (e.g. social capital)

The thesis set out to describe how activities, both technical and social, in an organisation are organised and managed in processes that deliver the system output. This provides a structure for the knowledge required to operate as well as improve the system (incrementally or drastically). It proposed an integration of transformative actions within the coordination context in which they take place. Through the coordination, i.e. social interactions, the social space of the socio-technical system becomes not only accessible but it can be organised in social activities and analysis dimensions that link back into the functional process in a transparent way.

The integration of three perspectives is critical for systematically understanding the underlying dynamics of a socio-technical system: (1) the functional logic of process as defined by the technology, (2) the social space that enables its realisation in process activities and (3) the information flow that partially represent the knowledge that manages their interactions.

Process activities are described in an ecological valid way, modelling normal practices and how those are implemented to deliver a defined outcome. In a complex system, there is a variety of processes activities that can be described at different levels, each delivering a specified output. These provide anchors for dedicated perspectives on people's relationships and the information flow which are more generic properties of the system. Their structure is a response to the processes they support, defined by formal system features (such as reflected in organisational structure) and patterns of informal activities (defining a complementary set of relationships or customising existing social structure). They do not vary as much as process descriptions do, i.e. identical or similar versions of these deliver to a set of different processes. An example: Different maintenance task process models can have an identical stakeholder map associated with it.

3.3.2.2.2 Characteristics of the proposed models

Consolidating the knowledge about the socio-technical issues in the aircraft maintenance system (described in Chapter 2 and further explored in this case study by means of ethnographic research) with existing approaches to process modelling, a novel modelling approach was developed.

The representation of the parameters was delivered as set of diagrams and table layouts that provide a format that is suitable for presenting the accumulated knowledge and facilitate interactive processes that engage in its transformation.

Diagram 1 gives an illustration of the key formats used. These key methodologies were developed as part of the knowledge structure in the TATEM research, and populated for the use in the knowledge transformation activities discussed in the second section of this chapter. The methodology is a result in itself which attracted intense research activities with organisational staff, including several validation iterations to be consolidated for creating further research results in its application.

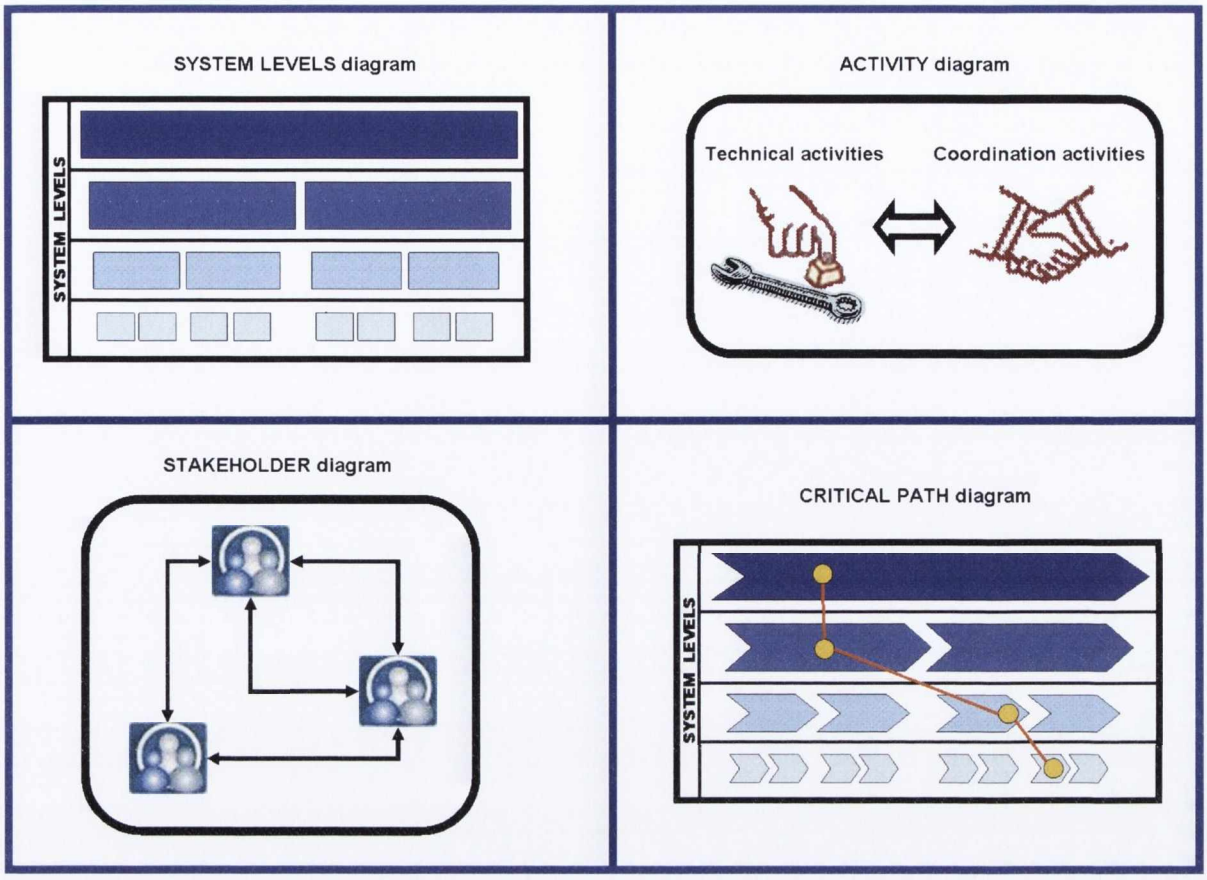


Diagram 1: Overview of model representations

In addition to the representations illustrated in diagram 1, a perspective on information flow was developed and discussed but only partially implemented in TATEM.

3.3.2.2.2.1 Process System levels

Systems and processes can be described at different levels. The description and analysis of the complexity of a socio-technical system and its processes is informed by this approach. Each level poses constraints for the next one which define degrees of freedom for possible system activities.

There are different levels at which processes can be modelled. Parallel to the model of system and its subsystems, the process model describes activities at different levels of granularity, aggregating across levels. For the maintenance operation the following levels were proposed, refined and validated:

- Maintenance tasks
- Unit of tasks
- Check
- Maintenance operation

3.3.2.2.2.2 Process map

3.3.2.2.2.2.1 Generic process logic

Based on existing knowledge of the maintenance operation, the assumption that the thesis was starting from is that processes delivering an operational goal follow a generic functional sequence. The

actualisation may vary across companies, e.g. the sequence of sub-steps or the support of function by technology, but overall the same logic applies to equivalent processes.

There are key activities at each level in the operation, independent of the object worked on, leading through a succession of states. These activities can be described generically, which enables the model to adopt a broad scope.

Example: a removal/installation follows a similar logic when removing a brake unit or an engine.

Example: There is a pattern of activity to a sequence of inspection, damage assessment and subsequent repair, independent of the component or area.

Therefore, in contrast to specific processes or tasks analysis based approaches the process maps were described at a generic level, identifying activities that are defined by their logic within the process rather than specific task content. This provided a baseline that allowed more general conclusions on system mechanisms that are expressed in the functional logic as well as informed the assessment how to best target interventions or envisage a future version of the processes.

3.3.2.2.2.2.2 Distinction between 'technical' and co-ordination activity

Technical activity is required to manipulate the technology object and thus is technically defined by the object operated on, mediated by technical procedures (information tasks). While a large extent of the technical activities are described in manuals using procedures or formal processes, some flexibility is left for possible modifications in systematic informal practices, e.g. customised tools, or additional steps.

Co-ordination activity is partly accounted for in manuals, but most of those occur in the process as a means to enable the progression from one process state to the next. Co-ordination is defined as managing interdependencies between activities (e.g. Malone and Crowston, 1994) and is a key nexus that links information, social and material resources as inputs into the technically defined logic of the process. Both sets of activities are dependent on inputs and produce outputs through which they are linked within and across processes. Although the coordination activity only occurs because the technical task exists and is being worked on, in turn its technical realisation would not be possible without the social interaction that facilitates it.

3.3.2.2.2.2.3 Stakeholders as Actors

In the mapping, actors are limited to people. They are represented as separate elements that are annotated with additional information and used again in the stakeholder map (if appropriate).

3.3.2.2.2.2.4 States, gates and dependencies

States deliver to gates in the process progression at which point the status of the process is consolidated to provide a stable platform for its progress. In order to achieve a state, actions using resources have to be enabled. The requirements or demands that the process logic puts towards resources and enablers/process controls can be expressed as a set of dependencies, i.e. each dependency is the expression of a causal mechanism that enables the process to function. These dependencies can be located within a process, span across process levels, or arise outside the operational processes.

3.3.2.2.2.3 Stakeholder Map

Processes in socio-technical system such as aircraft maintenance are people mediated. Therefore, it is not sufficient to only review individuals' activities but also the pattern of their relationships needs to be modelled for further analysis. The notion of stakeholder includes every role that has a direct or indirect contribution to the processes and as such is defining the constraints in which the people operate. The stakeholder perspective summarises the main exchange between roles and the objectives of the function that they represent.

3.3.2.2.2.3.1 Stakeholders

All stakeholders are indentified through comprehensive analysis (technical as well as coordination relations). The difference to an actor in the traditional swimming lane concept in BPM is that the input can be indirect or mediated. Also it can be group of people (e.g. organisational unit) rather than an individual actor. These people or groups have a stake in the outcome of the process but are not necessarily involved in any of the activity.

3.3.2.2.2.3.2 Key functions

Each of them has a role and therefore a function associated with them. The main function in regard to the process system under review, here maintenance operation, is identified in this diagram.

3.3.2.2.2.3.3 Key relations

The predominant nature of the relationship is annotated. Dimensions include frequency of exchange, type of exchange, managerial authority, distance/proximity etc – see also annotations for actor.

3.3.2.2.3 System dependencies: critical path

Critical path is an expression that is used in check management. It organises a work pack into a series of milestones and highlights key dependencies that are technically based such as a requirement for power off in a particular task that will affect all tasks that need a powered aircraft.

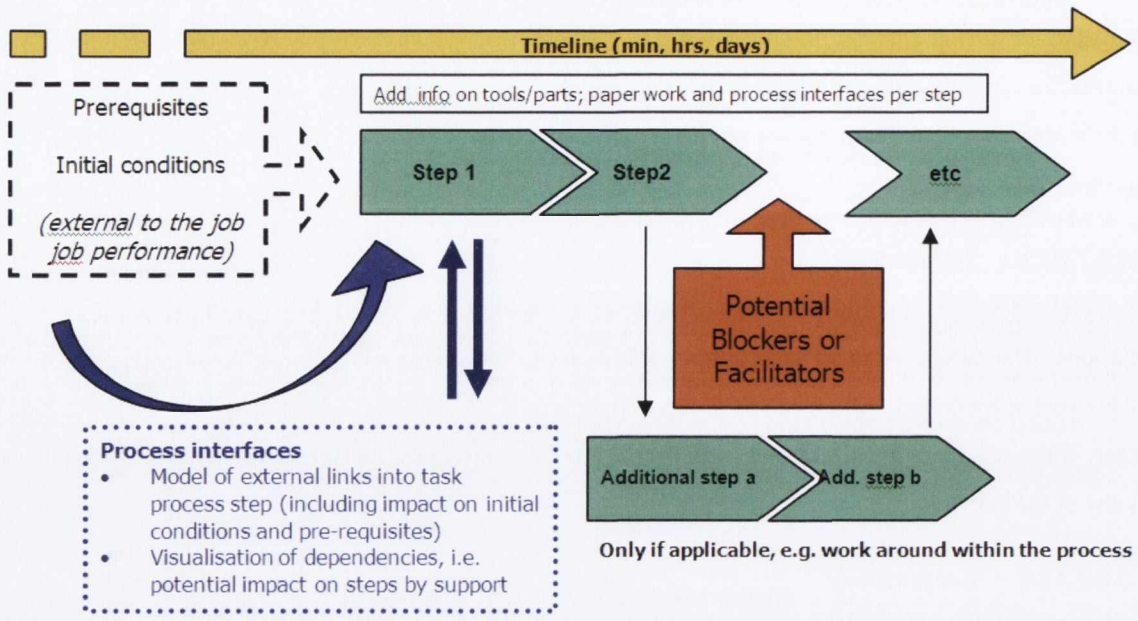
In the context of TATEM it was adopted to extend the concept of interdependencies into a fuller socio-technical view of the process as part of a system. This facilitated the communication of the extended concept and acknowledged its origin in the actual operational situation.

Dependencies were organised around the core dimensions of the knowledge structure: resources (people, material, and information), and how their use in the process is enabled by coordination, which draws on team, competence, and social relationships as well as the internal logic of the workflow.

3.3.2.2.4 The pilot study map structure

In the pilot study the features outlined above were discussed using the diagram shown below. Initial conceptual assumptions derived from the existing knowledge base and relevant literature were checked against operational knowledge and as a result emerged more clearly. This then informed the second iteration of process map structure. It also led to utilising a BPM based process modelling tool called MEGA (www.mega.com) when opportunity presented itself in the project. However, the BPM standardisation

was revised and elements used differently to accommodate the conceptual approach to process modelling taken here.



The development of the methodology and its iterative refinement is a result in itself. For example, the concepts of blocker and facilitators as well as pre-requisites were central to further exploring the process within its system context and allowed advancing concepts such as system levels and interdependencies in a grounded way.

3.3.2.2.4.1 Universal narrative structure

A key data collection method deployed in the context was the universal narrative structure which collected information about blockers and facilitators. The narrative structure is well suited to explore process issues as it creates a snapshot of the operational situation.

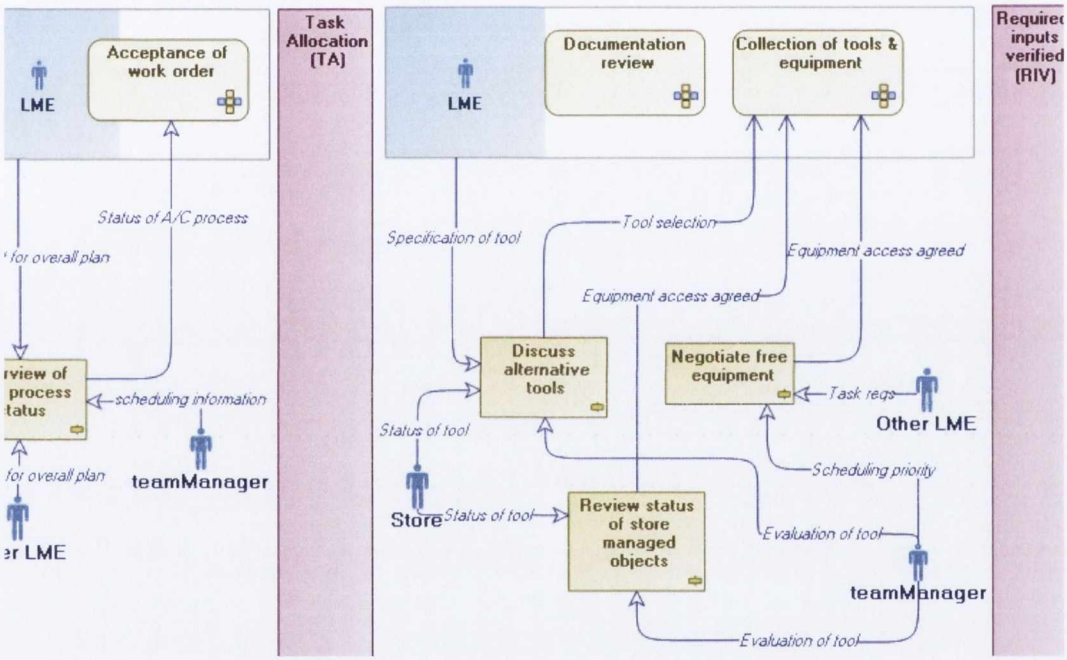
Category	Topics explored
Abstract – Executive summary	What is the story about?
Orientation – 'Setting the scene'	What process or process stage? Who are the agents involved? What are their social characteristics? Goals, interests, strategy, attitudes etc What are the paper work, tools, parts, equipment being used? Time and location.
Complication – Situated actions and events	How is the process stage instantiated in this particular situation? What happens (normally)?
Evaluation – Comments & Judgment	Why does it happen like this? What motivates the actors? What is the significance of the events?
Resolution – Outcome	What are the results of the actions overall/at each stage? What are the consequences for each agent and the organisation? Are there future or later dependencies of the actions and results along

	the overall process?
Moral - Conclusions/lesson learnt	Which social processes have a bearing on what happened? What are the lessons learned for the future?
Coda – Current Status	What is the source of information for this narrative? What is the current status of this account?

3.3.2.2.5 Consolidated process map structure

The consolidation of the pilot study results and advancing the understanding of the dimensions that were defined as being critical in Chapter 2, the initial model of the process was advanced to incorporate the elements outlined before and extended to have additional maps attached to it (stakeholders, information, and system interdependencies) and organised at different levels.

The following is an Illustration of process map to be contrasted with the one in pilot study. The full implementation is presented in the results section of this chapter.



3.3.2.3 Model-based knowledge transformation

The models define a knowledge base that is the reference system for further analysis and derivation of interventions and visions of a 'to be' situation. Core principles in creating new knowledge around the models are derived from Nonaka (e.g. 2002) and include: requisite variety and redundancy and creating a social setting (BA) that supports the conversion of knowledge (see also Chapter 2). In contrast to Nonaka, the thesis defines a structure for the knowledge and thus delivers the capability of model based knowledge transformation, from populating the models to further investigation and assessment and delivering directions for system transformation.

In summary, having a framework enables a process for facilitating the transformation of knowledge about that operational system, held by the stakeholders (across the lifecycle) in the new system, into a common

understanding of the operational implications of the new technology. Populating the models collaboratively is a KT instantiation as are the activities reported in the second section of this chapter: dedicated events labeled knowledge transformation workshops (KTWS). As part of this process, validation of existing maps and analyses are performed. While the validation of the contents occur iteratively during the population of the maps, the KT set up that emphasizes Nonaka's principles of redundancy and requisite variety to define the group is appropriate for the final validation, utilizing the fact of having access to different stakeholders knowledge at the same time.

3.3.2.4 Data collection methods

The following gives an overview of how ethnographic and process mapping approaches were implemented in specific data collection methods. Most of the research and data collection was performed in collaboration with an independent MRO which was part of the TATEM consortium. In addition, interviews and observations were performed with two airlines, one of them in the TATEM project, the other a partner in the HILAS project. While in the MRO both base and line maintenance were researched, the interactions with the airline research were strongly focused on line maintenance.

Documentation Review

Relevant documentation was reviewed to prepare the population of the process maps and stakeholder map, including task descriptions in the aircraft maintenance manuals, procedures in the maintenance organisation exposition documents and related previous and current project results and resources (e.g. ADAMS2, scenarios and process maps in TATEM project).Where relevant and appropriate, different types of reports were reviewed (e.g. quality report, query note) as well as supplementary information (e.g. Service Bulletin, Airworthiness Directive).

Focus Group (FG)

The Focus Group sessions followed a semi-structured approach, starting with a short presentation of each session's agenda followed by a review of previous results. The group consisted of operational staff from different hangars and bays. The group discussed the nature of their work, validated iterations of the proposed process mapping methodology and chose the tasks to be mapped and provided the contents while the moderator/researcher specified the goals, presented on process map iterations and facilitated the discussions. In total nine sessions were conducted, including an introduction and a final review session, each session running for 90 minutes.

MRO participants: Aircraft maintenance engineers (AME), crew managers and check managers from different hangars and bays, base maintenance manager (Total=12; NOTE: participation varied due to operational commitments)

Workshop

After the FG was completed, the results were consolidated and presented to a group of operational staff, four of which had been involved in the Focus Group. A particular focus was on consolidating the conceptual decisions taken within the framework and to extend initial insights into systemic influences on maintenance execution.

MRO participants: Check manager, AME, Crew Manager, Instructors, LME, Live planner (Total n=10)

Observations

Observations were conducted for one process to supplement the information obtained in the FG sessions and to validate its result. Observations took place on three different occasions and involved the researcher observing the tasks and taking notes. Clarification and follow up questions based on the notes were asked at appropriate points in the process (e.g. break, only one person required for a certain steps in the task) and at the end a de-brief conducted reviewing: how the process worked overall, what was different, what was as per usual. The reason to choose one particular process for more in-depth observations was driven by the project requirement as expressed in the emerging use case 1.

MRO participants: Removal Installation task: Aircraft maintenance engineers (AME), Crew Manager (Total n=5); Aircraft Turn Around: LME (n=2)

Additionally informal observations and tours took place to continuously follow up and ground outcomes of interviews, documentation review and focus groups. The focus of these was the overall maintenance operation, its infrastructure, processes and practices.

MRO participants: a range of relevant roles from line and base maintenance, planning departments, and stores

Airline participants: Line Maintenance Manger, line maintenance production staff for clarification questions

Interviews

Semi-structured interviews were conducted. The protocol for process based interviews was based on process map structure and included sketching of processes.

MRO Participants: Check manager, Support Planner, AME, Base maintenance Manager, Crew Manager, LME, Supervisor; Duty/shift Manager, Production Planner, Business Analyst

Airline participants: Director of Line Maintenance; Production Manager ('scheduled item planning'), Line Maintenance Manager (A32x/MD/B757) ('technical division')

Participatory process mapping and validation

In addition to KTWS and Focus Groups, dedicated sessions were run to advance the process mapping and to validate process mapping approach from operational actor perspective. These sessions involved reviewing the progress on process maps and concepts with individual participants or small teams. These activities were usually linked to other activities such as observations or interviews. These sessions included the collection of narratives of events in which the process was blocked or facilitated.

A key role in these was played by company project representative in that he iteratively reviewed concepts and supported their communication in grounded language.

MRO Participants: LME, AME, Crew Manager, Check manager, Live Planner

Knowledge Transformation workshops (KTWS)

The models which structure was developed and populated with knowledge were used in KTWS to envisage a future version of the process, talking into account the emerging technology capability in TATEM. The process of which the workshop defined a critical milestone is described in the second section of this chapter. For the purpose of this section, it provided a methodology to advance the validation of the concepts developed here in that it demonstrated their capability to deliver relevant outcomes.

Participants: see Table 12 in Section 2 of this chapter.

3.3.2.4.1 Protocol for populating models

The ***process protocol*** gives an overview of the guiding questions that were used in semi-structured interviews, observation de-brief, and participatory sessions. It is aligned with the narrative approach as part of the data collection.

- What triggers this process?
- What are the main activities in this task or process?
- Are the additional steps that are regularly taken, even if not covered in the manual?
- Who are the actors and stakeholders in those activities?
- What is the process outcome?
- What are the interfaces? With other tasks or other processes?
- What are the milestones the process?
- What has to be in place to achieve those?
- What is done to ensure that everything is in place?
- What influences the process performance: blockers/facilitators?
- Use of universal narrative to describe blockers/facilitators

The ***stakeholder protocol*** gives an overview of the guiding question that were used in semi-structured interviews, observation de-brief, and participatory sessions.

- From the process, identify actors and stakeholders associated via interfaces and validate those
- What is the people's role?
- What is the core function that the stakeholder represents?
- What is the type of relationship?
- What is the direction of the exchange?
- What is delivered in the relationship?
- How effective are the interactions?

3.3.3 Research activities

In order to address the research questions the thesis developed a mix of appropriate methods and the research activities deployed these and validated the concepts and content. The research was implemented in a phased approach, iteratively developing and validating content and methodologies. Here the main activities were organised around the modelling with in the proposed framework.

The initial step in the research was the review of related research, both from a series of Human Factors programmes as well as contributions from organisational psychology and related disciplines. From this, the main dimensions for a human centred perspective of the socio-technical system were extracted and integrated in an explorative framework which at its core has a structure for relevant knowledge about the real system.

The framework was refined and its models populated through a series of research activities.

3.3.3.1 Initial modelling

At the beginning of the project, activities consolidated findings of previous research and further explored the key features of the maintenance system, including the role of technology and people in regard to their role in delivering an integrated set of functions that the operation of a real system as described in Chapter 2 defines. A process modelling approach was developed that included key concepts and complemented the knowledge existing a priori with new operational insights, elicited into an initial framework structure.

The initial focus was on maintenance tasks, and was located in base maintenance, driven by the end user partner agenda. At the core of the pilot study was the series of Focus Group meetings, complemented with additional methods such as interviews and observations. During the course of the research, the detailed investigations of tasks supported the inputs into the task based TATEM strands such as mobile maintenance support but also highlighted the limitations of a local perspective. Therefore, using the basic task logic that is largely defined by the aircraft technology as an anchoring point, the implications of operating those in processes within a system was explored.

3.3.3.2 Developing use cases

Over the course of the project, the ground crew work pack identified processes as an appropriate vehicle to explore the benefits of the technology. Different strands defined use cases: Use case #1 developed a storyboard around a maintenance tasks within its local context. The decision was made to position it in line maintenance. Another use case described the planning functions (use case #2).

Building on the pilot study, the modelling approach was advanced and used to develop process models within the use case #1 scope. These activities kicked off with a workshop that validated the content that was collected in the pilot study and further developed afterwards. The base line that emerged from this was then transferred in to the line maintenance context reviewing the differences in implementation in dedicated research, such as interviews and observations. Thu tome was a set of line maintenance models in addition to the base maintenance instantiations developed in the pilot study.

3.3.3.3 Dissemination meetings (in organisation and project)

The main research effort for developing the novel approach as presented in the thesis was located in a dedicated research task in the work programme work TATEM. It then provided inputs into the strands dedicated to developing ground crew support technologies, targeted to their needs at certain milestones, including a perspective on research scope; task selection; system context and others.

In turn the work in other project strands gave access to knowledge from the design cycle, both process and content. General technical meetings, including dedicated work shop elements for discussing the

relevance of the approach developed here, as well as documentation were used to share knowledge and create a common understanding of how to integrate the efforts. A core task was the communication of the approach, targeted not only to inform how the activities in the strands shaped up, but offering a reference point for facilitating the overall integration of these.

Ongoing was also the promotion of an action research agenda that was aimed to transform the relationship with the end user from data exchange to actual collaboration and knowledge sharing. Making progress on the above allowed designing and running two events dedicated to this. This was a major achievement, as it was afforded extensive resources from both MRO and project partners and thus was an implicit acknowledgement of the relevance of the propositions promoted iteratively from day one of the project. These Knowledge Transformation Workshops (KTWS) and how they came into existence are reported in section 2 of this chapter.

3.3.3.4 Knowledge transformation activities

The group interactions with the MRO were designed around KT principles, using the models to ground the discussions. In addition there were two dedicated events that are reported in section 2 of this chapter, which brought together the stakeholders to collaboratively utilise the knowledge structure develop here to envisage a to be operation.

3.3.4 Results

Table 1 gives an overview of the methods that are associated with each results section.

Table 1: Overview of presented results and the data collection methods

Results	Data collection method
Maintenance task classification based on task functions	Documentation review, FG, interviews, workshop
Type of maintenance tasks processes	FG, interviews
Maintenance system	Interviews, FG
Generic coordination activities in maintenance execution (task to check)	Interviews, process mapping, FG, workshops
Base maintenance check context around R/I task	Interviews, FG
R/I map	Documentation review, observation, FG, process mapping, Workshop
TBS map	Documentation review, FG, process mapping, workshop
Functional unit	Interviews, observation (In LM), workshop
Stakeholder diagram	Process mapping, interviews
Information model	Interview, observation/demonstration
Independent validation of framework concepts	Workshop, KTWS

These results and their subsequent integration delivered a rich picture of operational practices in the aircraft maintenance system, some of which were directly relevant to the TATEM research task while other provided the platform for consolidating the KSM framework.

While the research was informed by the TATEM remit, and more specifically by the selected use cases, a systemic perspective was adopted, in line with the research trajectory of the thesis.

3.3.4.1 General results

When collecting the data to populate the maps, the overall dynamic of the maintenance operations was reviewed. As part of the naturalistic, in depth research approach more information than used in the maps was collected. Examples include

- information on other levels besides the two in the scope of the project
- information on where knowledge resides in the organisation
- information on variations in understanding of challenges

These results informed the consolidation of some of the framework dimensions.

3.3.4.1.1 Functional view on tasks

The starting point to develop the maintenance task logic was review of the relevant documentation such as maintenance planning information provided by the OEM which gives an overview about different task types. In interviews more information about how they were performed in the operation was collected. From this two results arose. Firstly, the different task types have an inherent logic that can be expressed as a series of generic steps that are valid to different instantiation of the task. For example, a removal/installation logic can be drawn up that applied to removal/installation of a brake unit as well as an engine. This is implemented in the process maps that were developed as part of the use case #1. Secondly, the existing classification doe not represent their functional role in the process well. These results were further explored in the focus groups and consolidated in process maps and a functionally based task classification. As result the following overview was developed to represent the role of the tasks in the process context (see Table 2).

Table 2: Task classification based on task function in process

A/C set up	Access	Identification	Investigation	Rectification
(De)Fuelling Ground power set up Configuration tasks Scaffolding Cleaning	Jacking Opening/closing of systems or zones Removal/Installation	Inspection Check Function test	TBS Damage assessment Function test	Removal/Installation Approved repairs Servicing Cleaning/painting Modification Adjustment

The same tasks, following the same generic series of steps can play different roles in the process, e.g. the removal/installation which can be performed to gain access to a system or to exchange a part with the view to rectify a malfunction. This put tasks into their functional context and identified characteristics that are not captured within the description in the aircraft maintenance manual which described them largely in isolation.

3.3.4.1.2 Type of maintenance task processes

As shown before, the same tasks types can deliver different function in the implementation of the work pack as a process. It is this role in the work pack that defines their relationship with other tasks. Within a work programme that consists of several tasks, the following classification system for tasks within a check was proposed by the operational project partner to further explore the complexity that has to be managed as part of a work pack.

1. A simple independent task
2. A sequential task that interferes with other tasks
3. A parallel task that depends on external input

The assumption that all tasks within a given set of maintenance tasks e.g. check contract, can be organised into these categories was initially based on the experience of the project partner and initial interviews covering a variety of tasks, and then validated in the Focus Group.

For each type an example was identified and further explored as part of the Focus Group, supplemented with observations and individual interviews: (1) Brake unit change, (2) Structural repair after lightning strike and (3) Fuel tank float switch exchange. Elaborating examples for these three types showed that the configuration of tasks into a work programme creates interdependencies with other tasks or support functions that can have a direct effect on the local performance in maintenance task execution.

In combination with the functional task logic, this provided the starting point for the dependencies concept advanced in this thesis. In response to the TATEM project remit an initial focus was put on the maintenance task. When exploring the origin of issues that people who executed those were facing, it became clear that those could not be explained by the internal tasks dynamics within the check but had to take into account their interfaces with the wider system.

In a next step, the notion of functional relationships between tasks within a work pack was extended to processes at different levels of the maintenance system to account for the different way support was provided in the maintenance operation.

3.3.4.1.3 Maintenance system levels

In contextualising the TATEM use cases, the overall systemic context for those was established. Based in interviews and Focus Group activities, a general overview was established of how work packs or checks are built up from individual tasks and then reside within the overall base maintenance operation. An additional outcome was that the processes at each level could be summarised using the same set of phases. It is built up from maintenance tasks which functional logic defines units of tasks that in turn constitute the elements of a check.

The following table outlines the building blocks of the base maintenance operations, managing and executing scheduled tasks in a work package.

Table 3: Aircraft maintenance system process levels

	Initiation	*Set up*	*Execution*	*Close up*
Base maintenance operation	Contractual agreement with airline	Review of hangar production plans	Monitor production progress	Review capabilities
Work pack management	Production plan	Work pack organisation	Monitoring progress and updating plans	Review of targets
Unit of tasks	Scheduling of activities/tasks	Reviewing resource status	Allocation and supervision	Evaluate outcomes
Maintenance task	Work order allocation	Effectivity of task inputs	e.g. Rectification	Sign off activities

3.3.4.1.4 Generic coordination activities in maintenance execution (task to check)

Looking at tasks and their interdependencies locally as well as in a wider system context highlighted the role of coordination. While it had been discussed as a function, it was not explicitly conceptualised as part of the process activities. Interviews about tasks and their process context and their observation showed that there were regular patterns of activities which were not described in the formal documentation such as manual information. These were systematised and introduced as part of the generic process mapping. Table 4 gives an overview of generic coordination activities.

Table 4: Generic coordination activities in aircraft maintenance processes

Coordination activity	Description	Examples
Manage supply	Supply management is a function of external support processes, however, operational staff interact with their managers and internal suppliers to ensure the adequateness of task relevant support	• Robberies • Heads up for NDT
Activate resources as inputs	Introduce resources as inputs at certain points in the process	• Agree the timing of part delivery • Discuss shift composition
Negotiate priority	This describes the active management of sequencing activities or inputs; in regard to task sequence, resource allocation etc	• Discuss task based interference • Negotiate access to free equipment
Reduce ambiguity – common understanding (knowledge based)	Establishing a common understanding of the process etc is based on experience etc in the face of uncertainty.	• Discuss work share with 2nd staff • Communicate criticality of support such as part availability in check context
Retrieve special information	Specific information required in the course of action is retrieved from the sources, e.g. QN.	• Feedback loop with engineering about QN

Orientation/ Status consolidation (information based)	Obtaining a full picture involves reviewing the situation with all people involved, exchanging information. In the light of uncertainty, this is complemented by knowledge	• Establish status of support, e.g. access • Review MEL with flight crew

The outcome of the research is a set of coordination activities that are part of the operational process. The interviews and Focus Group discussions highlight that, in their absence, the process would not be able to progress and achieve its transformative milestones that ultimately deliver the outcome.

3.3.4.1.5 Process bottlenecks and outcomes

Interviews and Focus Group discussions showed that the set up of a check and its close up phase are seen as the biggest bottlenecks. They have the most intense coordination requirements, especially with external processes. The issues that were referenced most were resource/input management. On a side note: This finding was replicated by using quantitative data from a dedicated operational report with a different group of maintenance staff (see chapter 4 for more). Other key issues were managing interference by or with other tasks, sharing resources such as equipment or staff across maintenance production processes and the role of external decisions which staff felt were not based on the operational reality.

If coordination failed to manage the dependencies the following effects were reported in interviews and Focus group discussions and validated in the workshop

- Different work style or alternative and or additional work steps
- Task interruptions which may lead to unplanned hand over
- Changes in scheduling that can have knock on effects across the check
- Underutilisation of operational knowledge resources

These translated into operationally negative outcomes such as delays, increased time pressure, re-work or inadequate work. In addition to their effects on the process, staff also reported that these experiences of ineffective processes led to negative effects on motivation, morale and trust.

3.3.4.2 Ecologically valid process description

The maps were populated using the outlined methodologies. Within the overall research that explored the maintenance production system and its interfaces, a focus was put on the target processes selected within the TATEM project.

- Use case #1 was a maintenance execution illustration, looking at the removal installation of a brake unit (in the line maintenance context)
- Use case #2 focused on proactive maintenance planning which was concerned with decision support within an emerging new information based process

In response to use case #1 the modelling focused on the processes activity and stakeholder diagram. It extended the use case perspective by modelling the process context it resided in and put the task process into the context of the functional flow of tasks which centred around the removal installation activities

themselves. Additional process maps were developed to represent the overnight activities as well as base maintenance context for the task, but not in as much detail due to resource limitations (e.g. participants, project, and researcher). The information collected on the check level was advanced as part of the HILAS case study (which can be seen in Chapter 4).

In response to use case #2 the focus shifted. In the initial formulation of the approach, information was conceptually seen as mediator between operational and social space. In use case #1 there was no separate information perspective developed, however information aspects resided within the maps of process activity and stakeholder diagram (represented in the links between activities and stakeholders).

Use case #2 was a means to develop decision support ability for proactive planning. For that purpose an information function based view was developed in interviews with a senior business analyst and an operational manager. The process backdrop was provided by the examples of the check level, which, representing the consolidated set of maintenance work was subject to the newly developed decision support capabilities. The decision was taken not to develop more specific maps (e.g. planning processes) for this, due to both the different focus as well as, again, resource constraints.

3.3.4.2.1 Process maps

The process mapping has undergone a series of conceptual refinement, as outlined when introducing the methodology in the earlier section. The maps that were delivered as inputs into the knowledge process as introduced in the second section of this chapter, and worked on in the knowledge transformation workshops, were in the final format.

The conceptual development coincided with the exploration of tools available to best express the concepts and define elements such as coordination activities. It moved from Microsoft Office applications such as Power Point and Visio to a dedicated BPM tool called MEGA.

The process maps presented here reflect this progression and thus are in different formats. Each one has been chosen as a good illustration for a conceptual feature, which was given priority over the need for unity in format or presenting the latest versions that were used in the workshop. Current work is ongoing to consolidate the modelling approach introduced here with other strands of research such as risk management into dedicated software.

All maps were iteratively developed and validated with relevant staff. Process maps made use of variety of data collection methods, including the proposed template. Stakeholder diagrams were developed in a second step and are based on Focus group discussion around processes as well as interviews. Details can be found in Table 1 at the beginning of the result section.

3.3.4.2.1.1 R/I map

The removal/installation task was chosen as it corresponded with the use case #1 selected by the project: the removal and installation of a brake unit. In addition its was seen as an example of an independent straight forward task as per the classification scheme proposed for the Focus Group based process modelling. An initial review of relevant documentation was followed by observations. The mapping was performed as part of the Focus Group activities and advanced and validated in the workshop.

The steps in a generic removal installation task can be organised in a series of gates/states as outlined in Table 5.

Table 5: Removal installation task series of states

State	Description
Task card allocated and accepted	Based on the work card organisation, scheduling information and shift plan the task is allocated and the feasibility of the procedure is established.
Required inputs verified	The status of the A/C, tools, equipment, consumables and parts required for the task are checked and their availability confirmed.
Workspace open and prepared	A/C status has been changed (access and system deactivation) to allow the task procedure execution. Also safety precautions for the person and the environment are in place.
Part removed and stored (partial sign off)	The component subject to the R/I task has been removed and processed according to the particular case's requirements (e.g. stores; OEM; discard etc)
Part installation completed (partial sign off)	The (new) part has been installed and the paper work has been processed.
A/C status rectified & checked (Final sign off)	The A/C status has been returned to normal, the functioning of the part validated and general close up performed. The work card has been signed off and returned.

The core activities and how they are coordinated can be seen in the process activity in the figures 1 to 6. Table 6 gives an overview of the elements used in the process map depicted in the figures.

Table 6: Overview of elements in process map

Element	***Explanation***
Pale yellow rectangles with round corners	Technically define activities
Yellow rectangles	Coordination activities
Pink columns	Gates/States
People icon on lane	Main Actor
People icon (Blue/Green)	All stakeholder (internal/external)
Blue arrows	Relationships between elements

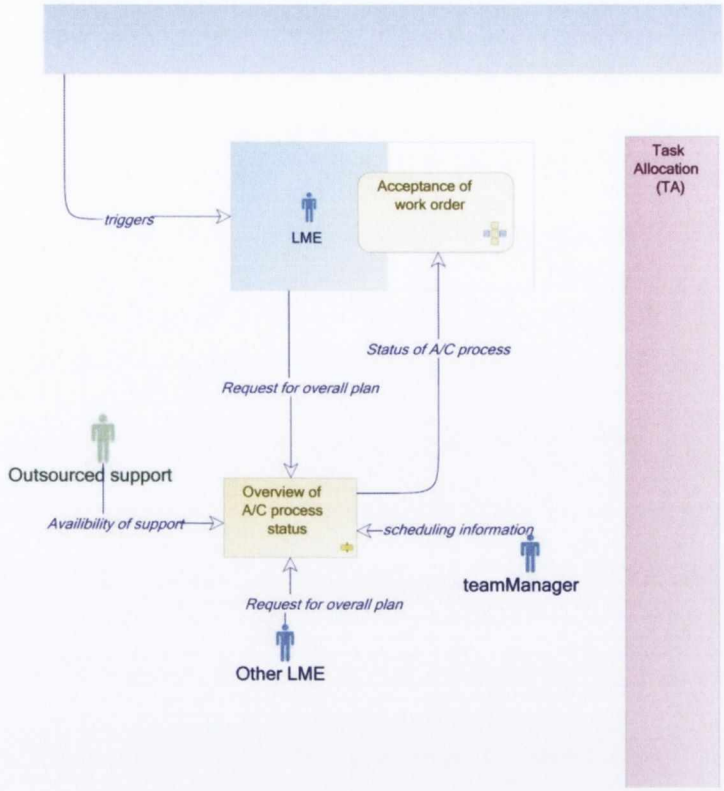


Figure 1: Process activity map for generic removal/installation task - part1

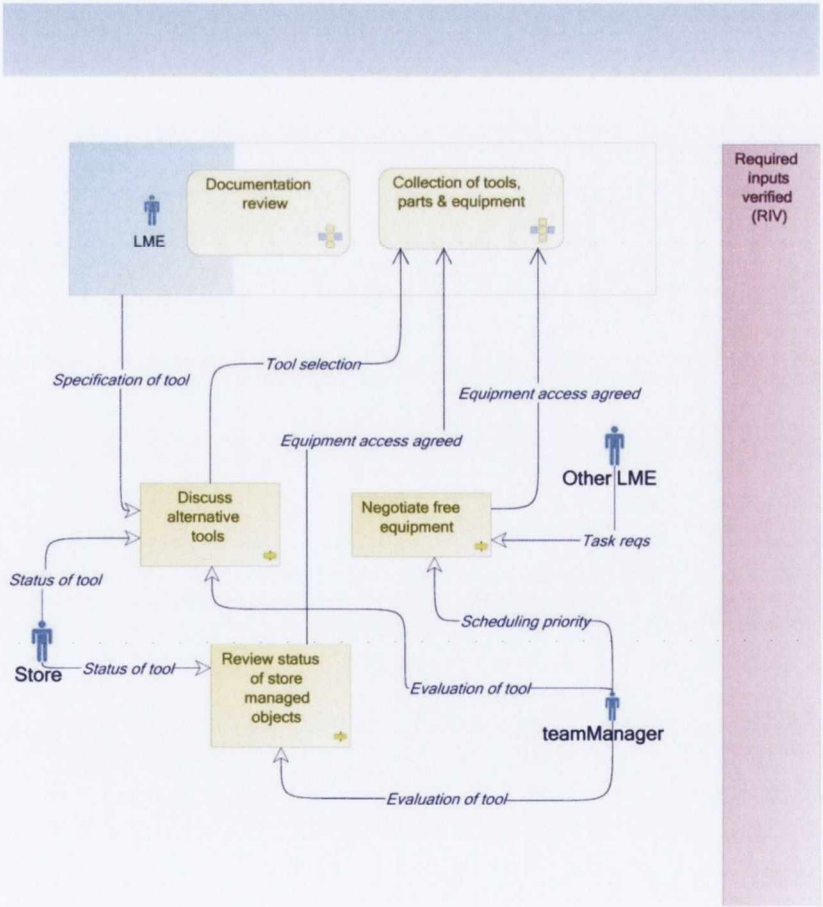


Figure 2: Process activity map for generic removal/installation task - part 2

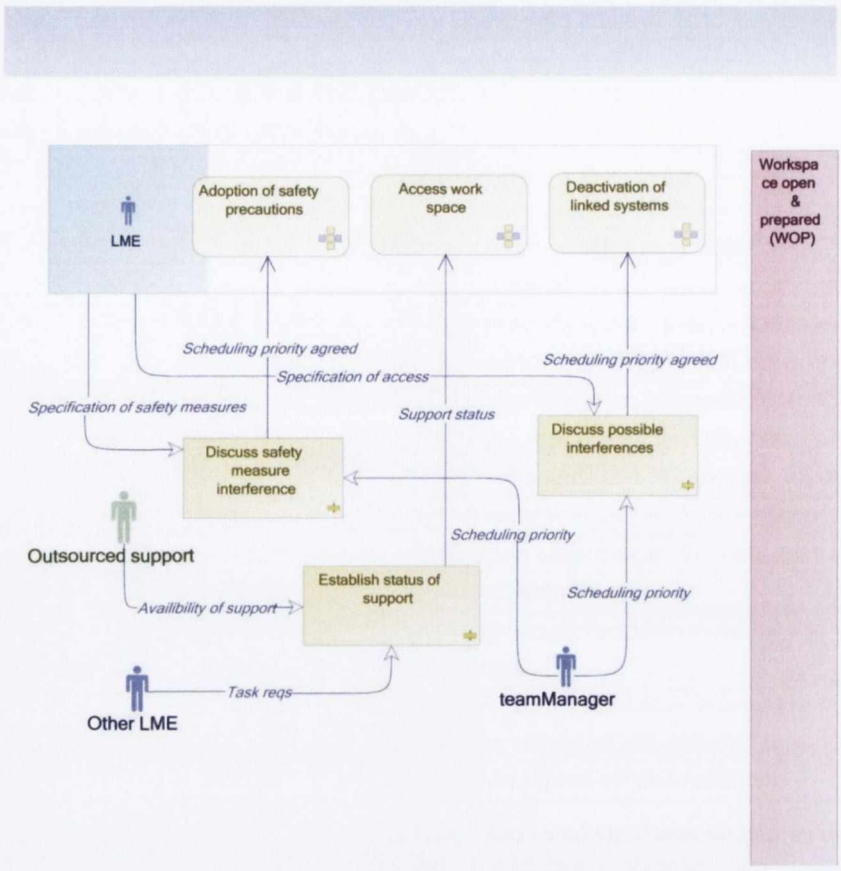


Figure 3: Process activity map for generic removal/installation task - part3

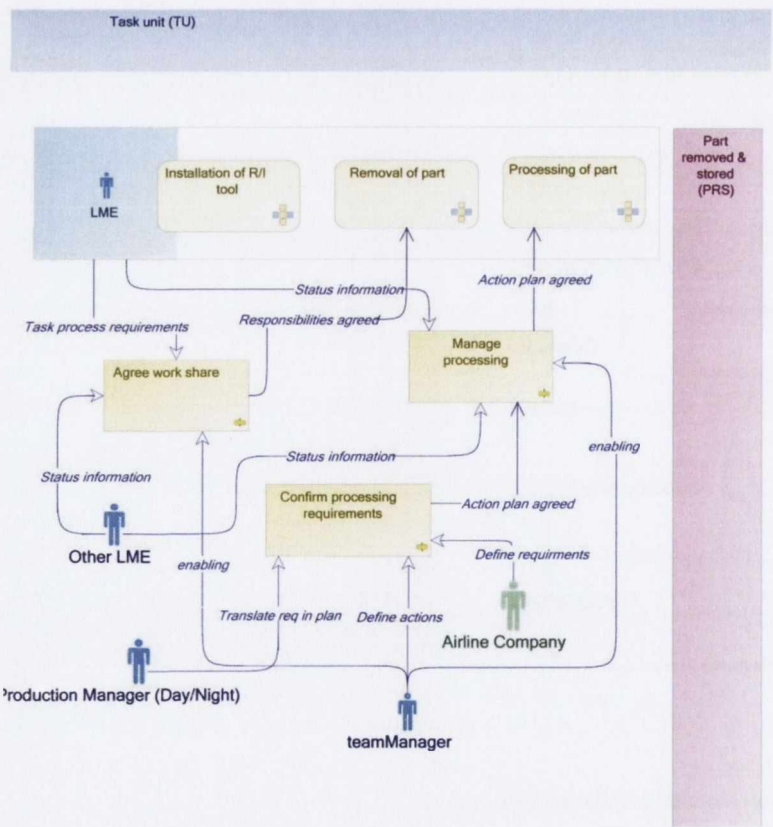


Figure 4: Process activity map for generic removal/installation task - part4

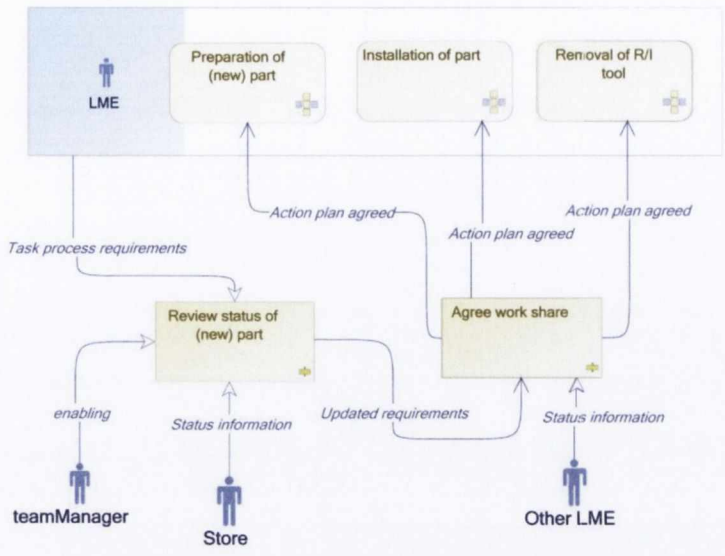


Figure 5: Process activity map for generic removal/installation task - part5

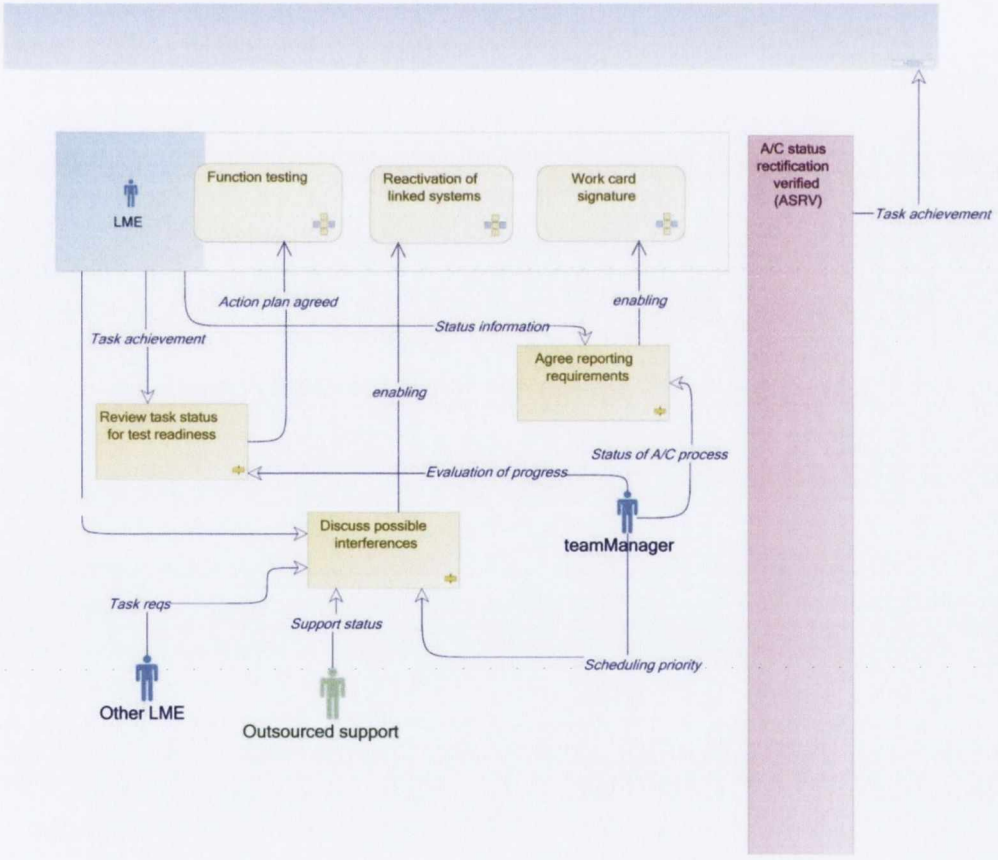


Figure 6: Process activity map for generic removal/installation task – part6

The process map shows the main activities that occur in each state and the stakeholders that are involved in enabling these activities. The line maintenance engineer (LME) is responsible for the task assigned to him and performs the technical activities, sometimes supported by another engineer. In order to enable the process to progress, coordination activities manage the dependencies that exist within the process

and with the wider system. These coordination activities draw in more people than reviewing a manual would suggest, enabling the task in its operational context.

3.3.4.2.2 Task sequence: Functional unit

The R/I task does not occur in an operational vacuum. It is part of a functional sequence of tasks that is defined by the aircraft technologies and their maintenance requirements. In the functional sequence outlined below the R/I task delivers the rectification role (as previously defined in Table 2 that gives an overview of tasks functions in work pack).

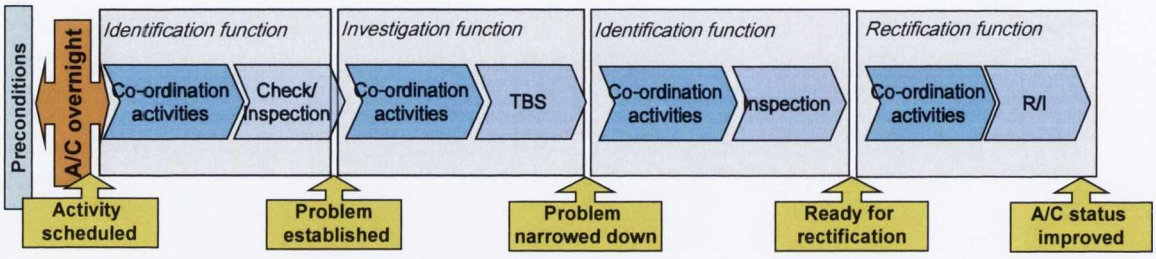


Figure 7: Task sequence illustration

The steps in the functional unit of tasks can be organised in a series of gates/states as outlined in Table 7. It includes a short narrative for each state that summarise key characteristic for this particular task sequence which was designed to match the use case storyboard for use case #1.

Table 7: Task sequence (functional unit): series of states

State	Description	Short narrative
Activity scheduled	Maintenance has been scheduled with the aircraft being taken out of operation	Today a LME takes in the A/C and does an initial check, during which he also checks the ECAM messages. In case of a finding he reports back to the MCC, finishes his checks and depending on MCC decision returns to MCC or goes ahead with the investigation of the problem. In many companies there would be one LME accepting the A/C and doing the checks, while teams of LMEs are deployed to deal with the items planned for the A/C as well as everything that comes up during the check. The check/inspection tasks can progress while fault isolation and rectification starts. The team of LMEs deployed for the A/C have the information on the plan of actions for the night, including their prioritisation. Depending on how the TBS relates to other scheduled tasks they agree on a schedule to do the work during the night. The TBS requires an initial overview about the situation, this requires a discussion with the LME that detected the message, and potentially had a chance to talk to the flight crew leaving the A/C.
Problem established	The status of the aircraft has been established as problematic based on a full picture using all available sources.	The collection of information to compile the best possible picture is leading into TBS section of the use case. Besides the information from people who experienced, detected the problem the LME doing the TBS is looking for A/C health status data (from A/C systems, A/C history). In this case he would try to contact the pilots, if available, and retrieve information from the technician who has previously dealt with the A/C to learn more about

		the findings / symptoms, i.e.the point of TBS reached so far. He also might, even in LM, initiate paperwork, i.e. response to tech log entry (NRC in BM). Documentation is kept in the Line Maintenance office, e.g. AMRS (A/C maintenance record sheet) which records information from previous turn arounds. The question is in how far TATEM technologies will facilitate this initial investigation and paperwork or in how far they will make them obsolete. At the moment this stage may involve a lot of mutual adjustment, co-ordination built on personal relationships. So far information may have been lost or overlooked, because people haven't been available (pilot, previous technician) or paperwork has been done carelessly, e.g. pilots sometimes leave empty pages between tech log entries, so technician might not find new entries. Except for AMRS and tech log with its drawbacks there are only informal information channels. Also, the technician might have an initial idea about the timeframe of TBS and can plan other tasks around this. Support might also come from a "Historical TBS database" which covers former TBS activities and highlights ways that have proven to be successful then. This is currently managed in informal co-ordination.
Problem narrowed down	The system or component where the problem originates is identified and maintenance requirements are set.	Before the inspection is triggered there is usually a check if any other inspection for this area is scheduled for this stop; or other activity that would require the same access. The crew manager chooses the person according to Qualification and experience (this could be a different person from the person performing so far). Inspections are restricted to the instructions in the manual but in many cases good practice (enabled by experience) make the person look for other problems in this area as well. Utilising this knowledge enables streamlining the process, schedule and prepare follow up task and not re-do work. This is why in some organisation s the crew manager arranges tasks in a sequence that a certain person is available to do the inspection. Example: Filter in engine blocked by debris: can be fixed by cleaning or exchanging filter. If the inspector has a good knowledge of the system he can identify the origin of the particles (e.g. result of corrosion or damage at another part of the A/C). Otherwise this would only be found out in another inspection, or not at all in this check. If possible the inspector talks to the people who have done the pre-task to get a picture of the work so far; if there was anything unusual etc. It might also help to get information from related system inspections (knowledge of system interaction required).
Ready for rectification	The problem is specified in a way that defines rectification action	The result of the inspection is documented and fed back, resulting in a 'go ahead' or re-allocation of personnel. The R/I can only start when the new part is available. Part effectivity is often managed by the shift or crew supervisor; it requires co-ordination with different functions (stores, shop, airline rep (if MRO), other overnights or BM checks if robberies are considered

		etc). This might be facilitated by information of the same task planned somewhere else (for crew manager) and its current status (sign off info). The LME can be involved in this management. Upon arrival the part number has to be checked, if the right part has been delivered and if it is effective for the A/C (IPC); also if the part is complete (e.g. temperature sensor) or if subparts have to be retained for reinstallation. The processing requirement impacts on paper work and storage requirements and thus links into the job set up, e.g. different handling tool if storing the component. Critical to the progress of the task (especially during set up and close up) is the knowledge of interaction with other systems and the status of ongoing work on those – e.g. decision which test has priority.
A/C status improved		Currently paper work is either done when the tasks are finished, or more often at the end of the shift. Progress is informally communicated. One reason for this is that paper work in the IT system is not always well supported and also often located at the offices .The hand-over happens informally, giving more information than the formal report that is written at end of shift or if required earlier, on request. Sign off is related to paper work, happening at the end of the shift or at any opportunity. The information is communicated informally in the meantime.

3.3.4.2.3 Overview of operational level

The operational context in which the use case occurred was reviewed. It is not a complete representation of all the processes and their activities but illustrates some dimensions such as

- System levels
- System-wide interdependencies
- High level logic

Both, the tasks and how it links with other tasks can occur in both a line maintenance and a base maintenance operational context. While TATEM focused on the line maintenance environment, the participating organisation had an interest in the base maintenance application. Here base maintenance results are presented as they provide a more accessible illustration of the concepts. For the purpose of the use case a more detailed map of the line operational level can be found in Appendix 1.

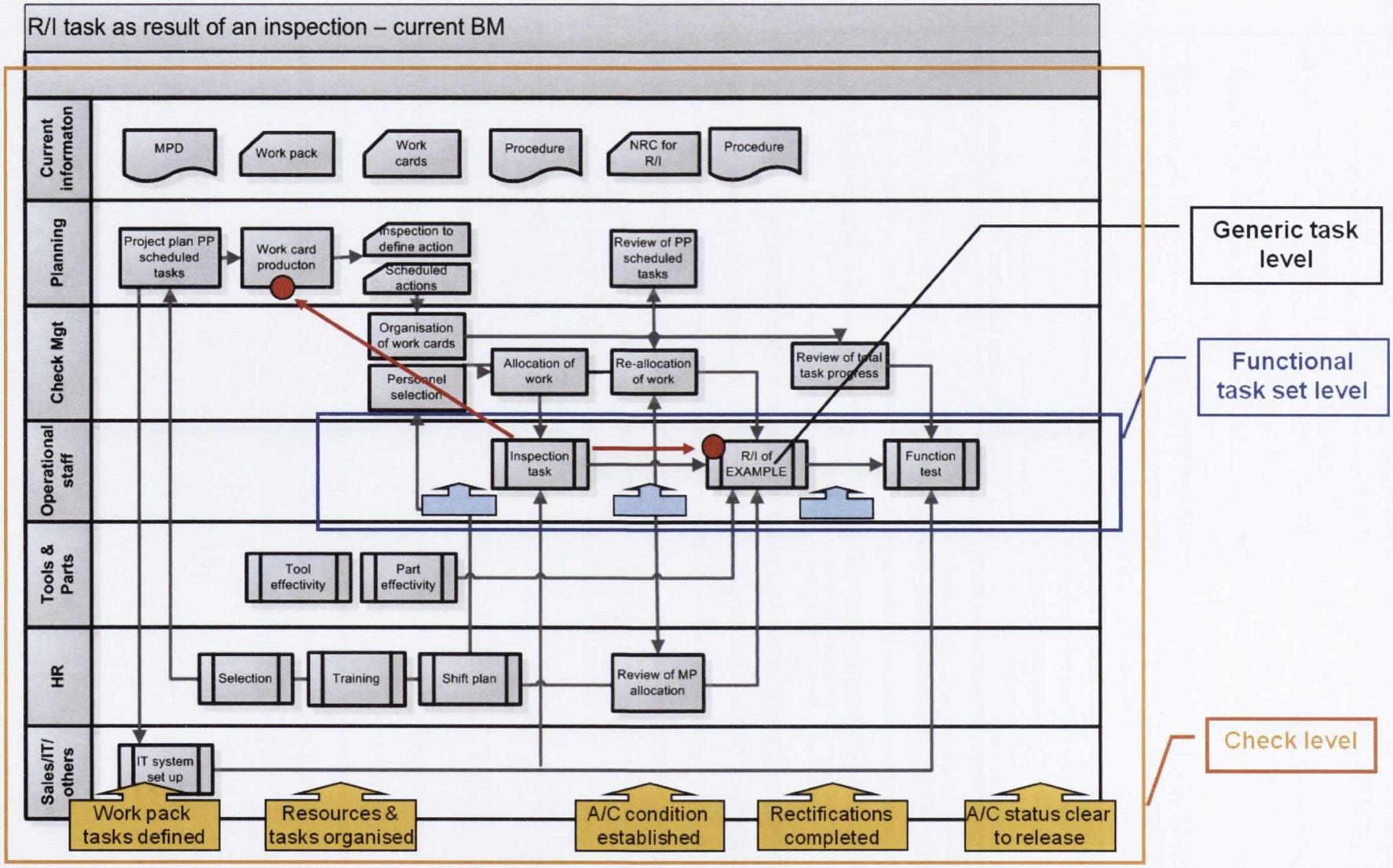
3.3.4.2.3.1 Base maintenance check context around R/I task

At a base maintenance level, the implementation of a work pack process can be organised in a series of gates/states as shown in Table 8

Table 8: Base maintenance work pack series of states

Gates/states	Description
Work pack tasks defined	Maintenance requirements are translated into maintenance tasks and issued as work pack.
Resources and tasks organised	Based on the work pack requirements are established from different sources and tasks organised according to internal work pack logic as well as resource status
A/C condition established	Work pack is complemented with tasks that result from identification activities such as inspections or checks and scheduling adjusted accordingly.
Rectification complete	All maintenance requirements as expressed in routine and NRC have been addressed, either having been performed or deferred.
Aircraft status clear to release	The aircraft status is verified as being operational.

The following map is an illustration of the concepts proposed for the modelling. It varies from the final format as it was aiming to showcase the integrated levels and system process that are relevant for understanding removal/installation tasks in one diagram. Support processes are included as swimming lanes and are not detailed in their activities but have sub-functions included. Coordination is implicit in connections between activities. States and gates are included at the bottom. Within the diagram the red line represents a set of dependencies the quality of delivery of which impacts on the removal installation tasks. The power point presentation where this diagram originates included interactive features that allowed exploring the functional sequence and removal installation task.


R/I task as result of an inspection – current BM
Current informaton
Planning
Check Mgt
Operational staff
Tools & Parts
HR
Sales/IT/ others
MPD
Work pack
Work cards
Procedure
NRC for R/I
Procedure
Project plan PP scheduled tasks
Work card producton
Inspection to define action
Scheduled actions
Review of PP scheduled tasks
Organisation of work cards
Personnel selection
Allocation of work
Re-allocation of work
Review of total task progress
Inspection task
R/I of EXAMPLE
Function test
Tool effectivity
Part effectivity
Selection
Training
Shift plan
Review of MP allocation
IT system set up
Work pack tasks defined
Resources & tasks organised
A/C condition established
Rectifications completed
A/C status clear to release
Generic task level
Functional task set level
Check level

3.3.4.3 Stakeholder diagram

The process description at each level is complemented by a separate representation of the stakeholders and the core functions of their relationships as part of making the process work. Here an example is presented at the maintenance task process level. Complementary views were mapped for the task functional sequence as well as the overnight management and can be found in the appendix.

3.3.4.3.1 At task level

The stakeholder diagram presented here gives an overview of the key roles and their main functions as well as their relationships at the level of the maintenance task in line maintenance. They are derived from the process activity model. Coordination highlights the stakeholders who have a role in the process, even though not everyone is in situ on the hangar floor or in the office.

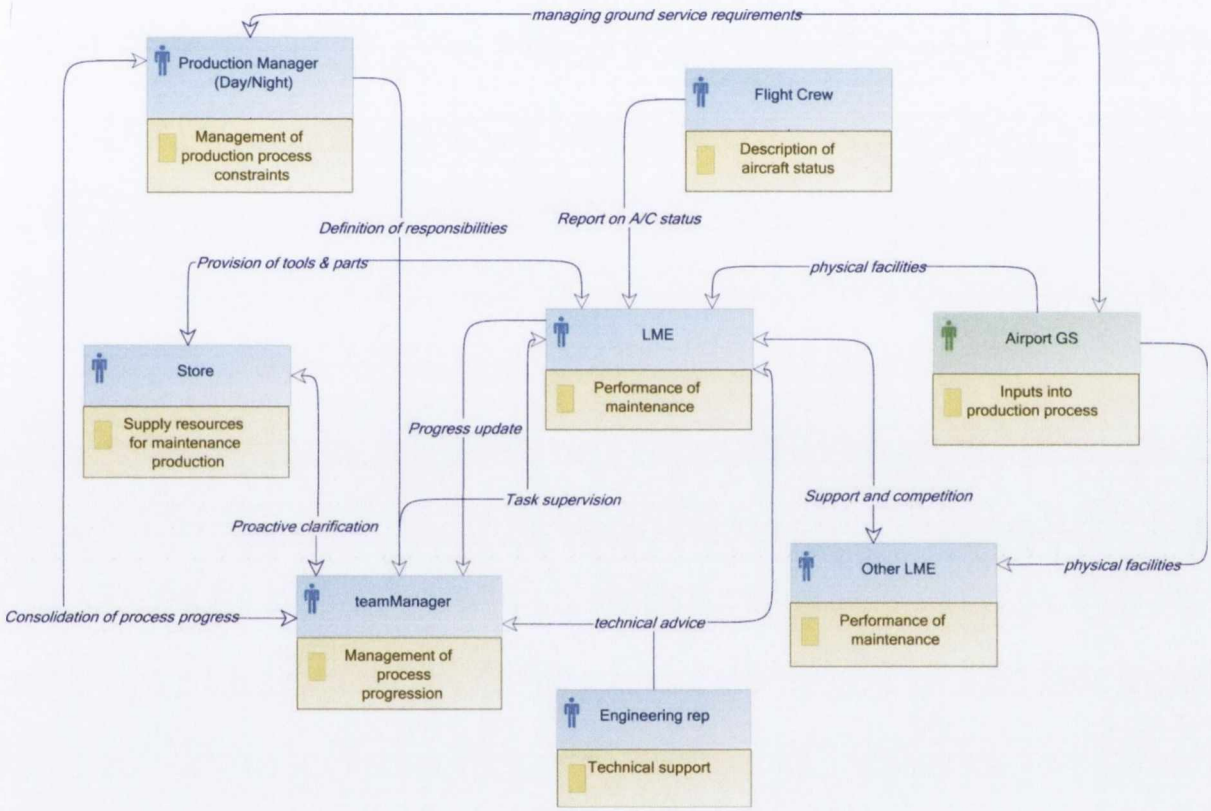


Figure 8: Stakeholder diagram at task level

Table 9: Legend of elements in stakeholder diagram

Element	Explanation
Yellow rectangles	Key function of the stakeholder at this process level
People icon (Blue)	Stakeholder internal to the organisation)
People icon (Green)	Stakeholder external to the organisation)
Blue arrows	Relationships between elements, annotated with main functionality

3.3.4.4 Information model

Use case #2: Information perspective

Figure 9 gives an outline of some of the key information and decision functions performed by different organisational departments (engineering, planning (technical and operational) and scheduling) and their relation with the production of maintenance.

It represents an overview the current functions that were implemented in the information system in the maintenance operation at the time of the research. Planning functions based on scheduled items are merged with data based on deferred defects as well as trend monitoring. This defines the universe of known work to be performed per aircraft. It is the basis for the definition of work packs across the fleet. These work packs are updated with emerging information – events and findings in line maintenance and pick ups in base maintenance.

The information is regularly updated and the information based functions can be organised around

- Engineering function — What must be done?
- Planning function — When must it be done?
- Scheduling function — How can it best be accomplished?

These are implemented in different sets of processes, including the operational check management.

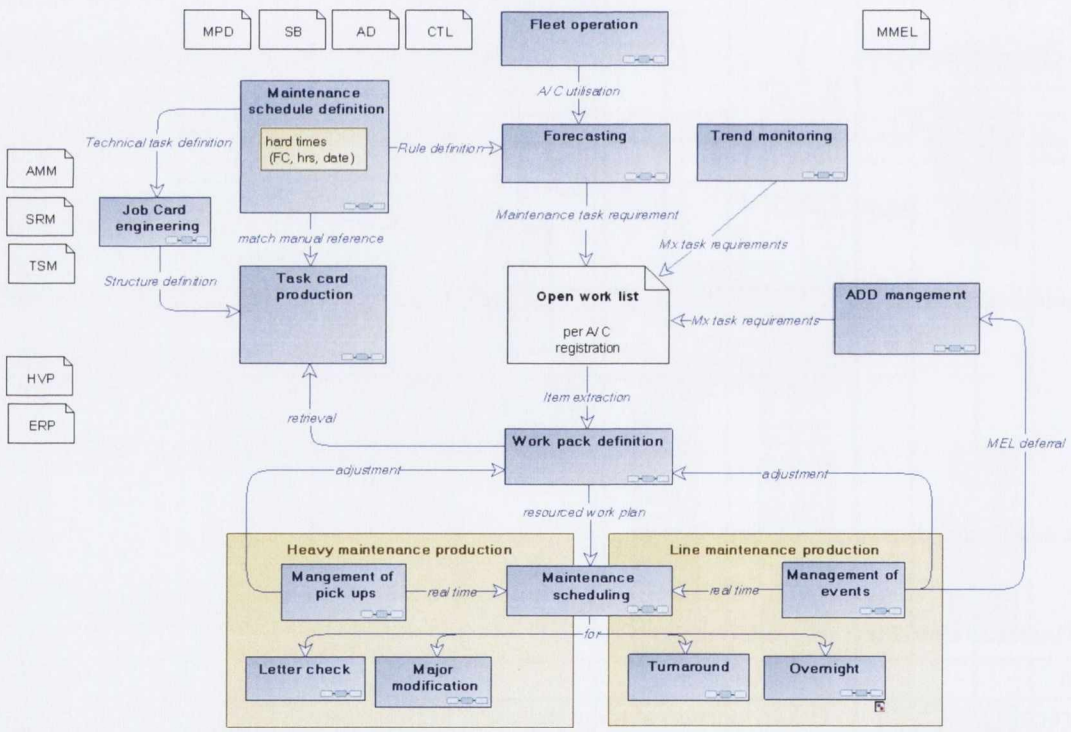


Figure 9: Information perspective: Maintenance planning cycle - 'as is'

There are different information streams that drive maintenance requirements and thus provide an input into the decision to plan and schedule a maintenance action. **Forecasting** is based on the projection of the average utilisation of the aircraft. Matched with hard times it defines maintenance requirements to be managed on a timeline. 'Hard times' or fixed intervals are the basis for **Rule definition.** Today the maintenance of components is managed by interval rules defined in the MPD (hard times such as flight

cycles or hours) as well as in reaction to events and pick-ups. **Trend monitoring** is realized for the engine and successfully integrated in the maintenance operation. It provides real status information on the health of the engine for maintenance planning. In addition to those the **Aircraft Deferred Defects** (ADD) are centrally monitored across the aircraft of a fleet. Maintenance requirements resulting from all of these are managed in the **open work list.** Today's open work list combines scheduled and deferred items (line maintenance)/'pick ups' (heavy maintenance). It is the basis for scheduling and managing the delivery of resources such as manpower, tooling, parts, hangar space etc into the operation.

In parallel to forecasting the MPD is translated into **task cards** that can be called up into a **work pack** definition emerging from the open items list.

External information inputs are required in the complex process. In order to manage tasks resources and constraints included across manuals today need to be provided in a standardised, synchronised, integrated form. Today this information is largely manually extracted from the different sources the manufacturer, OEM and flight operations procedure. Examples include Service Bulletins (**SB**) or Airworthiness Directive (**AD**).

Line maintenance scheduling

In the current line maintenance environment the management of hard time items and unscheduled findings to provide appropriate maintenance opportunities is an iterative process that relies heavily on coordination across different functions. Two main contributing factors are that planned/scheduled items can have unexpected effects as well as unexpected events can happen at any time. Currently utilisation is adapted in the light of updating the average forecasting.

Heavy (Base) maintenance scheduling

The timeline in regard to heavy maintenance is different. Currently a key challenge is to manage the amount of items that are involved in a check, including their potential for 'mushrooming'. Being concerned with larger work packages, heavy maintenance is aiming to optimise the downtime for an aircraft, e.g. by pulling items forward to prevent another operational interruption.

3.3.4.5 Dependencies

Process activities can be organized according to a series of gates at which the process has to be in a certain state to allow for its progression. Within each of these phases activities occur that create a demand for a certain configuration of elements: technical, social and information.

Dependencies arise between tasks which are part of processes, either internal to one process or linking activities across processes. They can be organized around

- Resources/Inputs: availability and quality
- Process logic: internal and external
- Social aspects: team; common understanding in coordination; quality of relationships

The following table gives an overview.

Table 10: Overview of dependencies for R/I task

Gate/State	Process map coordination activity	Associated generic coordination activity	Dependencies managed
State 1: Task allocation achieved	Overview of A/C process status	**Orientation/ Status consolidation** (information based)	Clear task trigger/work order Status of parallel processes Adequate qualification Actor's experience Team definition Relevance of task in process Task context information Shared task view
		Reduce ambiguity – common understanding (knowledge based)	
State 2: Required input verified	Discuss alternative tools	**Manage supply**	Documentation access Equipment status Understanding of alternatives
	Negotiate freely available equipment	**Negotiate priority**	Unconflicting schedule Resource schedule Team system Open communication Negotiation skills
	Review status of store managed objects	**Orientation/ Status consolidation** (information based)	Information adequacy Adequate information channel/devices
State 3: Workspace opened & prepared	Discuss safety measure interference	**Reduce ambiguity – common understanding** (knowledge based)	Shared understanding of process requirements Understanding of system interferences Team work
	Establish status of support	**Orientation/ Status consolidation** (information based)	Delivery of pre-tasks Availability of support Availability of material resources Team work
	Discuss possible interference	**Reduce ambiguity – common understanding** (knowledge based)	Control of task interferences Understanding of system interferences Shared understanding of process requirements Team work
			System status information (real time)

State 4 : Part removed and stored	Agree work share	**Reduce ambiguity – common understanding** (knowledge based)	Overview of (sub)-task structure Work share agreement
	Confirm process requirements	**Reduce ambiguity – common understanding** (knowledge based)	Availability of equipment Access to technical support
	Manage processing		Experience with system System information
State 5: Part installation achieved	Review status of new part	**Activate resources as inputs**	Agree processing requirements
	Agree work share	**Reduce ambiguity – common understanding** (knowledge based)	*carried forward*
State 6: A/C status rectification verified	Review task status for test readiness	**Reduce ambiguity – common understanding** (knowledge based)	Return to initial A/C status
	Discuss possible interference	**Reduce ambiguity – common understanding** (knowledge based)	Understanding of key points in procedure for reporting Knowledge of other tasks' requirements (follow on/linked)
	Discuss reporting requirements	**Reduce ambiguity – common understanding** (knowledge based)	Access to reporting system Agreement of task outcome Functional check results Work card sign off procedure

3.3.5 Discussion

Uncertainty and instability are defining features of aircraft maintenance operation as discussed in chapter 2. The results of the research indicate that there is a set of sources for this, which vary depending on the operational context, i.e. long-term hangar based (base maintenance) or short-term ramp based maintenance activities (line maintenance). TATEM started from the premise that it is the task that has to be supported, however, the research indicates that the main challenges are not a result of task itself (even though they manifest themselves there as blockers) but their system context.

Table 11, adapted from McDonald and Morrison (2006), gives an indication of main sources on uncertainty in line and base maintenance.

Table 11: Main sources of instability in line and base maintenance

Base maintenance	Ensuring preconditions for check processes (planning & supply) is the major source of instability	Interference between parallel, interdependent, tasks is second source of instability	Factors within the task are third (least) source of instability
Line maintenance and dispatch	Interference between parallel, interdependent tasks is major source of instability	Ensuring preconditions for work packs and checks (planning & supply) is the second source of instability	Factors within the task are third (least) source of instability

3.3.5.1 Conceptual advancements

Chapter 2 outlined the territory that defines the challenges in effectively addressing issues that manifest in complex socio-technical system such as aircraft maintenance. In an intensive effort that was facilitated by having an a priori body of knowledge, critical knowledge about the dimensions was advanced and further systematised. The key conceptual advancement is its consolidation in an integrated approach.

The model base for the KSM framework delivered a functional view of coordination in processes which gave access to the conceptualisation of the underlying logic as a series of states and gates with associated dependencies. Targeting knowledge at this level opens up the system space in which apparently local issues are situated and which has to be systematically considered when addressing them. This process core was complemented with a stakeholder and information perspective associated with that allowed for insights in the role of social processes and information flow in relation to the process activities, completing the functional picture of a socio-technical system.

The model base that was developed here around a process core can be described as a functional model which

- Stores and manages data, information and knowledge about the current system
- Represents the system graphically in different ways (system level, process activity, stakeholder relations, dependencies, information flow),
- It preserves a context for tacit knowledge in that it positions it in its context of meaning, integrating functionality hidden in informal practices and realised largely in social actions
- Provides a systematic knowledge base for further analysis and has the potential to incorporate its outcomes (e.g. annotating process element with identified risk)
- Supports the systematic transformation of the operational process into future or alternative versions

The models are the anchor for the implementation of the KSM framework as a process which iterates the key dimensions for the purpose of description, i.e. eliciting hidden knowledge about the system, evaluating system vulnerabilities along these dimensions and their interactions, and the identification of change requirements and implementation issues. Building a process around a series of iterations on the

same knowledge structure allows for a transparent, systematic, comprehensive process, an instantiation of which is demonstrated in section 2 of this chapter.

The validation of the concepts being relevant to gaining a better understanding of the operation was initially achieved in that staff in various operational roles the organisation recognised their daily practices and agreed with how those were represented. The validation was furthered by demonstrating that it could be used to systematically transform the existing understanding of the operation into a 'to be' version

3.3.5.2 Benefits of having a knowledge structure

"Any useful model of the human role in operational systems should ideally conform to two broad criteria – relevance and leverage. The criterion of relevance states that because it is never possible to have a complete and comprehensive description of any social process, it is necessary to focus the description on what is relevant to the enquiry. The principle of leverage directs attention towards those underlying mechanisms at each level of analysis where the relevant interdependencies are strongest, and where the possibilities of influence through system design are strongest." (McDonald & Morrison 2006)

The models within the KSM framework do not aspire to account for all possible sources of variance in the system. Its focus is on the recurring pattern in socio-technical activities that maintain the relative stability of the system, enabling it to deliver its outcome, and which define the critical dimensions that need to be considered when attempting to transform the system.

In consolidating knowledge in a model based framework that systematically relates key dimensions, which relevance to the system behaviour have been demonstrated in empirical research, the KSM framework realises multiple advancements that enable the overall research trajectory of the thesis.

- The system and its processes are at the core of the framework, instead of cognitive views of individual or group processes that have been dominant in Human Factors. The main focus is on what people do as part of the system. In people mediated processes such as those that instantiate the aircraft maintenance system it is their activities that produce the system outcomes.
- As an approach designed to address the complexity of socio-technical systems, it is not favouring one perspective but integrating different system dimensions (technology, information, social) and thus offers a more comprehensive view on what is part of the value chain that underlies the process
- Integrating dimensions that are often looked at separately into the system space, and developing their internal logic (relations) enables a dedicated HF inquiry of system activity
- The framework consolidated system properties at a high level. It provides a reference that prioritises systemic view on operations and invites integration of existing or emerging methodologies within these parameters, e.g. novel task analysis approaches.

3.4 Section 2: Knowledge Process

This section of the case study focuses in the role of knowledge and how having a framework enables its systematic and effective deployment and thus addresses **Research question 2**: How can the relevant knowledge be captured and effectively utilised in system design? (Knowledge process)

Generating the knowledge content in a systematic way as described in the first section is the starting point of the overall knowledge process. Its focus is on the creation of relevant knowledge about the 'as is' situation, integrating technical and social aspects into one account.

In the first part of this chapter, it was outlined how the framework and its models elicited previously hidden knowledge in that

- All operational stakeholders were systematically asked about their experiences, using different data collection methods
- It provided a new framework that opened up conversations that were not had in any operational context, even informal one, although upon reflection it was deemed highly relevant
- When engaging with people the focus was on informal practices and tacit knowledge to complement the formal manual version of activities
- Questions addressed aspects of dimensions familiar to them, e.g. tasks, resources, but extended these and also introduced new dimensions such as coordination that were practised regularly but never reflected upon and labelled as such

The second section of this chapter shifts the emphasis to how the knowledge is deployed in further activities and by that transformed into new knowledge that is targeted by a research question. The core dimensions of the KSM framework that informed the capture of knowledge into the models were continued into its evaluation and transformation into a roadmap for re-design. The main deliverable was the design and implementation of a set of two knowledge transformation workshops and their results, the 'to be' version of operational processes utilising new technology.

The application of the approach showcases a process that was designed to manage the role of operational knowledge in system engineering project in order to deliver the transformation of 'as is' maintenance processes to a 'to be' vision based on the insertion of proposed technology innovations. While relevant results were delivered, the integration into the design process was not fully achieved, for various reasons that included the structure of the work programme, the type of existing relationships between industry partners, a narrow notion of impact and value, and a general lack of common understanding. These will be further outlined in the discussion of the chapter.

3.4.1 Background of the case study

Technology innovation can dictate a step change in the operation of a system and open up opportunities for, or even mandate, new ways of doing business, either as an individual company or in collaboration with others. As discussed earlier, the TATEM project was large scale technology project which main innovation was based on the concept of integrated vehicle health management (IVHM) and promoted this concept as the vehicle to deliver major cost reductions in the (maintenance) operation. Key industry players came together to design and deliver this step change.

"Designing for operations requires that the designers understand the operational system as it actually works (as opposed to how it is meant to work). This is rare because designers do not often have

operational experience, and the design process is remote (geographically, commercially, organizationally) from the operational situation. Bridging this gap between design and operations requires two things:

- The capacity to model the operational system in naturalistic and ecologically valid manner, capturing the 'tacit knowledge' of the operational community
- The ability to transfer and transform this knowledge into a capability to envisage and design how a future system might operate.

This knowledge (transformation) process involves getting the key stakeholders from design and operations together in an active engagement collaboratively developing a new concept." (McDonald, 2009)

The proposition of a HF approach that is systemic and facilitates the effective deployment of relevant knowledge about how the actual system works can act as key facilitator to meet the demand and bridge the gap. Currently, there is little interaction between design processes and the operational sector. Extending existing system engineering approaches by offering a way of actively dealing with the relevant knowledge defines not only process activities but is the basis for transforming the relationships that further foster effective collaboration towards achieving the common goals design for operations is based on.

In the project the application context for the KSM framework was defined by the project work programme structure which reflected a traditional system engineering approach, focusing a lot of effort on technology development and integration while organising the people questions around task support and HMI issues and Cost Benefit Analysis (CBA) dimensions such as human resources.

From a system perspective, this raised the question of the project value proposition. While the objectives were firmly grounded in operational domain, such as 20% cost reduction in maintenance operations, the technology work packages strongly centred on a technology agenda. During the course of the project, this disconnect became apparent in the challenges the supporting work packages tasked to develop operational scenarios and manage top level requirements struggled with.

3.4.1.1 System engineering paradigm: V-cycle

A standard paradigm in system engineering is the V-Cycle which can be best represented as a process. It starts off with inputs namely requirements and transforms them into the specification and plans necessary to build a new technology which is the outcome subsequently evaluated against the initial requirements. As a system engineering process the v cycle is a means to drive consistent design that is quality controlled and safe to operate.

There are different representations of it available but the following figure can be taken as a generic overview of the overall logic:

Figure 10: The V cycle

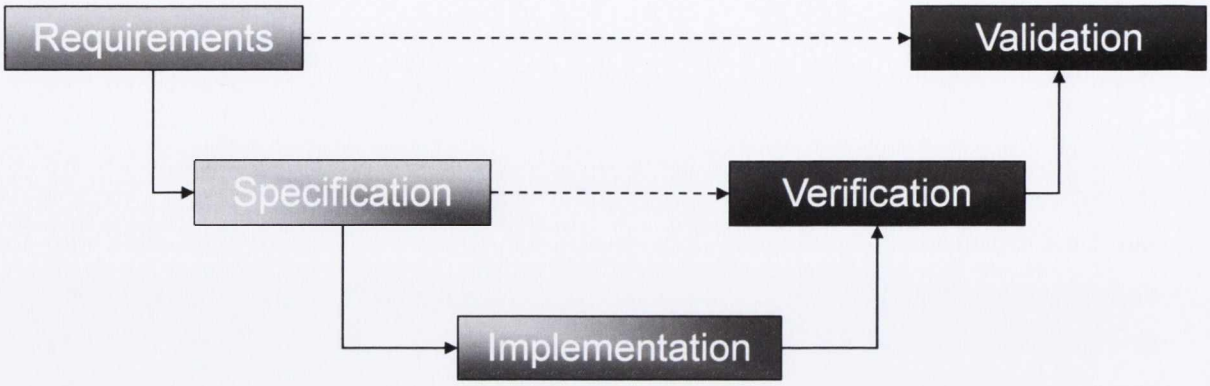


Figure 10 outlines a framework in which activities are to be performed in system engineering product development.

Each box in this process represents a series of steps/set of activities. On the left side of the V requirements are collected to derive a system specification which is built and then subsequently tested against its specifications and validated, following the steps on the right side of the V. The V-model is meant to be iterated until the outcome meets the criteria defined for the technology. Those iterations allow for learning and adaptation to meet constraints or for realising additional potential, but once the system is at the building stage the room for changes is limited.

As with every process the quality of the outcome depends on the qualities of inputs as well as the transformation activities itself. There are two levels of outcome of this process. **One** is the technology product itself: The design is implemented and evaluated against its specification, i.e. the piece of technology is coherent in terms of functionalities and safely operating within its technical margins. A **second** outcome is the capability of the technology to transform the operational outcome, i.e. the impact that introducing the technology has on the process system. The impact to be considered is not limited to local achievements but the overall operational system performance. It goes back to the set of requirements that started this process and is validated in the final step.

While the first outcome is well supported, the second one is less explicitly and or coherently addressed. From experience in several system engineering projects, there seems to be a lack of ownership when it comes to the operational aspects of validation. The system integration on test beds is cost intensive and thus easily draws attentions and careful planning. In this set up, operational aspects run the risk of being reduced to a mix of HMI issues, hypothetical CBA and local information tasks. The question is whether this is due to lack of understanding, lack of interest, lack of capability, lack of access to a fuller picture or a bit of everything.

It highlights a gap in the system engineering process and the opportunity for integrating a new service. The system engineering process drives consistent design that is quality controlled and safe to operate. It is a complex process that is not going to be reviewed here in all its details. The focus of the discussion is the role of knowledge in defining its main input in form of requirements. Currently, there is no well defined capability to allow for operational reality being systematically represented. Instead it is managed through requirements derived from document analysis, experience and participation of end-users. While these sources, including operational staff provide valuable insights into what is needed in the operation, there is no strong mechanism to ensure the adequacy or relevance of these inputs and their value depends on how the requirements stage is planned, characteristics of people participate in the activities and how they are engaged, and how knowledge is elicited and managed. While there are techniques improving the quality of this, those do not systematically address the main challenge of how to define an adequate operational knowledge base that can drive meaningful and comprehensive requirements. The most easily accessible information for this step is operational manuals, procedures and other document based information. Their use is flawed for many reasons, many of which can be seen as reflections of the disconnect between formal systems and the actual operational reality that was demonstrated in Chapter 2. Firstly, they only represent the formal reality or rules, but not the complete set of actions that realize the process. Secondly, formal systems are captured in manuals originating in the OEM and organisational documentation such as the MOE. If only manuals are available, it reflects manufacturer knowledge thus not even broadening the basis of formal knowledge. Thirdly, documentation is usually focused on one process and its sequence rather than its interfaces, and thus limits the view of the interlinked with the system. Lastly, the definition of users: The focus is on direct users of the technology to support HMI and usability. If this restricted notion of a user is applied, critical requirements are missed out on: there are stakeholders that are not using the technology per se but whose processes are affected by the how the local processes change in response to the new technology, i.e. delivering new/different outputs or requiring different or new inputs and support, or even shifting responsibilities, e.g. remote maintenance.

Operational experts are consulted and brought into the definition of requirements where possible. This increases the operational relevance and highlights strengths and limitations of initial concepts. However, following the argument outcomes in chapter 2, knowledge about the complexity of the real operational situation is often hidden. Therefore, expert input can vary in quality. Firstly, knowledge is not shared because it is tacit, i.e. people cannot easily express it, or/and it is informal, i.e. people do not want to express it. If the manuals and procedures are the reference point for the exchange with experts, then issues are missed out on, especially those who create the most challenges in the operation and thus would

be most beneficial to be address by technology innovation. Secondly, gaining access to operators does not necessarily mean that it includes the right people in terms of critical experience and knowledge. Depending on the scope of the system engineering project, representatives from different level can be engaged: senior management, middle management or workforce. This delivers a variety of inputs from strategic vision, to daily issues in the operation. The challenge is to align and integrate those in a hierarchy of requirements.

In addition to these issues around identifying and accessing the relevant knowledge, there is a more fundamental issue that poses a barrier to the above. The nature of the relationships within the aviation lifecycle inform how people interact and what knowledge (they have available) they feel they can share. What has been observed in projects and proposal developments, operators are generally reserved when it comes to sharing the reality of their business. The reason is that there is a (real/perceived) issue around accountability when things do not go as expected. The question is going to be whether the part was faulty or degraded, i.e. is it a design issue or was the way it was maintained, i.e. to the letter of the manual and SBs or, or not (which is more likely). While this only becomes a reality when an incident occurs, a history of those (experienced or transmitted in the community) shapes the relationship. Informal discussions in TATEM have shown that there seems to be a grey zone and a lot of mistrust.

A similar approach seems to be taken by the OEM, with each other and with the potential customer, the operator or MRO: in the TATEM project it rarely happened that limitations of the technology and its design process were acknowledged. The operator is also the customer who eventually buys the product – so while eager to address his requests at the same time there is a certain element of "keeping up appearances". Being connected by the product and its subsequent maintenance results in an interesting relationship: longstanding, including issues of power and trust, and involving various stakeholders across organisations at many levels.

The proposed framework is designed to address the issues raised around accessing and utilising knowledge: it informs both a structure of relevant knowledge and a process that brings together key stakeholders in a facilitated knowledge exchange.

3.4.1.2 OSA CBM

At the core of the technology innovation was the transformation of information based capabilities. Within the IVHM approach, technologies were developed and advanced that allowed for delivering new information on the overall status of the aircraft. The benefits were expected to be delivered by integrating the new information capabilities into a full picture of aircraft health that could be taken as an input into operational processes to improve their efficiency, both in terms of planning and production functions.

OSA CBM is an open source communication standard for the maintenance domain. It was introduced into the project to facilitate technology system integration. It advanced the exchange between the engineering communities in the project and was seen to be critical for enabling the test bed based evaluations. From an engineering point of view, this represents a system of system that the aircraft and its system constitute.

OSA CBM is concerned with the treatment of data, leaving open the question what the knowledge base and shared understanding is that drives the initial data model. It has several layers that support the standardisation of technology development and integration from data acquisition to presentation to an HMI to a (single) user. Again, the perceived role of people is dominated by a technological view point and reduced to an individual, focusing on local information display. Within it, the standard functions are considered. But as with the V cycle the question is what knowledge the selection and definition of these functions is based on.

OSA CBM played a critical role in the technology system integration, as it was designed to do. But like the traditional v cycle, it is another example for a system engineering approach/tool showing that the operation as a customer is not well conceptualised. Doing this does not have to be a system engineering task, in fact other disciplines are better equipped to bridge this gap. However, it has to be integrated and thus the system engineering process needs to be open to accept the required change.

3.4.1.3 KSM framework

The KSM framework structured knowledge and guided its transformation into a new version, all along the same socio-technical dimensions. The core concepts and their implementation into a model base were demonstrated in Section 1 of this chapter. The core conceptual assumptions include that

- processes deliver outcomes not only by implementing transformation but also coordination activities and their activities can be described generically, in a series of gates and states
- the overall functional logic is a composite of functions defined by the technology and the social functions that are a response to uncertainty in the system
- the characteristics of people (e.g. competence and sense making) and the quality of their relationships (e.g. team cohesion and trust) are key to delivering social functions
- Value is attached to outcome, and thus by proxy to all process activities and their enablers, e.g. social capital

3.4.1.3.1 Knowledge structure

The previous section of this chapter introduced a framework that organises knowledge about the system into a set of models. In advancing the models towards a new version, additional information is sought around the process logic, the role of people, their characteristics and relationships, and resulting dependencies.

3.4.1.3.2 Model based knowledge transformation

Nonaka's approach is a prominent one in the field (e.g. 1994, 2002). Main characteristics that informed the research presented here are the social nature of the proposed knowledge process and its conceptualization of the relationship between tacit and explicit knowledge within it. It stresses the social components of knowledge creation and transformation, which are critical in such a process. As discussed in Chapter 2, the knowledge creation process is based on four conversion modes which integrate tacit and explicit knowledge in an iterative cycle.

The approach proposed in this thesis builds on Nonaka's principles and introduced the process system models as functional reference, providing content and structure to target the socially based knowledge activities. As discussed before the process system models represent, as comprehensively as possible, current knowledge about how the system functions. As such it is a key knowledge resource that supports all functions which involve an understanding of the operational system, including the transformation of knowledge to envisage the 'to be' alternatives.

The KSM framework is intended as a structured guide to facilitate the mustering and interpenetration of diverse but relevant sources of expertise (system designers, different operators, human factors experts, etc.) in order to generate a new synthesis which can provide a set of requirements for improving the system. The models store a systemic overview of daily 'as is' practices in the organisation while their assessment draws from HF theory and a large body of research to deliver a better understanding of the current challenges. Along the KSM conceptual dimensions people share and integrate information and knowledge to create new innovative solutions and improve the 'as is' situation.

3.4.2 Methodologies

3.4.2.1 Project research process

Within the project, the research presented here originated within a task that was part of one work strand (among five) that was fostering local integration of the Ground Crew support work package activities and outcomes. The position in the work programme supported a research process that implemented the main principles advocated of a systemic HF approach.

It allowed for having partners from all other stands involved in the development and deployment of the framework. Over the course of the project it also allowed access to the top level requirement work packages (WP3000) and the overall integration activities in WP8000.

In addition to this, internal dissemination events were used to communicate how a systemic perspective on HF in system engineering can create value for all stakeholders. These interactions allowed establishing relationships that resulted in external dissemination opportunities that were beyond a single task and also steadily build support for the investment of effort into the KTWS.

Al these were elements in establishing a process that shared knowledge and transformed it towards supporting the project in achieving its outcomes and demonstrate operational benefits.

3.4.2.2 Model based Knowledge transformation workshops (KTWS)

KTWS is a participatory exercise that acknowledges Nonaka's (e.g. 1994 2002) premise of requisite variety and redundancy facilitates an exchange of knowledge around a process based question, using a model of activities in socio-technical systems as a reference. Having the reference knowledge baseline advances Nonaka's approach in that it defined the requisite variety in terms of the target system and ensures that the relevant knowledge is available, thus allowing comprehensive consideration of solutions alternative in a relatively shorter time frame

The design of KT activities adheres to the following principles in Nonaka's approach:

- Social setting

  A social situation was created in which the events occurred. People interacted iteratively along a shared agenda. Relationships are defined by goals. The model supports the clarification of target and goals which provides a baseline for effective exchange, even without pre-existing relationships. Mediated by type of existing relationships different interaction forms are possible: face to face, virtual or others.

- Requisite variety

  Basing the knowledge transformation on a model of process activity allows to systematically addressing the principle of requisite variety. The target process can be used to identify key stakeholders in it, which ensures requisite variety. It defines strong criteria for the implementation of this principle, rather than relying on judgment calls by the facilitator or ad hoc groupings such as CoP which have their limitations. In contrast to Nonaka, requisite variety is extended beyond individuals and is defined by the relationships that are the basis for delivering system relationships. It is these combinations of roles that have to be present to address an issue or envisage innovation potential in a target area.

- Redundancy

  Based on the identification of requisite variety, redundancy is sought. It allows for a broader representation of perspectives and opinions and encourages people to speak out. The extent to which this can be achieved is usually limited by constraints posed by operational demands. Having a model base introduces more knowledge into the situation than held by the participants. This by default broadens the perspective and arguably counteracts subjectivity. In addition, this knowledge base can be utilized to position the questions or issues to be addressed in their wider system context, highlight potential consequences and thus strengthen an argument for investing time and effort into KT, including redundancy.

Knowledge transformation is participatory exercise, which here is organized around the knowledge base that the models in framework provide. It can be described as a generic set of steps implementation of which can vary depending on context, e.g. workshop or series of events.

- Establishing its objective and scope
  - Introduction to KT approach and objective
  - Definition of target operation and driver of change (e.g. CI, technology innovation, market change)
  - Introduction to characteristics of the particular driver of change
- Presentations of the existing knowledge base (or populating it)
  - Review of frameworks in the light of KT objectives and validation with all participants to ensure common understanding and shared baseline
  - This includes (a) a generic introduction to the models and (b) in TATEM, the envisaged concept related applications, including demonstrators and mock ups.
- Knowledge exchange in interactive exercises

This includes plenum discussions and small group exercises. Participants engage with the existing knowledge base, further explore key socio-technical dimensions and identify where the system can be leveraged. In interactions with each other, they manipulate the existing knowledge base (e.g. on paper, verbally, virtually) and consolidate a different version.

- Consolidation of transformation

  Here the outcomes of the different activities are consolidated. This is especially relevant if the previous step included work in small groups which allows covering more territory in shorter time.
- Updating the knowledge base (with initial results)

  This can be done on paper or in dedicated software.
- Feedback to participants

  Feedback to participants is critical for the credibility of the process, especially given the sensitive nature of knowledge as a resource. In TATEM reports were produced and a second iteration of workshops was envisaged.
- Setting a further agenda (for further specification, implementation, validation)

  It is envisaged that such workshops form part of an iterative process in refining and evaluating requirements for technology change as well as generating and managing any changes in organizations or inter-organisational partnerships
- Evaluation

3.4.2.3 KSM assessment dimensions

Additional information can be captured to annotate the models' elements and relationships. An assessment methodology was developed and iteratively advanced, even as a web based application, core elements of which were deployed in the research. Reasons for using it as heuristic in this case study included overall usability due to the complexity of dimensions and the general effort in populating it. However, its concepts informed the collection of data when developing the models and also the activities in the KTWS, even if at a higher level.

It guides the review of general changes, aggregating across processes, and shows the impact of a new technology not only on the task logic but also its social enablers. At the time of the study the following modules were considered:

- Within task

  The within task module examines the structure and activity within a task.
- Coordination

  The co-ordination module examines all the activities which link that task to other tasks in the sequence, to parallel tasks, and to the outputs of previous processes
- Operational system

  The operational system module reviews the functional coherence of the processes and tasks that deliver the system's outcomes. It is not restricted to the core operational processes but also evaluates interfaces with direct support processes. Interfaces are a critical element which links to coordination activities.

- Team system

  The Team system module examines the extent to which the participants in the task and co-ordination activities possess the essential characteristics of a team, and how well these team characteristics are supported by the process design and organizational context.

- Competence

  The competence module goes beyond KSA and reviews the understanding of the work and the performance and evaluation dimensions which are driven by the process logic.

- Relationship quality/Trust

  The quality of social relationships has a fundamental conditioning effect on the way in which those relationships are worked out, not only in terms of how people conduct their everyday tasks in the processes, but also in terms of social processes in organisations between different levels and groups in the organization.

3.4.3 Research activities

The research activities were focused on designing and implementing a knowledge transformation capability within the project. Starting with populating the models, subsequent effort was targeted to utilise the knowledge base to envisage the future. Since it was a novel approach, a core part of these activities was communicating concepts and integrating outcomes iteratively into the design activities of other work strands.

3.4.3.1 Foster engagement with the approach

The dedicated tasks of developing said framework for the TATEM project gave the opportunity to hold meetings with all partners, which included technology providers and operators. A year into the project, there were additional meetings with the project manager and technical manager to elaborate on the approach and what the challenges in implementing it in the project were. To engage with partners that were driven by the strong technology agenda as outlined in the work programme, it was critical to facilitate a common understanding of the rationale of the research and what value would be added to the project by realising it, across all parties involved. This internal dissemination process worked both ways. It promoted the KSM framework but at the same time was an opportunity to learn more about the opportunities and constraint of the current design processes as they were represented in the project.

While the effort was spent to develop the KSM framework and its initial content, progress was iteratively shared with the partners in the tasks as well as in other strands in the ground crew support work package. These initially bilateral interactions were later consolidated in the local integration that was dedicated to bringing the ground crew support activities together for an integrated demonstration.

Similarly, the framework was promoted in interactions with the end user organisations. With one MRO a close working relationship was set up that generated most of the ethnographic data reported in section 1 and through this delivered the basis for their commitment to resource the KTWS with a variety of operational personnel. Part of this was presenting it to different management levels and promoting the project events with staff locally engaged in the research.

3.4.3.2 Design and implementation of KTWS

The KTWS brought together key operational stakeholders for validating the different maps; both from a conceptual point of view as well as from a content point of view. In a second step these maps were used as a resource to envisage the transformation of the processes by introducing new technologies. The new technologies and knowledge about them were represented by a second set of participants; project partners who represented the design domain in the aviation lifecycle. They presented on design assumptions, technology capabilities, proposed functionalities and interface mock ups which presented another set of knowledge. Together both groups developed a to-be process that demonstrated the benefits that could be realized in the operation by inserting the new technology. The outcomes were consolidated into a report. Based on this, the participants representing the technology provider adapted proposed functionalities. In addition, the KTWS outcomes informed the ground crew support narrative of its achievements at the final evaluation event of the project.

Initially, an iteration of the KTWS was envisaged to advance the assessment based on the consolidation of the event but this did not happen as the project ran out of resources and time, and thus effort was placed elsewhere.

3.4.3.2.1 KTWS #1

The first workshop was run in collaboration with the project partners in the work strands dealing with mobile maintenance and process orientated information. The overall structure of the workshop and its key activities were as follows:

1. Workshop Objectives & Conduct
2. Project Introduction & Overall Objectives
3. Operational Need and Future Maintenance Concepts
4. Project Solution and Approach
5. Review of process modelling approach
    a. Validation of input maps
6. Demonstration of Portable Support System (PSS)
7. Discussion of technologies and techniques that support demonstration
    a. Process oriented technical data
    b. Use of Multi Media
8. Transformation exercises
    a. Narrative of presented maps
    b. Guided evaluation of potential of change
        i. KSM dimensions
        ii. Transformation mechanisms
    c. Consolidation of resulting requirements
9. Consolidation & Wrap up

The introduction of the TATEM concepts included a review of the health management approach (architecture and technologies) and of the expected impact on the operation in terms of availability and

reliability (as key elements of the operability concept that drives the TATEM project). Ground Crew Support activities have been located in the off board segment where the integration of onboard as well as off-board data delivers new operational capabilities.

The concepts of the TATEM approach were the terms of reference in the discussions and demonstrations. Given that TATEM explored future technologies that are not yet implemented (or only partially in new generation aircraft), in the process review exercise the following assumptions were made explicit as an input:

- Health status of aircraft systems is known
- All relevant information (onboard/off-board) is integrated (MIS) and accessible

The main focus of the workshop was the line maintenance environment since the use case #1: 'Brake unit replacement' is located there. Some discussions dealt with the difference of the current heavy maintenance and line/light maintenance and elicited different potentials for some of the TATEM technologies.

The demonstration of the technology solution developed against the TATEM concepts used the mock ups developed in the project strands. Those included the interface mock up of the Personal Support System (PSS) functionalities as well as multi-media simulations and an overview of the process oriented information structure of maintenance manual information.

The transformation exercises were designed as interactive sessions working on posters of the system models, in the first step validating the content with all participants, ensuring a shared understanding of the reference points and then the review of transformation potential due to the presented concepts and technologies. Questions guiding the creation of a future vision were based on the KSM methodology. Participants (seeTable 12) worked in small groups interactively with the poster material, aided by facilitators (HF experts), and consolidated outcomes in the plenary forum

Table 12: KTWS#1: Workshop participants

System engineering representation (n=7)	**End user representation (n=10)**
Work package 6000 lead (Ground crew support)	Airline Programme Manager
Strand 6300 (Portable support system)	Projects Executive (IT)
Strand 6200 (Process oriented tech. data)	Project Engineer
Task 6140 (Human Factors/KSM)	MCC liaison manager
	Planning/Scheduling representative
	Check Manager
	Team Manager

3.4.3.2.2 KTWS #2

A second KTWS was run, addressing the system transformation potential of new information and decision capabilities that the IVHM concepts promised to deliver in the future. This workshop was run in collaboration with the work strand "Proactive Planning" and while it followed the main principles outlines in the methodology section and implemented in KTWS#1, the workshop did not use process models but a

representation of current information logic of the maintenance planning cycle and its interfaces with flight operations and manufacturers as the main reference point for addressing future changes. In contrast to the workshop #1, no complete set of process maps was available at the time of the workshop. However, the process map at the line operation level was available in the workshop as backdrop for the discussion, as was the base maintenance illustration. The presentations by technology providers were application centered, building on an existing tool, with additional functions sketched out in presentations. This set up allowed for the application of the methodology at a more abstract level.

The overall structure of the workshop and its key activities are as follows:

1. Project Introduction & Overall Objectives
2. Operational Need and Future Maintenance Concepts
3. Project Solution and Approach
4. Key TATEM concepts
5. Presentation on the current planning system
6. Discussion: Today's challenges
7. Presentation on maintenance strategies
8. Presentation on proactive planning and Sapphire tool functionality
9. Exercises: Future vision
10. Wrap up and feedback

A total of 14 participants attended the workshop, including the facilitators. Table 13 gives an overview of participants.

Table 13: KTWS#2: Workshop participants

Project representation (n=7)	**End user representation (n=7)**
Strand 6400 - Proactive Maintenance planning	Airline Programme Manager
Task 6140 (Human Factors/KSM)	Projects Executive (IT)
	Project Engineer
	MCC liaison manager
	Planning representative (total airline support)
	Planning representative (operational planning)
	HR/Organisational learning manager

3.4.4 Results

The main outcome of the knowledge process was the knowledge that it created; initially in populating the models, consolidating available and hidden knowledge into an accessible account, and then in transforming the new knowledge base into a vision of a 'to be' future, enabled by TATEM technology innovation. The two workshops targeted both the maintenance production system and its support, i.e. the planning function, and delivered insights into dependencies that extended beyond organisational boundaries. In addition to this, the interactions with project partners throughout the project and specifically in communicating the approach and promoting the KTWS gave additional insights into the current state of the art of system engineering and the opportunities of barriers to integrate the proposed approach. These will be highlighted in the discussion of this chapter.

3.4.4.1 Knowledge transformation workshop #1

The KTWS brought together operational staff and project partners representing the design sector. In collaborative interactions that were driven by a model based KT approach as outlined in the methodology section, they exchanged their knowledge and created a vision of future operation.

It has been argued before that technology innovation has the capability to transform processes not only locally, but change the wider system interdependencies. Therefore, the system level with which partner engaged were maintenance task level, task sequence level and the operational unit level (all in relations to the defined use case).

The following section will present the KTWS outcomes at a maintenance task level, including process activity, stakeholder relations and dependencies. The results for the other two levels can be found in Appendix 1.

3.4.4.1.1 Process activity diagram

The process activity is organised along critical states. Per critical state, the current (left column) and future (right column) activities in the processes are listed, both technical and coordination activities. The activities are perceived at a generic level, not reflecting e.g. one specific AMM reference.

The description of the transformation (middle column) is presented under two main headings: Quantitative and qualitative.

The quantitative discussion points to opportunities where expert judgments on time savings (and thus of cost) could be applied (or other data sources, e.g. observations in trials)

The key dimensions of qualitative transformations in the process activities addressed include

- REMOVED- obsolete steps in the process (or elements of the step)
- CHANGE - qualitative changes within the activity performed in the step
- SHIFT - shift of activities/responsibility from one process/role to another
- OPPORTUNITY - wider opportunities opened up by the above transformations (e.g. (a) organisation maximizing the benefits of the maintenance production process changes through redesign of other organisational processes or (b) consortium identifying further design challenges/opportunities for future projects)

TATEM concepts are listed in order of relevance to the discussed transformations. Concepts reviewed are health managed scheduling (focus on prognostic aspect), process orientation and mobile maintenance.

3.4.4.1.1.1 Results

The scope of this section of the report is the maintenance task level. The task discussed is the generic removal/installation tasks. The use case #1 describes a sequence of fault isolation including inspection and removal/installation (R/I). Depending on the impact of the TATEM HM approach inspection and troubleshooting activities have the potential to become obsolete or be reduced to verification actions (this

will have impacts on the task unit level). Thus it has been decided to look at the removal/installation tasks at the maintenance task level.

Current	Description of process transformation	Future
State 1: Task allocation achieved		
Trigger from task unit level process	Quantitative[1]	Review PSS task allocation
	New process step which was formerly part of the local task triggering process which included a situation debrief.	
	Qualitative	
	Removed: tbd[2] Change: The PSS concept formalises the triggering process. No or reduced communication between central management function and LME is required if tasks (based on HM scheduling) are transferred to PSS. Shift: Reduced involvement of team manger in triggering process; decisions are made more remote form the operation. (see also task unit process level). LME gains local autonomy through better task definition and information integration. Opportunity: tbd	
	TATEM concepts: HM scheduling, mobile maintenance	
Acceptance of work order	Quantitative	Accept task
	The step is shorter, i.e. it is automated in the PSS functionality (e.g. after log on task list appears and one is selected to start with) and it does not include input from a coordination activity to establish the function of this particular task in the overall aircraft maintenance process	
	Qualitative	

[1] Possible to be made subject to expert judgement or other means such as data collection in the field. Note: applicable across all comments on quantification

[2] Tbd – this reflected the expectation that the KTWS would be iterated before the project end which did not happen

	Removed: tbd Change: Acceptance of the works order was closely linked with an evaluation of the overall process. In the PSS functionality this is replaced by a decision based on HM and the provision of information such as purpose for the task (HM evaluation output) Shift: Aspects of current responsibilities are removed from the local operation. LME experience is less relevant since LME is presented in outcome of process rather than being part of the process itself. Opportunity: Review of the HR strategy, e.g. re-organisation of LME skill sets.	
	TATEM concepts: mobile maintenance; process orientation	
Overview of A/C status	Quantitative	Remote HM task scheduling
	Local coordination between process stakeholders is replaced by remote HM scheduling. Time savings.	
	Qualitative	
	The coordination activity to establish the task in the overall maintenance process for the aircraft is remote, HM enables decision to be taken at an earlier stage, remote of the execution/operation. Removed: Local processing of information and its evaluation in the team is obsolete with the outcome being represented in context. Change: The output displayed on the PSS is a task and all relevant information 'ready to go' for the LME. This is enabled by HM, i.e. earlier detection enables advance planning and preparation; system status knowledge triggers relevant information provision and is adequately supplied into the point of operation. Shift: Aspects of current responsibilities are removed from the local operation. LME judgement (experience) is less relevant since LME is presented with the outcome of the process rather than being part of the process itself. Opportunity: tbd	
	TATEM concepts: HM scheduling, mobile maintenance, process orientation	
State 2: Required input verified		
Documentation	Quantitative	Task structure &

review	The time required for establishing an overview of the task is reduced (due process orientation including better presentation and integrated information access).	effectivity review
	Qualitative	
	Removed: The current effort of accessing sources, collecting information and organise it for the task at hand is reduced due to its PSS presentation. Change: LME spends less time collecting information (from diverse systems (on-board/off-board) as well as from people) Shift: The presentation of information (especially the info that extends the manuals and is particular to aircraft and context) is defined by the PSS info specification. Administrators are responsible for keeping it adequate to the operational requirements and ensure that the required information is available. Opportunity: Demonstrating the benefits of local information integration within a particular area can create a case for extending it further across the organisation and into external sources as well; e.g. customer systems (e.g. A/C history) or airport authorities (e.g. A/C movement).	
	TATEM concepts: Process orientation, mobile maintenance	
Collection of parts, tools and equipment	Quantitative	Collection of parts, tools and equipment
	There is a possibility of a time saving, depending on how the organisational set up is realised that supports the new process.	
	Qualitative	
	Removed: Depending on the design of preparation support the LME involvement in collection is reduced. RFID can further facilitate the activity, matching tools etc with specification in PSS. Change: Integration of availability information reduces the effort of the LME in the collection activities. This is enabled by the improved definition of the task at an earlier state (incl. subsequent resourcing). Shift: tbd – Alternatives are pre-selected centrally. Opportunity: Quantitative changes depend on whether the logistic chain in the organisations is changed, e.g. delivery of pre-drawn Kits to the aircraft. HM offers the possibility of integrated advance planning which can support efficient pre-planned delivery across the fleet	

	maintenance operation rather than delivery on demand (today: short lead time for logistics) This creates a potential business case for investing to save time across the work force (LMEs).	
	TATEM concepts: Process orientation, HM scheduling, mobile maintenance	
Review status of store managed objects	Quantitative	Check resource list with material resources (e.g. RFID)
	Time savings due to information integration and its timely delivery.	
	Qualitative	
	Today in line maintenance events the availability is checked close to real time since there is little previous knowledge (prediction) of possible event occurrences which would trigger a particular task. Depending on the type of tool or part the lead times differ enormously. Once the requirement is established the LME (or supervisor) check the availability of the resource. Removed: Communication with relevant departments, e.g. calls or visits to stores. Change: In the future this will be managed in advance, having the tool or part ready for the time when the task is called up on the PSS. Shift: The remaining requirement is to check if the collected or delivered material resource matched the requirement. RFID technology could further enhance this step (also integrating information on part, serial and FIN numbers around part processing). Opportunity: Improved lead times for initiating maintenance action enable better leasing/acquisition agreements and deals; while at the same time increasing control over leasing own equipment. The process formalises a two stepped of effectivity check (upfront and on collection)	
	TATEM concepts: HM scheduling, mobile maintenance, process orientation	
Discussion of alternative tools and parts	Quantitative	
	This possible step will be removed.	
	Qualitative	

	Removed: This step is obsolete. The decision about alternatives in regard to tooling and parts (e.g. directed 'robberies') are taken in advance. Change: n/a Shift: HM scheduling enables advance planning and gives total resourcing control to the production management or planning cell (depending on timeline that is to be realised), releasing the LME from the decision process. Opportunity: Improved lead times for initiating maintenance action enable better leasing/acquisition agreements and deals; while at the same time increasing control over leasing own equipment.	
	TATEM concepts: HM scheduling	
Negotiation of free equipment	Quantitative	
	This step has the potential to become obsolete.	
	Qualitative	
	Removed: Obsolete activity under condition on organisational set up. Change: Extent of HM scheduling impact on logistics processes drives changes. Shift: Local coordination is replaced by central management of equipment (preferably within production). Opportunity: HM (information on when the failure of a system/component can be expected) enables advance planning of resources. How well this capability is realised depends on what resources are managed in the integrated information space. If resources such as jacks remain freely available and are not store managed there is still a requirement for this step. However, RFID management concepts can be easily extended to these, facilitating local management.	
	TATEM concepts: HM scheduling, process orientation, mobile maintenance	
State 3: Workspace opened & prepared		
Adoption of safety precautions	Quantitative	Adoption of safety precautions
	Time savings only applicable if seen in conjunction with new programme innovations (outside TATEM).	
	Qualitative	

	Removed: n/a Change: Steps such as pulling circuit breakers (CB) is changed in new aircrafts, from manual action to being supported virtually via a mobile device. Manual activities (e.g. safety barriers) remain the same. Shift: n/a Opportunity: Integration of TATEM external concept into the PSS functionalities, such as virtual CBs (A380)	
	TATEM concepts: Mobile maintenance, process orientation	
Access work space	Quantitative	Access work space
	Time savings are not achieved for a single task but across tasks at fleet level (see also task unit level process and overnight level process). HM enables to manage access better or more integrated/synchronised, trying to optimise the number of occasions when systems are accessed. Time savings at task level are possible if orientation for access (e.g. panel location) is better represented (e.g. use of multi-media has been suggested here). At the same time additional time requirements re access may result from introducing new components such as sensors.	
	Qualitative	
	The task remains the same; the sequencing is improved (see also task unit level). Possible changes can be due to additional technology such as sensors. Removed: tbd Change: Better orientation for access tasks (e.g. multi-media for location or complex access). Shift: Increasing the coordinated of tasks with same access requirements gives room for job card engineering in the context of process orientation and may define access as separate task performed by another LME. Opportunity: see 'quantitative'. Job card engineering linked to process orientation.	
	TATEM concepts: HM scheduling, process orientation, mobile maintenance	
Deactivation of	Quantitative	Deactivation of

linked systems	Time savings in new aircraft types.	linked systems
	Qualitative	
	Applicable if seen in conjunction with new programme innovations (outside TATEM). For some systems the process may change due to functionalities imported on the mobile device (e.g. virtual circuit breaker) Removed: tbd – Access to CBs and their physical deactivation. Change: Flagging of system deactivation on the PSS. Shift: tbd Opportunity: Real time A/C configuration control for the central control, e.g. MCC or production centre.	
	TATEM concepts: Mobile maintenance, process orientation	
Discuss safety measure interference	Quantitative	Flag changes on PSS system (e.g. deactivation, safety barriers)
	Time savings due to quality change in this activity.	
	Qualitative	
	Removed: The local coordination aspects of this activity become obsolete. Depending on the improvement in scheduling (e.g. 100% HM tasks in a work pack) system interactions are anticipated and are managed in advance. Change: Depending on the improvement in scheduling (e.g. 100% HM tasks in a work pack) the LME contribution to the coordination activity is reduced to flagging the deactivation on the PSS, rather than at the point or effect (e.g. cockpit note). This results in less interaction and information integration requirements on his part. Shift: Coordination outcomes are delivered to the LME rather than him being part of the previously more local process. Opportunity: tbd	
	TATEM concepts: HM scheduling; mobile device; process orientation	
Discuss possible inferences	Quantitative	(Centralised overview of A/C status) as reference point
	Depending on the degree to which HM scheduling is realised this step becomes obsolete.	
	Qualitative	

	Removed: The local coordination aspects of this step become obsolete. Depending on the improvement in scheduling (e.g. 100% HM tasks in a work pack) system interactions are anticipated and are managed in advance. Change: Task and their constraints such as interferences with other tasks/systems are known and managed, thus no requirements to review or discuss. Shift: Local coordination is replaced by advance decision making. Opportunity: tbd	
	TATEM concepts: HM scheduling, process orientation, mobile maintenance	
Establish status of support	Quantitative	
	Time savings due to activity being obsolete.	
	Qualitative	
	Removed: The better definition of the tasks defines its requirements and enables advance set up of the resources, including support such as trade element, second person for heavy item etc. Change: The coordination of how LME activities add up across the aircraft or the fleet is reduced to calling up the resource required which has been planned for in advance. PSS communication functions can be utilised to alert the other LME (who is scheduled to contribute) Shift: tbd - Improved service to LME. Opportunity: tbd	
	TATEM concepts: HM scheduling, process orientation, mobile maintenance	
State 4 : Part removed and stored		
Installation of R/I tool	Quantitative	Installation of R/I tool
	Neglectable opportunity for quantitative savings since activity remains largely the same.	
	Qualitative	
	Removed: tbd Change: The task is better supported by process orientated information and especially the use of multi media for orientation purposes. Depending on the component that is exchange there may be additional	

	requirements or sub-steps around the new HM technology. Shift: n/a Opportunity: n/a	
	TATEM concepts: Process orientation, mobile maintenance	
Removal of part	Quantitative	Removal of part
	n/a - tbd	
	Qualitative	
	Removed: n/a Change: Depending on the component that is exchange there may be additional requirements or sub-steps around the new HM technology. There is also an additional requirement for reporting the progress (successive tick off of steps) which may increase the time locally but save effort in the improvement of the overall management of tasks progress across the aircraft or the fleet. Shift: n/a Opportunity: Performance management aspects of data collection via PSS (e.g. time per step; interruptions etc) for HR strategy update and continuous improvement.	
	TATEM concepts: Process orientation, mobile maintenance	
Processing of part	Quantitative	Processing of part
	Possibility of time saving (if electronically supported reporting is accepted; further improvements via RFID)	
	Qualitative	
	Removed: The transformation reduces LME effort for information integration (serial no., part no., etc) as well as physically filling out the forms. Change: With improved information of the origin of the task and the resourcing details a mobile device (as part of a MIS) can define the processing requirements and pre-populates information requirements in e.g. U/S tag or other processing reports. Shift: Local effort is reduced and gains aspects of quality control of processing set up.	

	Opportunity: tbd	
	TATEM concepts: Mobile maintenance, process orientation	
Agree work share	Quantitative	Establish work share
	tbd	
	Qualitative	
	Removed: n/a Change: The PSS supports coordinating the task sharing during the process (e.g. brake bleeding example). The work share can be further defined in the process orientation but will due to the fact that LME's work in close proximity keep a personal component. Shift: The pre-definition of work share, e.g. job card engineering elements of process orientation is used to prescribe the work share which is a change from the more mutual agreement in today's situation. Opportunity: tbd	
	TATEM concepts: process orientation, mobile maintenance	
Confirm processing requirements	Quantitative	PSS supported processing coordination (RFID)
	Time savings depend on situation, e.g. type of part, lead time to event (range of time savings)	
	Qualitative	
	Today the confirmation step is frequent because of less task control in advance and changing customer/MCC requirements due to the limited lead time for decisions. Removed: Local information integration and coordination is not required. It can be further advanced with the use of RFID. Change: PSS (linked into MIS) supports the information integration of relevant requirements and information pieces. This constitutes a form of remote coordination. Requirements are updated centrally rather than locally confirmed with managers, airline reps etc, which reduces LME effort in coordination. Shift: Management of customer requirements/organisational reporting is managed centrally as it is envisaged in organisations.	

	Opportunity: tbd	
	TATEM concepts: Mobile maintenance, process orientation	
Manage processing	Quantitative	
	Time savings due to activity being obsolete.	
	Qualitative	
	Managing the processing includes storage of parts, transport of parts to shop, reporting activities etc in which the LME has been involved through communicating the task progress and ensuring the adequate support. Removed: Activity is obsolete. Change: n/a Shift: Elements of local task management are now performed centrally and outputs delivered. Opportunity: Improved logistics control within the organisation.	
	TATEM concepts: HM scheduling	
State 5: Part installation achieved		
Preparation of (new) part	Quantitative	Preparation of (new) part
	n/a – Activity to be largely the same.	
	Qualitative	
	Removed: n/a Change: Depending on the component that is exchanged there may be additional requirements or sub-steps around the new HM technology. For less skilled or experienced LME or difficult tasks the process orientation on the mobile device supports task progress. Shift: n/a Opportunity: Review of the HR strategy, e.g. reorganisation of LME skill sets.	
	TATEM concepts: Process orientation; Mobile maintenance	
Installation of part	Quantitative	Installation of part
	n/a – Activity to be largely the same.	
	Qualitative	

	Removed: n/a Change: Depending on the component that is exchanged there may be additional requirements or sub-steps around the new HM technology. For less skilled or experienced LME or difficult tasks the process orientation on the mobile device supports task progress. Shift: n/a Opportunity: Review of the HR strategy, e.g. reorganisation of LME skill sets.	
	TATEM concepts: Process orientation; Mobile maintenance	
Removal of R/I tool	Quantitative	Removal of R/I tool
	n/a – Activity to be largely the same.	
	Qualitative	
	Removed: n/a Change: Depending on the component that is exchanged there may be additional requirements or sub-steps around the new HM technology. For less skilled or experienced LME or difficult tasks the process orientation on the mobile device supports task progress. Shift: n/a Opportunity: tbd	
	TATEM concepts: Process orientation; Mobile maintenance	
Agree work share	Quantitative	Establish work share
	tbd	
	Qualitative	
	Removed: n/a Change: The PSS supports coordinating the task sharing during the process (e.g. brake bleeding example). The work share can be further defined in the process orientation but due to the fact that LME's work in close proximity will keep a personal component. Shift: The pre-definition of work share, e.g. job card engineering elements of process orientation can be used to prescribe the work share which is a change from the more mutual agreement in today's situation. Opportunity: Review of the HR strategy, e.g. reorganisation of LME skill sets.	

	TATEM concepts: Process orientation, mobile maintenance	
Review status of (new) part	Quantitative	Review status of (new) part
	Time savings are possible across tasks due to reduction of ambiguous situations (e.g. change in customer requirements due to short decision lead time; delivery of wrong part, part robberies/swaps across fleet etc).	
	Qualitative	
	Removed: Integrated information presentation on PSS (extended by RFID) makes review of paper work obsolete and enables display of part information and history on mobile device. Change: Information integration facilitates the review (e.g. list of part number, serial number, effectivity against A/C configuration status) – possible with or without RFID. Due to advance planning and resourcing the occurrences of ambiguous situations will be reduced, facilitating the LME in his task. Shift: tbd Opportunity: Supply chain and logistics improvements. Quality insurance in real time. Improved feedback process to/from OEM (e.g. RFID for retaining complete history of part).	
	TATEM concepts: Process orientation; Mobile maintenance; HM scheduling	
State 6: A/C status rectification verified		
Function testing	Quantitative	Function testing
	n/a – Activity to be largely the same.	
	Qualitative	
	Removed: Documentation navigation in search for data points. Change: PSS provides limits, thresholds, decision points in a easy accessible way and collects feedback from LME of required. This reduces relying on memory or searching for data points in documentation. Function tests are tasks which are highly reliant on following the exact procedure (sequence) which is support by process orientation. Shift: n/a Opportunity: tbd – can function test results be used as input in (offline) prognostics or does this only apply to some inspection results?	

	TATEM concepts: Process orientation, mobile maintenance	
Reactivation of linked systems	Quantitative:	Reactivation of linked systems
	Time savings in new aircraft types.	
	Qualitative	
	Applicable if seen in conjunction with new programme innovations (outside TATEM). For some systems the process may change due to functionalities imported on the mobile device (e.g. virtual circuit breaker) Removed: tbd – Example: Access to CBs and their physical deactivation, including the use of tools (rings/caps) Change: progress monitoring, real time system status across work at A/C (e.g. larger overnight work pack) Shift: tbd Opportunity: Real time A/C configuration control for the central control, e.g. MCC or production centre.	
	TATEM concepts: Process orientation; Mobile maintenance	
Work card signature	Quantitative	Check & sign off pre-populated report
	Time savings due to digital sign off on the spot and digitalisation of progressive sign off (tick off) – to be balanced with new reporting requirements on PSS (e.g. number of ticks).	
	Qualitative	
	Removed: Reduction in typing/writing due to automation of reporting. Change: Pre-populated reports with data form the system (e.g. aircraft registration), activity reports (e.g. ticked off steps) and findings where applicable (e.g. issues encountered observations) reduce the time of signing and reporting. The digital sign off is possible at the aircraft, saving a possible return into the offices and thus facilitates easy reporting in-time for further management (currently there are issues around collating work orders until end of shift). Shift: tbd Opportunity: Improved quality control (QA, planning audit etc) because of standardised pre-population of reports. Time savings allow for collecting other relevant information. Real time feedback facilitates maintenance management.	
	TATEM concepts: Mobile maintenance, process orientation	

Function test scheduling	Quantitative	Function test scheduling
	n/a - tbd	
	Qualitative	
	Function test pose requirements for overall aircraft configuration. Today the emerging requirements in maintenance require coordination within the production process to agree best function test schedule (also equipment or airport constraint, e.g. engine run) and sees the LME involved in raising a work order for outstanding test (if time gap). Removed: n/a Change: The LME is provided with better information on the opportunities for function test. Depending on the utilisation of real time feedback from work on aircraft (if team situation) the function test is called up on mobile device immediately or put on hold. Shift: Integrated information on overall process provided on mobile device reduces active role of LME in scheduling coordination. Executive decision by manager based on available real time information in agreement with LME. Opportunity: tbd	
	TATEM concepts: Process orientation, mobile maintenance	
Discuss possible interferences	Quantitative	Remove flag on PSS
	Depending on the degree to which HM scheduling is realised this step becomes obsolete.	
	Qualitative	
	Removed: The local coordination aspects of this step become obsolete. Depending on the improvement in scheduling (e.g. 100% HM tasks in a work pack) system interactions are anticipated and are managed in advance. Change: Interferences are known, thus no requirements to review or discuss. Shift: Local coordination is replaced by advance decision making. Opportunity: tbd	
	TATEM concepts: HM scheduling, process orientation, mobile maintenance	
Agree reporting	Quantitative	

requirements	Time saving due to activity being obsolete.	
	Qualitative	
	Today different customers provide different documentation and have different reporting requirements (also applicable for airline maintenance department). Also there are different practices between team leader/supervisors what information they look for (especially if involved in signature process). Removed: PSS standardisation makes this activity obsolete. Change: PSS prescribes the reporting requirements (and facilitates the process – *see also other activities above*) Shift: n/a Opportunity: Standardisation of work practices across the organisation and mechanism to monitor it.	
	TATEM concepts: Process orientation, mobile maintenance	

Task sequence level

The task is part of a functional sequence, results on which can be found in Appendix 1.

In summary, at the level of task sequence, a focus will be on the transformation of the coordination activities. Today the crew manager is key to local coordination. In response to the reduced uncertainty delivered by better information (based on IVHM based prognostics and diagnostics) and its integration, an overall reduction in coordination is foreseen, with remaining coordination activities becoming more.

In the process this enables more control, supported by the PSS capability which creates a real time feedback loop that can be integrated in the new information picture. In this context there are also additional requirements defined for the mobile support functions that extend beyond the tasks and support the shift manager and additional requirements for data capture from the operation to be integrated into other systems such as sign off which impacts consequent scheduling. In addition, improvements are expected in the supply of resources.

Many of these process changes will result in a shift of responsibility, from local operation to support processes with direct interfaces such as planning or stores.

Operational level

Sets of task sequence are organised at an operations level, results on which can be found in Appendix 1.

At this level, the transformation capability of the MIS becomes clear. Coordination is shifted upstream, as the overall IVHM benefit is realised in the opportunity of information integration triggered by better status knowledge. This information integration on ground is part of having a MIS which extends connectivity which does not happen as part of on-board solutions.

The activities in the process are transformed by the shift from pulling information from different sources (formal and informal) to it being pushed as part of a new information strategy. This shifts activities and responsibilities.

Reduction in uncertainty reduces tasks, especially coordination, which opens up opportunities to create more activity more upstream, changing interactions with OEM and customer/flight ops differently.

3.4.4.1.2 Stakeholder diagrams

The relationship between the process owner (e.g. LME in the task process) and all other stakeholders at this level (as identified in OPM) are analysed. The key dimensions are the following.

1. Changes in the relationship between functions are classified as
   - REMOVED – A relation between functions that will become obsolete in the future (or aspect of the relationship)
   - CHANGE – Qualitative changes in the relationship between functions (or aspect of the relationship)
2. Changes in the realisation of the relationship can include
   - Timeline of interaction
   - Frequency of interaction
   - Communication channels
   - Deployment of information system (IT)

3.4.4.1.2.1 Results

Figure 11 gives an overview of the change in the relationships between stakeholders.

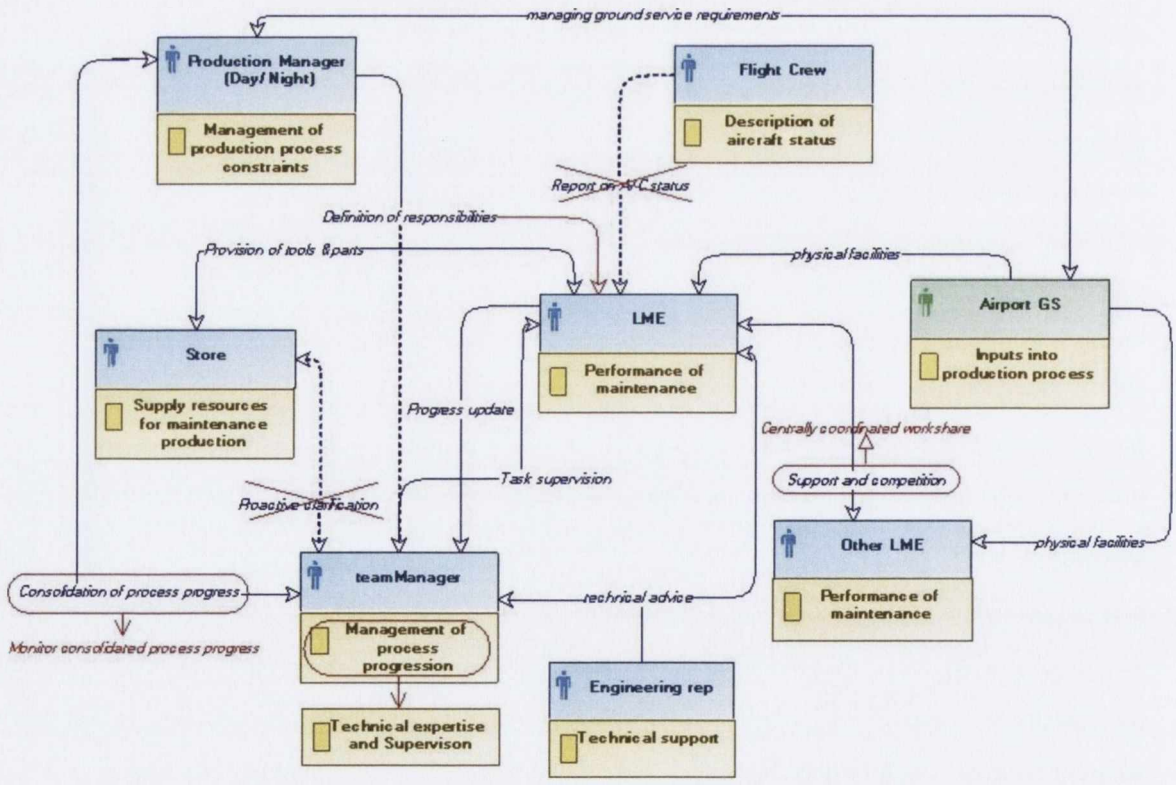


Figure 11: To-be version of stakeholder diagram at maintenance tasks level

The diagram highlights the changes that were envisaged which are to the relationship itself. The details can be found in the table below.

Table 14: Changes in stakeholder relationships

Stakeholders	Element	Transformation	
		Type	Description
A/C crew - LME	Report on A/C status	Removed	Today input from flight crew can give further context to fault, e.g. pattern, previous experience, aircraft behaviour etc. In the future, proactive maintenance addresses the degrading aircraft status before an event occurs and is experienced by flight crew.
Team Manager - Store	Proactive clarification	Removed	Today local coordination is required to adapt to changing requirements, e.g. short lead time for event occurrences, mushrooming of tasks, changes in scheduling priority across fleet etc. This involves constant updating and checking with support functions. In future the HM scheduling introduces increased control over the aircraft status and thus will transfer this effort into a central planning function. On occasion, a technical follow up from the production may remain the only interaction with store (except for collection)
Team Mgr - Production Mgr	Consolidation of process progress	Changed	Today local coordination facilitates a shared view on the process progress as well as anticipation of how it is likely to develop (e.g. mushrooming). Relevant information is largely communicated personally (face to face, telephone, e-mail etc) Functions on the PSS will standardise the feedback loop. Examples: Progressive sign off, indication of system deactivation etc.
LME - LME	Support and competition	Changed	Mutual adjustment is replaced by advance planning of manpower to match upcoming tasks. Each LME is allocated based on his skill and experience set and receives clear instructions (i.e. in advance maximising LMEs experience and skills in work share situation). This is facilitated by task allocation via PSS. As an outcome, the work of LMEs together is more structured; responsibilities are transparent from the start of a task. Today a lot of this is done together with the team leader through mutual adjustment after reviewing the given constraints, e.g. shift plan.

In addition, changes occur in how a remaining relationship can be realised differently in the future. Relationships retain their original functional logic in respect to the maintenance task process but this is better supported and thus can be realised differently, e.g. more efficiently using information tools. The following discussed the relation with other stakeholders from the perspective of the LME, i.e. task executing workforce:

- Team Manager/Supervisor

  Progress update via PSS information feedback; Automatic reporting as task trigger and input for follow on tasks (e.g. from inspection or fault isolation to rectification). Less personal interaction and coordination required (consequences for team leader - see also task unit level). Clear task definition and instruction via process orientation gives more localised autonomy to LME, especially with possible interferences being managed in advance or flagged.

- Production Manager

  Local management includes coordination between team manager and production management in which sometimes the LME becomes included as well, first hand report, experiences, judgment on situation. In future the increased control of the process (HM scheduling and resourcing, PSS reporting etc) reduce the requirement for it and remove LME from contact with production management.

- Stores

  Additional mediation of team manager to ensure resourcing is no longer required. Resources are set up. Interaction is reduced to technical clarification. The mode of accessing resources may change depending on how wider organisation is utilising advance planning information: e.g. delivery instead of collection.

- Flight crew

  - Enhanced diagnostic: Transparency of the fault root causes (possibly already in the event message to the crew). Shared understanding of the problem gives confidence in fixing it.

  - Prognostic – Proactive maintenance before event occurs. Today input from flight crew can give further context to fault, highlighting its additional characteristics such as pattern, previous experience, or aircraft behaviour.

- Other LME

  Mutual adjustment is replaced by advance planning of manpower to match upcoming tasks. Each LME is allocated based on his skill and experience set and receives clear instructions (i.e. in advance maximising LMEs experience and skills in work share situation). This is facilitated by task allocation via PSS. As an outcome, the work of LMEs together is more structured; responsibilities are transparent from the start of a task. Today a lot of this is done together with the team leader through mutual adjustment after reviewing the given constraints, e.g. shift plan.

- Engineering Rep

  If required the contact remains largely the same. However, advance knowledge of details of aircraft status may enable engineering to deliver inputs proactively to LME (e.g. today's query notes (QN) are anticipated and delivered as part of task information via PSS). For support in diagnostics remote assistance could be facilitated via PSS, e.g. automatic calling of QN (e.g. to finalise item that is deferred in the mean time) or direct expert contact.

- Airport authorities

  It remains largely the same. Today it is already usually mediated by production management (as the analysis of other levels showed). In the future outputs may improve, e.g. timing of fuelling in overnight. Contact with ramp personnel, e.g. towing company, fuelling company etc. remains with the LME working at the A/C.

Task sequence level

Relationships at task sequence level are transformed, results on which can be found in Appendix 1.

The technology innovation created the potential to formalise relationships and while not all is supported by IT such as MIS and PSS the interactions are reorganised around clearer in goals and shared responsibilities.

Operational level

Relationships at operational level are transformed, results on which can be found in Appendix 1.

The transformation of the information space increases the control over the process and thus the capacity for planning. This opens up opportunities for engaging differently, not only with internal stakeholders but also with OEM and customers.

The reduction in uncertainty allows for more effective coordination that transforms relationships. Instead of iteratively updating and negotiating departmental priorities the basis of relationships is transformed: away from fire-fighting based on local logic of departments towards shared goals, which are transparently met.

3.4.4.1.3 Impact on dependencies

Underlying the successful progression of the process is the adequate delivering of dependencies that are defined by the socio-technical characteristics of the system. Technology innovation has the potential to transform these dependencies, either the dependency itself by changing how technology is operated or by enabling a better capability of delivering it.

Thus, it is critical to review the potential of TATEM concepts and their supporting technologies to impact on the dependencies that are defined by the process logic. The dependencies are listed against their related process states. TATEM concepts which support each dependency are identified and their impact assessed to be either direct or indirect (see Table 15 for overview of results)

Table 15: Impact on dependencies at maintenance task level

State	Dependency	Impact			Main contributing TATEM concepts
		Direct	In-direct	n/a	
State 1: Task allocation achieved	Clear task trigger/work order	x			HM scheduling calls up tasks based on complete picture of aircraft system status and supports the allocation by information that is process orientated
	Status of parallel processes	x			Process orientation in combination with mobile maintenance allows for cross referencing of parallel tasks and signal possible conflicts.
	Adequate qualification		x		HM scheduling defines tasks in advance and this allows for supply of people with adequate characteristics
	Actor's experience		x		HM scheduling defines tasks in advance and this allows for supply of people with adequate characteristics
	Team definition	x			In combination HM scheduling (defining tasks), process orientation and mobile maintenance facilitate selection, deployments and monitoring of team
	Relevance of task in process	x			HM scheduling defines all tasks in their functions in the process while process orientation allows for preview of the implementation
	Task context information	x			Process orientation allows for integrating information along the process that is performed, e.g. different manuals
	Shared task view		x		Process orientation and mobile maintenance provide information on status and progress.
State 2: Required input verified	Unconflicting schedule	x			HM scheduling expands timelines and reduced uncertainty, which gives more control in designing and implementing a work pack.
	Resource schedule		x		HM scheduling expands timelines and reduced uncertainty, which gives more control over resourcing a work pack.
	Documentation access	x			At a task level, process orientation facilitates information integration, not only from manuals but also aircraft data such as status (e.g. value of parameters) or and mobile maintenance captures and delivers up to date information
	Equipment status	x	x		A combination of process orientation, mobile maintenance (HM scheduling) capability will improve availability.
	Team definition		x		HM scheduling allows for better

					resource planning, including allocation of staff.
	Understanding of alternatives		x		The process orientation allows for integrating information from documentation, open up the possibility of integrating actual status of resources or task plans.
	Open communication		x		In combination, process orientation, mobile maintenance, and HM scheduling improve
	Negotiation skills			x	
	Information adequacy	x			The process orientation allows for integrating information from documentation, open up the possibility of integrating actual data as appropriate, such as value readings.
	Adequate information channel/devices	x			Process orientation and mobile maintenance deliver this.
State 3: Workspace opened & prepared	Delivery of pre-tasks		x		HM scheduling improves planning capability and process orientation and mobile maintenance the timing of the implementation
	Availability of support	x	x		HM scheduling allows better control of plans (delivered by process orientation and mobile maintenance)
	Availability of material resources	x	x		HM scheduling allows better control of plans (delivered by process orientation and mobile maintenance)
	Control of task interferences	x	x		Process orientation in combination with mobile maintenance allows for cross referencing of parallel tasks and signal possible conflicts. HM scheduling reduces likelihood.
	Understanding of system interferences			x	
	Shared understanding of process requirements	x			Process orientation in combination with mobile maintenance allows for cross referencing of parallel tasks and signal possible conflicts.
	Team work	x	x		Transparency of process orientation and connectivity in mobile maintenance support team work.
	System status information (real time)	x			A combination of process orientation and mobile maintenance delivers real time activity related information.
State 4 : Part removed and stored	Availability of equipment	x	x		HM scheduling allows better control of plans (delivered and monitored by process orientation and mobile maintenance)
	Access to technical	x			Mobile maintenance gives remote

	support				access.
	Overview of (sub)-task structure	x			Process orientation facilitates outcome-directed navigation.
	Work share agreement		x		Process orientation defined requirements while mobile maintenance supports connectivity and communication.
	Experience with system		x		HM scheduling allows information integration in advance.
	System information	x			In combination process orientation and mobile maintenance improve access and quality.
State 5: Part installation achieved	Processing requirements	x			process orientation, mobile maintenance
State 6: A/C status rectification verified	Access to reporting system	x			Process orientation inserts reporting where required while mobile maintenance gives access at point of execution.
	Return to initial A/C status		x		Process orientation identifies closing tasks such as tests and checks based on actions performed before.
	Understanding of key points in procedure for reporting	x			Process orientation defines requirements and offers potential for pre-population.
	Knowledge of other tasks' requirements (follow on/linked)		x		Process orientation in combination with mobile maintenance allows for cross referencing of related tasks.
	Agreement of task outcome	x			A combination of process orientation and HM scheduling defines outcome at all levels.
	Functional check results		x		Process orientation defines requirements and offers potential for pre-population.
	Work card sign off procedure	x			Process orientation defines requirements while mobile maintenance gives access at point of execution.

Task sequence level

Dependencies at task sequence level are transformed, results on which can be found in Appendix 1. At the task sequence levels dependencies are addressed more directly as they are often information based. As information resources and their management change, their delivery is improved.

In addition this level is an intermediate link between execution and the wider system processes. Operational constraints are mediated by the extended information capability provided by the MIS and PSS.

Operational level

Dependencies at task sequence level are transformed, results on which can be found in Appendix 1. Similar to the task sequence level, dependencies are addressed more directly. At the operational level the new interconnectivity that the MIS enables links people in more effective coordination. The quality of new information and the associated functions such as decision support directly impact I the delivery of dependencies.

3.4.4.1.4 Summary of transformation implication at task level

In the interactive sessions participants were guided by the facilitators to address core dimensions of the KSM approach and consider implications for dimensions that are not immediately obvious to a technical person. Questions were put up together with the models and introduced into the interactions around: team composition, competence, relationship, information system and wider repercussions on the operational system and beyond.

- Information integration

  The TATEM HM approach improves the understanding of the aircraft status and thus increases the control over the maintenance production requirements. The main mechanisms to deliver the benefits into the maintenance operation (and also to other stakeholders) are (a) data management following the OSA CBM standard (from data generation to information presentation) and (b) the integration of information across onboard and off-board information systems (MIS). The benefits of the information integration are realised at each process level. Process orientation and mobile maintenance are concepts that further facilitate the improvement above and deliver the improved formation into the processes. However, both concepts also constitute an improvement in an operation without HM capabilities (current situation).

  At the level of the maintenance task execution the main benefits are

  - Increased transparency of current status (e.g. of process (via PSS functions), of aircraft (via HM functions) etc) through real time information management
  - Clear definition of task and its role in overall context
  - Standardisation of information in information flows in and out of the task
  - Less effort spent on information access, search and integration by LME
  - Support of workflow in the task execution by adequate information (flow representation as well as adequate inputs/outputs of additional technical information)

  One concern is the accessibility of background information to review outcomes of information integration presented to the LME. In many cases the outcome is sufficient to deliver the performance, but in cases of exceptions and deviations access to more background information may be useful.

Example: Reduction of numbers of possible fault massages to the most likely one (based on HM conclusion) is useful for process progress. In cases where the LME feels triggered to review background information to recommendation he can access further information.

Furthermore, the information integration can only be as good as the information in and out of the different systems, (e.g. when will aircraft deliver information, LME reporting behaviour versus automated information collection (e.g. log on/log off times) etc). This depends partly on how the customer organisations integrate the TATEM solutions in their wider systems.

- Operational system

  Main process changes have been describes along the dimensions outlined above (removed, change, shift, and opportunity).

  The introduction of HM gives the opportunity for a formalisation of processes that can be traced into the operation and monitored in daily practices. The reduction of local management due to increased control over the aircraft status and thus its current and more importantly emerging maintenance requirements enables a standardisation of inputs and outputs. This overcomes the current situation where formal systems do not necessarily reflect the daily practices which are driven by a requirement for flexibility within an operation characterised by constantly changing/updated requirements.

  Today, local coordination activities add essential value to the current process because of the constraints of the existing operational system such as changing requirements or short lead times for decisions. In the future, this effort is reduced or shifted to a central function and will be remote from the local management due to increased control delivered by HM information. For the LME, this development cuts out his (peripheral) involvement in local management as well as his reliance on outcomes of the local management effort. Thus is reduces a current workload which in the first place is not in the LME job description (or supported by training).

  Along the maintenance tasks process, the formalisation of interfaces is enhanced by defining standardised inputs re information, also re other resources that can be accordingly delivered into the execution. This supports the LME in managing the task and his expectations for support and inputs from upstream support processes (e.g. stores, planning etc).

  Clearer performance indicators can be derived since the formal process is closer to the activities as they happen. Formalisation of interfaces also includes the identification of responsibilities, aspects of which are currently distributed or cascaded down, e.g. supply chain management: from a central planning effort to a local management to deal with changes.

  Interfaces are supported by ground crew support technologies that represent not only HM outcomes but also integrate the off-board information such as availability of resources as well as better documentation structure.

  Overall the transformation promises to reduce ambiguity which is part of the current system at different levels.

The described transformations in the operational system are facilitated by the opportunities of the new HM information approach. Important for the benefits to be realised is the lead time for information and its accuracy (e.g. confidence intervals in degradation model).

One concern: The HM approach provides the opportunity to transform the operational system. These potentials can only be maximised if adequately backed up in the organisation by wider process and system changes. An example is the opportunity for redesign of the supply chain around the new parameters introduced by the HM solutions (increased lead time; root cause knowledge etc).

- Competence

  The information integration and subsequent change in the operational system have an impact on the human/social dimensions of the system such as competence, team and trust (in organisational relations).

  The LME is currently involved in coordination activities that are a response to the ambiguity in the operational system (in form of e.g. task mushrooming, changing scheduling priorities in response to events). Today this involves personal communication and negotiation (around e.g. access to equipment) that extend the technical skills that the person has been mainly trained in. (This is even more relevant for team leader/supervisor as evidenced at task unit level).

  The transformations of the operational system enable

  - a clearer job description for the LME that matches how processes are operated
    Example: The LME's current role in local management is replaced by alternative process design which is translated into PSS functions such as progress reporting.

    Today, the LME reacts to the changing requirements and takes on responsibility locally which is not part of his job. For example, the production manager is tracking resources, supported by the team leader. If there is an interruption or 'mis'-delivery in the supply chain for his task the LME becomes involved in an attempt to manage his task on hand. (even more relevant in heavy maintenance checks)

  - clearer task description, i.e. the anticipation and advance management of today's 'mushrooming'
    The better definition of tasks gives the LME more autonomy within his tasks, but less involvement in overall process management. Thus, process context understanding needs to be facilitated in another way, e.g. PSS information of task trigger; training on process logic etc. The advantage is that it establishes a more standardised shared understanding of the task and overall process which today is sometimes coloured by the particular people the LME happens to work with and their preferences and ways of dealing with ambiguous situations.

    It allows for improved task understanding in advance (HM – definition of task) and throughout the task (PSS).

- the application of process orientated technical data in the framework of job card engineering (customising work flow and also tailor tasks across team of LMEs)

The new system will affect the KSA (knowledge skills abilities) required today: the technical ones will largely remain the same (new elements may be introduced in dealing with HM technologies), the social will be less frequently relevant due to reduction in coordination and more centralised team management and the organisational ones are incorporated into the design of information technologies in more transparent processes.

The envisaged transformations in the operational system drive the competence requirements for the development of the workforce overall (HR strategy) and also for each task (performance management).

At the same time it gives the opportunity to define clearer performance requirements. The formal process is closer to daily operations with information channels clearly established to facilitate as well as monitor its progress. Examples for improvement in potential performance indicators are that execution times are less varied due to reduction in current blockers and better technical data access or improved task sequence management due to real time task progress feedback (defined task trigger plus information).

The increased control of maintenance requirements due to HM technology results in fewer changes in operational requirements. This in turn reduces the ambiguity that today results in the LME asking for iterative clarification, task interruptions, misunderstanding within tasks or across process etc, which today may result in undesired outcomes ("errors"). It creates a situation in which the LME is facilitated to act more competently in regard to the outcomes and also by adopting a transparent and widely agreed workflow in his task.

Today LMEs sometimes experience a lack of common understanding of what is the right thing to do because of the reduced control of how situations are developing (within and between tasks). Acceptable outcomes are defined I the situation in the light of the emerging constraints. With the better control of the overall process the LME will find its outcomes better defined and thus experience learning in a framework that provides a transparent reference point.

Better task definition and support decrease requirements for LME skills. Difficult/unfamiliar tasks and exceptions are addressed by embedded training and remote expert support.

- Team

In the future the role of teams and their structure will change. Today the perceived teams are located in the operation. With the envisaged transformations in the operation such as more focus on the advance control or maintenance requirements resulting in central decision making and resourcing, the potentially remote functions are directly linked to the outputs into the operation, e.g. task trigger for LME. Less local management shifts the emphasis from the people working together on the flow as a team to a wider notion of a team directly contributing to the overall outcome (e.g. delivery of A/C into the operation on time in the morning).

Formalisation of interfaces helps the definition of roles and mutual expectations for standard situations; the number of which is increased in the future due to better control. The problem solving capability of a team will be reserved for exceptions and difficult cases rather than being applied to daily fire-fighting (as experienced frequently today). With today's frequently changing or emerging requirements ambiguity is further increased because people in poorly defined teams have access to different information or different understandings of its meaning in a process.

Today there is a local team managing the changing requirements of the operation, and a more remote team providing inputs based on the current planning capability. In the future, the requirement of coordination is reduced while at the same time its quality is improved due to improved information and its integration, delivering a transparent basis for coordination requirements. The LME needs to get less involved because the information is consistent over time, less ambiguity along the process of what to expect (in terms or task, mushrooming, resourcing etc) within the task and from others and thus gains relative autonomy in a defined task (while having less decision involvement, changing his overall role in the process).

Transparency of the processes and its status facilitates a shared understanding which improves the work within a team. This is important because in more remote teams there is less personal contact that can support the creation of trust, so the processes need to be transparent and reliable to mitigate the impact of this change (Example: central decision making outcome is displayed on PSS to LME – including reason, instructions and resourcing status). The current perception 'we against them' (work floor/ramp staff vs. upstream processes) is managed by making processes and their information flow transparent. Being not involved in process requires transparency (e.g. where does own task sit within overall A/C process – people need purpose and overview – important to relate to quality to end product – sense of shared achievement).

- Trust/Social relations

  The transformations that are enabled through the introduction of HM address dimensions that contribute to an atmosphere of mistrust in organisational relations.

  - Formal versus normal

    Example: opportunity for congruence of daily practices and formal process via increased control and subsequent process transparency
  - Incompatible goals

    Example: Clear responsibilities within process framework; defined performance outcomes for each team member across system levels
  - Performance requirement

    Example: defined performance outcomes for each team member across system levels
  - No open communication
  - Example: Information integration; transparency of sources and use; tailored information for LME tasks, less involvement in wider issues with incomplete information
  - History of mistrust

Example: Criticality of implementation; positive experiences with HM technology benefits and how they are utilised to improve LME situation (compare introduction of engine HM)

At the same time the introduction of new technologies needs to address how it can contribute to the proactive creation of trust:

- Belief in future

  Examples: Transparency of LME contribution to overall outcome; Visibility that technology introduction is channeling improvements across the organisation;
- Genuine support

  Examples: Reliable delivery of inputs in LME processes through central control of maintenance requirements;
- Personal relationships

  Examples: Not everything needs to be done via indirect, automated information exchange (e.g. data links between system rather than people coordinating). Also personal means of communication can be used to control efficiency of processes and be monitored within the process context, e.g. call log book if communication function was to be included in the future on the mobile device.

These effects can be envisaged but are more difficult to trace and depend on the overall organisational management of introducing changes. This also relates to wider issues such as the coherence of business models, adequate key performance indicators for quality, safety and efficiency across all system levels.

3.4.4.1.5 General results

In addition to the detailed results that present a 'to be' version of the operation, there were more general observations within the project context.

Coordination activities were not part of the process modeling approach that was adopted in the Cost Benefit Analysis that the project performed based on the use cases. However, our approach showed that it is actually in this area that many improvements can be expected, thus saving time and money. As discussed earlier, these include many patterns of informal practices that are not represented well in the formal accounts that fed the CBA in TATEM.

Although focusing on line maintenance the operational staff continued to draw parallels to where they could see benefits for the BM. An example is the use of NRC that was reported in the build up to the KTWS in base maintenance. NRC are work cards that are raised if additional work has been identified during the course of work. Similar to routine task cards they are used to assign a task and also form the basis of scheduling, tracking and signing for the work performed. Patterns of informal practices were reported that demonstrated the use of NRC to deliver functions required but not well supported in the operational system:

- NRC for tracking purposes; otherwise a routine card would be open until the end of a check and then 6 of those (comprising 10 tasks each) could result in the supervisor checking 60 tasks at the

end of the check; in those cases the customer gets the impression that nothing has been finished which reflects badly on the organisation.

- NRC as reminder that things have to be finished, clearly visible on the rack
- NRC as work around for ordering parts when support functions such as planning have not delivered as expected. In cases where support should have delivered in advance, the routine work card has no capability to order.
- NRC increases importance of task, in cases where it might only be a line on the routine card or only implicitly mentioned. This practice accommodates different levels expertise in the workforce.
- NRC are produced on the floor and benefit from the way of writing them: they are clear and upfront.

The role of information management in general was repeatedly raised during the KTWS. Many benefits that were envisaged were lined to a ground capability that can process, integrate and push the right information to the right person at the right time. This however was not seen as being limited to the maintenance execution but more importantly was regarded as beneficial for setting up maintenance production processes and proactively managing their inherent uncertainty (see also KTWS 2). This highlighted the importance of the system dependencies that a local process has. Realizing the benefits of new information capabilities based on IVHM in maintenance production requires understanding the influence of upstream processes and based on that deliver an MIS that supports all organisational processes in an integrated manner. This was introduced in TATEM during the project, but only as a set of assumptions which were used in the KTWS.

As part of the set up and running of the workshop, the relationships between design representatives and operational participants were transformed. It started with traditional presentations but in the interactive sessions they had plenty of opportunity to interact. The discussions were based on the maps and the facilitators ensured that assumptions and requirements were grounded there. This allowed for an unbiased conversation that fostered common understanding quite rapidly. The constructive collaboration allowed to get through all process levels and deliver an integrated picture of what changes could occur. In these interactive sessions and discussions assumptions were validated and new requirements derived.

In one case, a bilateral relationship was established at the workshop that extended its duration and delivered further collaborative work in a localized aspect of WP6. However, overall it was too late in the project to sustain the new relationships effectively. A second iteration of the KTWS as originally envisaged did not take place as the project was gearing up for final demonstrating. However, some inputs were used to create the overall operational narrative for the final project review.

3.4.4.2 Knowledge transformation workshop #2

KTWS #2 generated results that both reviewed the current situation as well as envisaged future improvements. The focus was put on establishing the information logic as an input, rather than the process. This was deemed the appropriate level because of its criticality to all stages of maintenance planning (from long-term upstream functions to local adjustments) as well as it representing a logic that is

realized in various sets of processes (modeling of all of which was not in the scope of the research, and a targeted effort not possible because of the relatively immature definition of focus in the work strand on proactive planning).

After giving the overall TATEM context and position the objectives of the workshop within it, the presentation of the current information logic (internal to the organisation) for setting up maintenance work was discussed. A core outcome was an overview of the challenges in the current system which was anchored in the logic as presented in the map but went beyond organisational boundaries. It identified core process functions that

The following key dimensions were identified as being critical for understanding possible benefits of new information and decision support capabilities in the operation and beyond

- Quality of the information: including accuracy of the diagnosis or prognostic in HM system and confidence in it as well as improvements in associated information
- Timeline of availability: Timing of information inputs in an iterative planning cycle (from long-term to short term) define impact potential
- Information Integration: Based on above (quality and timing) integration can be advanced, extended by ground system capabilities

3.4.4.2.1 Current challenges

The review of the current challenges identified a set of issues. The following table gives an overview which organizes the outcomes of the discussion around main concepts in the framework: process, dependencies, coordination, and stakeholder relationships. It adds consideration on business models as this emerged to be a relevant system level when discussion information systems. These are complemented with a preview of possible impacts by TATEM IVHM capability and associated innovations.

Table 16: Overview of current challenges and potential TATEM benefit

Processes contributing to	Information related dependencies (incl. current issues)	Main Stakeholder relationship	Main Coordination	Escalation to business level	Possible TATEM IVHM concept impact on maintenance planning cycle
Acquire a/c operational & health data	Timing of data acquisition – Health data often only at A/C Difficulties to get access to data at outstations	Data transfer interface between Airline/MRO not optimal, e.g. different systems, data amount	OCC/MCC or airline/MRO coordination is managed by human actors The effectiveness of data sharing is constraint by extent of mutual understanding of respective processes	Investment at strategic level: Data transfer and integration is cost intensive if on an airline to airline basis: Cost of data transfer and A/C equipment for it	Timeline: earlier availability due to improved diagnostics and prognostic capability Information integration: MIS offers ground connectivity that reorganizes business relationships
Analysis of MPD for planning period	Lack of common and adequate data format in MPD Mixed counting of component life increases planning complexity No support for risk assessment of inspection tasks re 'mushrooming potential' Ambiguity on "New tasks" being existing ones which shift in classification	Information exchange between manufacturer and MRO is flawed – little support, mostly dependent on airline support [NOTE: Airline and OEM relationship is largely based on contracts]	Limited opportunity for coordination, worse for MRO	Lack of integration between industry stakeholders – manufacturer prioritises airline as customer that requires support	Information integration: WP6200 Process based information will benefit not only execution but also planning MIS offers new connectivity between stakeholders
Determination of a/c configuration	Requirement for both short term and long term view on fleet Requirements for through life record keeping Currency of A/C status	Customer/operations departments as information mediator between different mx providers/outstations IT systems interfaces	Coordination that is based on local knowledge and informal communication mediates information challenges	Outsourced maintenance (e.g. low cost) or different mx provider in A/C life result in disperse set of information Leasing of aircrafts impacts	Information integration: on-board/offboard information integration capability in MIS and new aircraft system information capabilities can allow for

	documentation, e.g. SB execution Cost of data	(function overlap; data mgt)		traceability and visibility of mx data	access to full configuration history, e.g. update every MIS promises to centralise
Determination of a/c and fleet condition view	Aircraft history data is incomplete or not available e.g. status of modification is not updated Accessibility- distribution of mx data across diff stakeholder Inadequate identification of shelf life time of materials for MODs and repairs, e.g. composite repairs limited integration of fleet condition and planning (more in short term scheduling)	Customer/operations departments as information mediator for access to aircraft history: OEM, operational department/customers and maintenance provider	Coordination is based on contracts: Airline and MRO have competitive relationship each aiming to achieving best deal	Outsourced maintenance (e.g. low cost) or different mx provider in A/C life result in disperse set of information Leasing of aircrafts impacts traceability and visibility of mx data	Information integration: Advancing on board information management could be extended to storing aspects of A/C history to determine condition & history Information quality: Revision of Mean time between failures (MTBF) for units Quality information & Timing: Always up to date Fleet condition plus prognostics on some system allows more accurate planning being performed
Determination of consequences for operations & maintenance	Little support for evaluation of task context & interdependencies Lack of integration in data from different manufacturer manuals	Transparent exchange of requirements between maintenance and operation and OEM	Lack of decision support tools is mediated by intensive coordination and information update as processes progress Quality depends on respective process understanding	Outsourced mx defines a stronger requirement for formal exchange process	Information integration: OSA CBM as platform to define common standards for aircraft data WP6200 Process based information will benefit not only execution but also planning
Packaging of maintenance tasks	Data flow from A/C to ground into task management is not seamless (when existent)	Manufacturer to operator to MRO – loss of information from design phase to technical	Pooling of hard times would reduce individual task review Different recipients of	Different maintenance strategies require different planning Different business models	Information integration: MIS to integrate aircraft status data with relevant ground information

	Critical information on task card is hidden in various documentation Lack of synchronisation of information across different sources Lack of realistic man-hours in MPD based on inadequate overview of associated tasks & requirements Inadequate integration of skill and experience information	publication	information (e.g. airline as mediator between MRO and manufacturer)	put different requirements on planning (e.g. full or part support; electronic or paper data sharing) In delivering increased operational time by extending intervals the manufacturer increases the risk of complex findings (=> AOG, i.e an aircraft being grounded and taken out of the operation)	system, incl integration of manual information attached to task card Quality of information: better diagnostics and prognostic capabilities facilitates better, operationally sustainable planning further upstream All: smaller, better supported work packs – beyond equalised maintenance
Resource planning for a/c	Managing additional resource requirements that emerge along the timeline, into maintenance production	OEM, and maintainer, (depending on business model mediated by customer) implement contracts in scheduling of support (e.g. hangar, resources)	Complex, multi-dimensional optimisation and ever changing situation	Complex supply chains in aviation lifecycle vary in response to business model (airline maintainer, outsourced to MRO, outstation etc)	Quality of information/accuracy & timing: Improvement possible on managing the availability of parts; advance ordering instead of NRC after Pick up or event Information integration: defined tasks matched to integrated manuals allows access to resource information in required detail
Generation of job cards/Job card engineering	Lack of synchronisation and linking up of electronic data sources Room of improvement in linking planning into	OEM and maintenance provider (mediated by airline customer) relationships is largely defined by contracts and	Integration of customer, planning and mx production expectations Various interactions to access sources for lessons		Information integration: MIS could support integration of AMM, IPC etc information in task card production in response to

	automatisation of task presentation and inform capture (see 6300 - PSS) Information integration lacking: problem of task centric approach, not adequately representing information on interactions	legislation	learnt when dealing with documentation shortfalls		diagnostic or prognostic based maintenance requirement

Overall the results show that new IVHM base information technology capabilities have the potential to transform not only processes, but also relationships by new establishing increased connectivity within the industry. Many of the challenges can only be productively met collaboration and require a more systemic view on decision support.

3.4.4.2.2 Information perspective

The discussions of the broader challenging in setting up maintenance work was anchored in the intra-organisational logic of the maintenance planning cycle, but extended beyond the internal processes which highlighted the potential of TATEM solutions to improve the collaboration with external roles that are stakeholders (see also upper left corner of Figure 12). However, there were changes that can be located in the internal maintenance planning cycle, based on the IVHM capability and supporting concepts, such as ground crew support.

They follow the three dimensions of quality, timing, and integration.

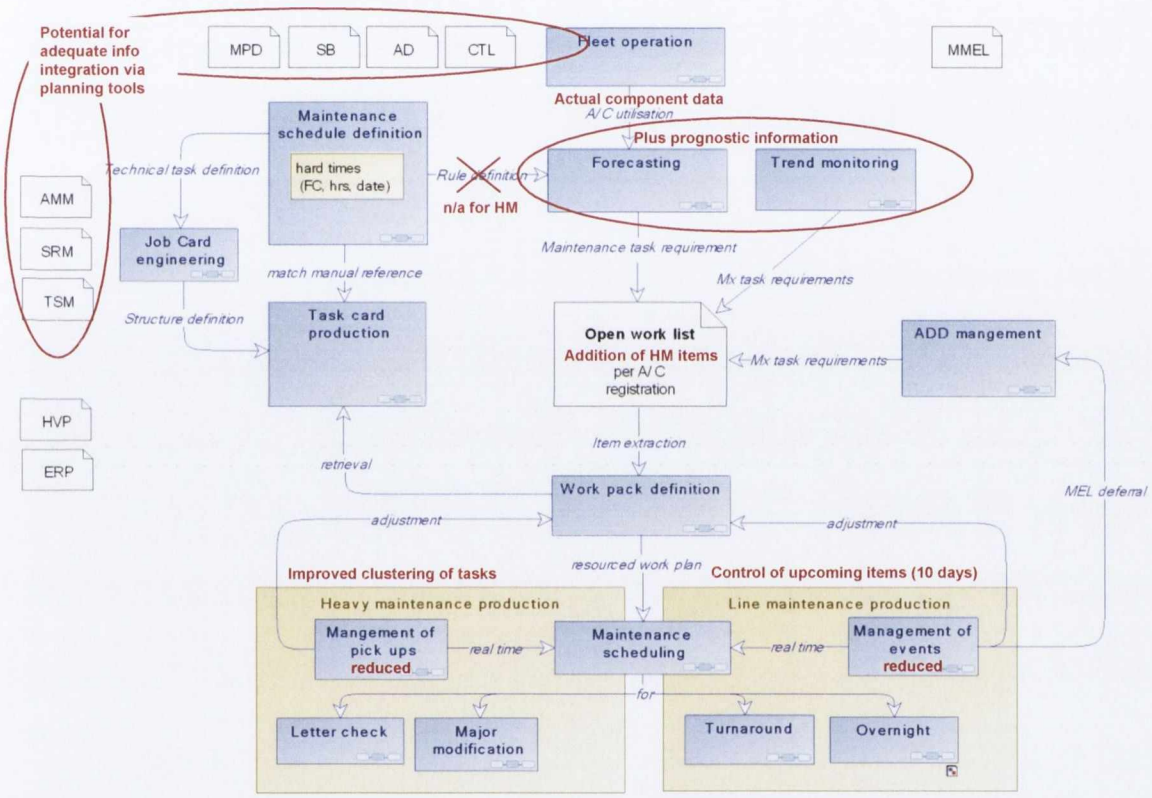


Figure 12: Information perspective: Maintenance planning cycle – to-be

Overall health management enables better control over maintenance occurrences. Maintenance tasks are predicted and as a result can be delivered in smaller units in a known timeframe. Through new information and its adequate integration a situation can be achieved in which current ambiguity in the maintenance system is reduced. Besides positive impacts on efficiency and costs this also promises to improve safety and human factors issues.

The envisaged changes in planning require more support for the macro and micro management, including new decision support tools at different points in the process (timeline). This defines the scope of the 6400 proactive planning activities in TATEM Ground Crew support activities.

The realisation of the expected operational benefits of HM depends on (at least) three critical dimensions

1. Quality of the information

   Engine trend monitoring has proven successful despite initial doubts in the operational world. A similar development of trust in the technology is envisaged in regard to health managed items. The better the accuracy is, the better it will be perceived and used in the maintenance system. There has been no quantitative suggestion in regard to the required accuracy, but more qualitatively it has to improve the rules of thumbs currently used n the processes (e.g. pulling forward of items in an upcoming check based on experience). Actual component status data is complemented by prognostic data, which replaces rule base decisions for HM managed components.

2. Transformation of upstream processes based on new timeline on which the information is available as an input into the planning cycle

   For line maintenance the optimal timeline for providing information on degrading components is 10 days. This allows enough time to get stakeholders involved in the decision process, effectively manage the resourcing and supply chain (e.g. part delivery) and integrate the upcoming task with other maintenance requirements. In many airlines scheduled inputs are managed along a similar timeline (14/15 days), while projections of work packs are done for only up to 3 days in advance. Today, the final plan for a Turnaround (TA) or overnight is developed during the day, managing emerging unscheduled events and operational constraints. The new capabilities are reduce uncertainty and introduce more control over planning and scheduling, allowing for better alignment with operational parameters, and as a consequence, alleviating operations of some of the reactive management required to keep the current system functioning.

   In heavy maintenance the timeline is different. A high level maintenance plan is developed for the year (MRO – hangar utilisation; airline – Fleet utilisation). The planning for a check is reviewed up to 3 months in advance, defining the downtime planned. This is then followed by a process of identifying check highlights, producing the work pack and sourcing the inputs such as parts. The integration of HM information can be relevant at each point, e.g. influencing the downtime requirement, constitute a major check highlight (e.g. requirements for power off) and finally when work pack is produced to ensure the relevant information and other resources are available for the HM item. In addition, the burden of a check will be reduced by having status information that required less checking of the aircraft system status which is a core task in today's maintenance.

3. Integration of information across processes and existing (IT) systems

   It is critical that the algorithms in any decision support application reflect valid operational assumptions. Information has to be integrated to reflect the dependencies that exist with the wider system, rather than being restricted to a local process logic.

   In a next step, their success in making difference in the operation then relies in the adequate data input. The data is currently spread across different owners and systems. Examples are the

information flow between airline and MRO (e.g. latest modification status; documentation; manufacturer input) or operations and maintenance department in a airline (e.g. in-flight events; operational changes such as re-routing etc); the presentation of data from the manufacturer and OEM (e.g. requirements for standardisation and synchronisation); and coordination of the supply chain (e.g. service level agreements between organisation/outstations/suppliers/customer etc)

3.4.4.2.3 Mediating systemic issues

New trends in the industry and emerging business models mediate the current planning process, and in future the maximisation of HM benefits.

Table 17: Overview of mediating issues in IVHM based vision

	Summary
Airport congestion	Congestion in the ground is becoming an increasing problem with negative impacts on punctuality and utilization (and thus maintenance opportunities and scheduling). Reasons for it are night traffic using stands, resulting in aircrafts being moved twice (from and to the stand); increased volume of flights, especially in the morning hours to deliver to business travellers. If an aircraft misses a slot this has not only a negative effect on that aircraft but also potentially impacts on the other aircrafts departing at that airport.
Age of the fleet	The early years of the aircraft lend themselves to concept such as equalised maintenance or reduced inspection requirements. After 5-7 years the aircraft will require different sets of tasks, more complicated, e.g. major modifications, composite repairs, opening up systems. Findings become more frequent when systems are opened up, degradation progresses quicker. This dynamic development of maintenance requirements needs to be reflected in the decision support logic
Outsourced maintenance	This raises a set of issues: - Variation in quality standards between providers In a competitive but at the same time safety critical industry the balance between quality and cost effectiveness of maintenance is a major driver. The market for maintenance is a global one, with different qualities and standards between providers of maintenance. The quality of the heavy maintenance outcome impacts line maintenance requirements. The experience is that the better the aircraft is maintenaned in the long checks the fewer occurrences happen during the operation. Currently, high standard MROs and maintenance departments are facing the situation in which scheduled work becomes unpredictable due to insufficient quality control of the overall maintenance of a fleet. - Aircraft maintenance information Managing the quality of maintenance is shared between the MRO and the airline maintenance department (responsibility/accountability). Today, in these situations the processes for maintaining a central maintenance information repository per aircraft are not always adequate.
Leasing companies	The increase in leasing aircrafts results in a set of issues - maintaining central maintenance record

	- maintenance at a limit in the early years by first operator which increases maintenance requirements subsequently - relationship between stakeholders: airline, leasing company, MRO – each tries to maximise their benefits in contract negotiations, with the MRO being in the least favourable situation as service supplier
Low cost models and Equalised maintenance	In an increasingly competitive market, there seems to be a general trend towards low cost models, either as business model for the whole operation (e.g. EasyJet, Ryanair) or for part of the operation, e.g. short haul flight operation in traditional airlines. The change in the operation results in changed requirements for maintenance; e.g. focus on the cabin - availability of seats; walk around in turn around by pilots etc. For any airline, the reduction of downtime is favorable. Especially in low cost models the utilisation of the aircraft is a main driver. Equalised maintenance promises benefits in regard to reduced downtime and increased control of maintenance actions. This is not true for all possible scenarios. The benefits are reduced or even turned into their opposite in the following situations - increasing age of the aircraft (e.g. more unscheduled findings; more complex tasks that extend one or a few nights) - inability to sustain the required highly skilled workforce (e.g. capable to work every possible combination of tasks) - inability to achieve high level of synchronisation between operational, commercial and maintenance requirements (e.g. operational rerouting resulting in a situation where resources are chased through the network)

3.4.4.2.4 General comment

The second KTWS was more explorative as the technology capabilities for decision support were less defined that the task support in KTWS #1. However, it deployed the same concepts and produced results that were valuable to the progression of the research. As TATEM was developing solutions at a relatively low maturity level (technology readiness), general assumptions had to be made. One qualifying comment that was iterated was the question of how much of aircraft technology would be integrated in the IVHM – depending on cost-benefit and certification constraints – and how many tasks would stay within the existing logic. An understanding of the relationship between new decision support opportunities and the management of residual non HM item would further inform the implementation of any application as part of a MIS.

3.4.5 Discussion

The core deliverables in the research process outlined in this section of the chapter were the two model based KTWS as it was those that demonstrated how the approach can create value, not only for the project, but for its diverse stakeholders. It delivered tangible results in terms of transformation of knowledge that created a new basis for assessing impact of technologies, but also showcased that stakeholder agendas can productively intersect and thus, took steps in overcoming barriers to data and knowledge sharing. The research process that was designed around the knowledge core of the approach

extended into all project tasks, thus creating the platform for building a shared understanding and developing relationships that could sustain actions based on it.

3.4.5.1 The overall research process

As discussed in the introduction of this chapter, there is a void between technology aspirations and operational impact in many system engineering projects. This is not intentional but reflects situation where agendas are internal and based on partial understanding of operational reality. This applies to within organisations, but more so between them, as discussed for the example of design and operation in TATEM. These issues manifested themselves in TATEM, which as a consortium represented said industry partners. One example is the struggle of the work packages tasked to develop operational scenarios (WP2000) and top level requirements (WP3000), as revealed in late delivery of deliverables or requirements for re-work. While the reasons were manifold, the experience in the project (in meetings and informal communications) suggests that the challenges experienced represent contradictions built into the work programme and limitations of V cycle approach for managing the operationally focused TATEM objectives. Another example is the selection of use cases which were driven by technology considerations rather than pertinent issues experienced in the operations. This was raised by both operational partners and reviewers and resulted in the TATEM narrative describing its achievements being less convincing that it could have been.

The approach proposed here aimed to bridge the gap and address the disconnect in the system, both within and across organisations.

The argument for transforming Human Factors and complementing existing, locally focused methodologies with a systemic approach was communicated widely in the project. As it was not an off the shelf application or adaptation of an existing concept, its development was resource intensive, taking time. While progress was disseminated iteratively and interim outputs were delivered to ground crew support work strands and other work packages, the final implementation in the KTWS happened only late in the project lifetime. While the outcomes and the overall experience demonstrated its value to the participants it was too late in the project to sustain the knowledge process that these workshops were meant to be a part of.

As part of communicating the rationale of the approach and demonstrating interim outputs to various stakeholders in the project as well as in the end user partner organisation, relationships were established that facilitated the research in numerous ways. It also was the place in which knowledge was exchanged and a common understanding achieved about respective agendas and how those could potentially intersect productively. As a result, the promoted approach which was located in a small task in a project of 50 plus partners was promoted in disseminations, all of these targeted at communicating value creation in TATEM to an external operational audience. Examples include: Presentation at the Project User Forum in Toulouse to the aviation community and a publication together with the WP6000 leader at an Institution of Engineering and technology (IET) seminar. In addition, over the course of the project new collaborations were invited with the work packages that were driving top level requirements and overall integration, which are key to the project achievements demonstration.

Unfortunately, the same was not achieved in regard to relationships between the design and operation. While the approach was a broker of knowledge in the KTWS, its development phase only facilitated interactions between the HF experts and both, design and operations, separately. These relationships were the basis for attracting resources into the workshops, but the baseline for a new relationship that was built there was not utilised due to the project ending. The workshops were successful in that the design principles and the availability of models of the actual operational reality accelerated the creation of a common understanding and fostered relationships through open and constructive interactions. One application designer went from a non-existent relationship to a bilateral collaboration with the maintainer for the brief remainder of the project, but overall these newly established relationships could not be exploited, e.g. no iteration of workshops or other KT activities due to the project time limitations.

In the project previous to the KTWS and in the absence of a fully operational approach recognised in its value by both sides, i.e. design and operation, a key mediating factor was the existing relationships between industry partners. Within the project there were symptoms of the disconnect that was discussed in Chapter 2 and echoed in the results, especially of KTWS#2.

A stark example is the parallel work that was undertaken in mobile maintenance by one airline, which agenda was not openly shared within the project. Another example was the challenge of getting access to operational data for CBA which was perceived as making oneself vulnerable rather than benefitting from the insights, an assessment that was informed by a history of mistrust (according to informal accounts). Further examples include the selection of use cases, target technologies for IVHM and the role formally assigned to operational partners, i.e. review.

In particular KTWS#2 highlighted that achieving sustainable changes through technology innovation requires a re-design of not only processes, but also relationships between key stakeholders, within and outside the organisation. While TATEM had the potential to start developing these within the project context and exploit them to further operationally grounded its technology solutions, the overall design and research process did not foster it actively and thus missed an opportunity.

3.4.5.2 Workshop outcome

Even if TATEM did not fully realize the potential value of having a systemic approach to addressing people functions in a system which core is defined by complex technologies, the research and particularly the KTWS nevertheless delivered critical outcomes and demonstrated its capability.

The main objective of the knowledge transformation process in TATEM is to integrate the knowledge of the main TATEM stakeholders who are represented by the technology provider as well as operational end-users to develop an understanding of how the innovation in TATEM delivers the transformation of the operational activities and consequently, improves operability. A fully integrated answer to these questions ensures the maximization of the benefits when introducing the products into the maintenance system.

The models provided a novel perspective on existing maintenance activity, at different system levels. Newly integrated concepts such as coordination and dependencies turned out to be critical for understanding changes not only locally but in their upstream effects, and thus hold the key for understanding how technology innovation delivers operational benefits. Operational staff that was not

involved in the development of the models validated their contents and re-iterated that they never fully appreciated the complexity of their work, especially the core role of coordination. Having this knowledge base created an understanding that was not only shared within one community but between different partners from different domains.

Another key conclusion of the workshops was that local solutions do not deliver the full TATEM potential. The impact of new technologies realised through an information capability that is even more relevant to upstream processes which provide critical inputs into the operation. This takes the focus from the shopfloor or ramp, and off the aircraft technologies, and puts an information management capability on the ground at the centre of the innovation potential. This was discussed in TATEM but only as a set of assumptions rather than a functional analysis of the wider maintenance system. It was argued that in the proposal phase it could not be included in the scope of an already extensive technology agenda.

However, considering the role of an MIS, the crucial questions were not so much technological ones, such as data protocols in data exchange, but more profound ones about how the system operates and where information is used for delivering what function, both technical and social. Overall KTWS#2 highlighted the systemic interdependencies of planning in operation for actual maintenance production which any solution has to take into account. As a consequence, the importance of the role of an on-ground MIS was confirmed and its relevance extended beyond the current assumption in the project. Again, this would have required an approach that gives access to knowledge about how maintenance system operate, or even a system of systems such as the lifecycle, and relationships between stakeholder that were conducive to its exchange.

3.4.5.3 Conclusions

The general experience is that organisations are reluctant to share widely data/information about their operational system. But they may share with a trusted agent in return for benchmarking and better knowledge about how to improve their operation. Besides the facilitation of a party that is neutral to business agendas, it is beneficial to establish a clear outcome for the knowledge process that has value attached for each partner.

TATEM technology innovation promises to reduce uncertainty which allows for increased process controls and a transparent platform for transforming existing relationships along with it. While the potential of technology innovation is there, it needs to be directed by an account of the actual system to be able to effectively address the uncertainty in the current system. The KTWS demonstrated how the proposed approach can facilitate this, and it also confirmed that the current gap in understanding is limiting impact.

In the TATEM project, creating a shared vision of a future operation was of relevance to both design and operation. Once this was established sufficiently, collaboration was further facilitated by the circumstance that a project is a somewhat protected space and that the technologies had rather low technology readiness levels, i.e. not close to market. The nature of the knowledge process is to transform data about the operational system into usable knowledge about how to change or develop the operation, with or without introducing new technology, in order to improve performance, i.e. make it safer, operationally more effective and efficient. Such knowledge is a valuable resource for improving the system at all stages

of the lifecycle and across 'systems of systems'. In order to realise its value, it has to be transferred across the lifecycle to where it can be put to use in fostering innovation, change or improvement.

Having a dedicated process creates value for each participating organisation. At each stage (data, information, knowledge) it is possible to share (with other system stakeholders) the output of the process. However it is assumed that processed knowledge is the most advantageous level for sharing, because

- Such knowledge is much more useful/applicable than relatively less processed information or raw data (so long as the knowledge transformation addresses the needs of these stakeholders)
- Such knowledge (and its potential use) is much more under the control of the originator of the data that underlies the knowledge, in so far as they have participated in the process.

By direct participation, such knowledge can be shared (by the original owners of such knowledge together with other stakeholders in the system – designers, other operators, etc.) in a knowledge transformation process in which participants have direct control over what knowledge they bring into the process.

3.5 Chapter 3: Overall Conclusions

The research process as outlined covered both the development of a framework (focus of section 1) as well as its deployment (focus of section 2).

The development was resource intensive both in time and effort spent consolidating existing knowledge, based on previous research, and validating and advancing core assumptions into a set of integrated concepts. Existing relationships with end user organisations were utilised to get access to the operational sector and facilitated a productive collaboration.

The resulting knowledge structure was iteratively validated with participants and demonstrated in its capability to effectively ground and enable the transformation of the as is situation as part of the knowledge transformation workshops. Core concepts such as coordination in processes and system dependencies elicited novel knowledge and enabled innovative methods that added value to the TATEM research process. The concept of coordination as implemented in this approach gave access to previously hidden aspects of the operation and identified new targets where TATEM solutions could create value and reduce costs. In fact, many improvements identified in the KTWS were linked to coordination which had not been accounted for in formal system accounts used in the project before (e.g. manual information as baseline for CBA). Coordination complements other activities and enables the process progression. Technology innovation that generates information advancements delivers mostly through transforming coordination and relationships between people, rather than transforming the technical task itself. The concept of dependencies that extend into the system delivered results that highlighted that the project technology solutions could only fully achieve their envisaged operational benefits by complementing IVHM on-board technologies with an MIS and organisational re-design – the latter two of which were not in the scope of the project. These findings were mirrored in project reviewers' questions about the operational implementation of technologies as part of running a business and managing a process system.

This snapshot shows that the framework makes relevant knowledge about the system available and thus offers a platform from which to derive requirements for change and transformation opportunities.

As discussed before, moving from a knowledge structure to implementing a process that can be utilised within the project required an iterative engagement at different levels of the project and successively 'bringing home' the core assumptions. The project partnership had a strong representation of key industry stakeholders and thus their relationships in the aviation system, including the aircraft maintenance domain, were largely replicated in the project. Especially KTWS #2 highlighted that many of the issues identified in a business and operational context, were mirrored in the project, e.g. reluctance to share data or insufficient capability of integrating of operational assumptions into the design process, delivering inputs that are flawed from an operational perspective.

In its systemic approach, the framework and its application extended the specific scopes of the research tasks in WP6000 strands and/or supported their clarification (see KTWS#2) and traced dependencies into the wider aviation system (i.e. SoS). Therefore the role of the approach taken can be seen as twofold in the project:

- **Knowledge process delivering to be version**: Within the research task remits of WP6000 strands it delivered results in that it allowed the generation of a 'to be' version shared by all project stakeholders and in addition, advanced the into the system context of particular solutions. Given the timing in the project, it reviewed, validated and advanced the requirements for the proposed technology solutions.
- **Lifecycle knowledge brokerage**: Within the project a wider knowledge process was facilitated to enable specific research activities. It started with communicating the inherent complexity of the maintenance operation that necessitated a novel approach to HF and extended into iteratively integrating the research efforts with local task as well as overall project integration (WP3000/WP8000).

Chapter 2 discussed the uncertainty that is inherent to socio-technical systems such as aircraft maintenance. While based in technology characteristics, it is exacerbated by the economic reality that shapes the operational implementation. The social space has an independent role in delivering system outcomes, in response to the functional logic of the tasks and processes, people taking responsibility for producing the outcome. In a system where complex dependencies cannot always be fully delivered coordination enables the process by optimising within the given constraints.

A reduction in uncertainty is the key to leveraging the situation and effecting positive change. This is a knowledge function: knowing more or having better knowledge about how the system works and what its current status is creates the opportunity for acting more efficiently, safely and effectively.

In today's system this knowledge function is approximated in the existing coordination where people manage the process within the given limitations by using experience (in tacit knowledge and informal practices). In these largely local interactions people are creating knowledge, transforming knowledge, using knowledge about dependencies and their status. New technologies or organisational process changes can deliver the basis for improving the capacity and capability within the system.

In TATEM, new technologies created the capacity for transforming system dependencies, both making them obsolete, e.g. in instances where improved diagnostics removed the troubleshooting and inspection

tasks and transform a fault isolation task sequences into a scheduled rectification and changing the way they are delivered, e.g. having the aircraft history embedded in systems on-board rather than consolidating information from various sources.

New IVHM capabilities transform the information space within which organisations operate today. The quality of information is improved, e.g. more accurate or clear and it is available earlier in the process, e.g. prognostic data rather than findings during maintenance checks. While TATEM had a strong focus on the on-board capabilities, the main interface with the operation and all the key stakeholders in it proved to be the on-ground system (MIS). Transforming the information space as described delivers an opportunity for information integration that connects diverse stakeholders within a seamless process. In that it instantiates a basis for not only transforming process internally and integrate them across organisations but also defines new interaction opportunities that change the relationships between all domains that have stake in the new system.

The challenge is to design it in a way that reflects the actual system (or improvements of it) rather than a partial version. The specification of data models and how they support the generation of information at different points in the system has to be informed by a knowledge base that ensures their relevance and targets them towards existing dependencies. Considering methodologies such as OSA CBM, it is the extension into a process layer that can be escalated into the system context, and turning it onto its head: starting with a profound understanding of how the system works defines what information is required and subsequently how this can be built up from data (see also Tuomi, 1999, for support of this argument). This was exemplified in both KTWS: the initial propositions from the design sector focused on the capability and data that the technology would be able to produce, rather than the operational context in which this data is used as information. Particularly KTWS#2 shifted the understanding of how leverage could be gained in the planning cycle on the one hand, and how far IVHM capabilities might realise it, with a MIS as platform.

In order to make a convincing case for stakeholders to invest in new processes and information system and build up social capital, i.e. networks of relationships, the value proposition needs to address their respective expectations. In order to formulate a sustainable outcome or set of outcomes that have a (possibly different) value attached for each stakeholder, and thus define the objectives of collaboration, it requires a shared understanding of how the respective systems work and interact today and a transparent to achieve a common vision of the future.

Further Implications

The implications of the research went beyond the technology induced transformation of the operational process that were defined in the use cases, but extended into creating a basis for re-thinking the design of the v-cycle and the core assumptions of a MIS that was identified as being central to delivering benefits of technology innovation into the operation.

V cycle

By establishing that the maintenance operation is a people process, where the network of relationship itself is a functional system, it becomes apparent that the traditional V cycle as it is received and implemented does not meet this aspect of operational reality. In the light of this, the design process needs to be rethought. The KTWS provided an illustration of how effective collaboration can be when based on a shared understanding of the target system and facilitated by a socially focused setting. However, it is not suggested to reduce the interface with the design process to these events. On the contrary, defining requirements has to be followed up by supporting the overall process, ensuring that the transformation of these requirements is consistent and transparently linked into the validation and evaluation. Given the complexity of the maintenance system the philosophy of iterations that exists in the current implementation of the V cycle has to be extended and systematically draw on the relevant knowledge, including an appreciation of each others constraints, e.g. cost models or technology limitations.

Technology is introduced into systems such as the maintenance operation with the view to improve performance. If the technology system is at a large scale such as the envisaged TATEM solutions, expected benefits are defined in terms of KPI at a macro level, not based on local individual performance. Technology innovations promise to deliver new capabilities that support operational functions. From this it follows that functional knowledge about the system is the premise for effective design. As outlined in the beginning of this chapter and shown throughout operational knowledge is only approximated in V cycle, for all the reasons outlined. With no systematic access to it there is little opportunity to effectively match technology capability to the functional relationships in the system. This issue also applies to any other process that aims to re-design of improve or support the system, be it technology design/system engineering, improvement processes, performance or risk management or others.

Maintenance Information System (MIS)

One can argue that information links the social and the technical spaces of a system. While knowledge can be seen as the currency of social space where meanings are created, data can be described as the currency of the technical space. Information is the intermediate between the two and as such its design in any system such as the MIS has to deliver to both logics.

Going back to an argument adapted from Tuomi (1999) and already made earlier, data is only as good as the knowledge base upon which it was defined in the first place. Therefore, it is crucial that both data and information design are informed by an account of how the system they are supposed to give a representation of is actually working. Arguing for a primacy of knowledge highlights the role of relationships. Considering the results emerging from the KTWS in TATEM, it can be argued that the core means of creating benefits is to understand the technology solutions as part of the people system. Based on the changes in information (quality and timing) the MIS advances information integration and creates a new interconnectivity between stakeholders. Based on the assessment of the complexity of today's challenges, for the MIS to work, it is a system not only used by SoS stakeholders, but also with a shared responsibility of populating and maintaining it, managing data across the lifecycle.

Having an approach that can support the definition of functionalities based on actual system dependencies can facilitate the design and contribute to ensuring that functions are targeted accordingly. However, the experience in large scale research projects such as TATEM suggests that the realisation and subsequent use depends on establishing the relationships that can realise and sustain a knowledge process facilitated by an integrated information capability. Both aspects are key to address, otherwise any investment in IT solutions is either not going to happen or it will lock stakeholders in a process that exacerbates the issues by cultivating the current disconnect.

4 Chapter 4: The HILAS Case Study

4.1 Introduction to chapter rationale

Aircraft maintenance as set of complex tasks coordinated by people has its particular configuration of issues as outlined in chapter 2, which are a reflection of the elements and their complex relationships that are at work in a socio-technical system such as this one. For any approach that aims to transform the system, they represent the baseline challenges that have to be addressed for it to be effective.

The previous chapter summarised the effort that was put into the development of a framework that implements a knowledge structure which integrates dimensions critical to assessing the reality of aircraft maintenance as a socio-technical system. The deployment of the framework in support of the technology design process demonstrated its capability, achieving new insights and bringing the features of the technology solutions more in line with the operational situation it is operated in (despite it being not fully integrated in the project design cycle). This represented a first step in implementing the second part of the overall research trajectory, as outlined in Chapter 2: how to effectively leverage knowledge once it has been identified and consolidated in accessible representations.

This agenda is further advanced in the system transformation challenge that forms the core of this case study which comprises the application of the framework in an organisational change initiative. The research was performed as part of an EU-funded collaborative research project, 'Human Integration in the Lifecycle of Aviation Systems' or HILAS, which provided the context for the design and implementation of an improvement process in an aircraft maintenance organisation.

As discussed in Chapter 1, the aviation industry is undergoing changes driven by various forces such as market changes (e.g. competitive low cost models), technology innovation (e.g. health managed aircraft) or regulatory requirements (e.g. introduction of SMS). In such an environment a good understanding of the existing system is key to not only optimize its performance but to proactively engage in transforming it towards a vision of future. Strategic decisions have to identify real change opportunities and deliver solutions that prove sustainable.

People's knowledge about the system and how it operates is an important contributor to successful problem solving and innovation, and thus can be regarded as instrumental in attempting to transform systems, whether in organizational change initiatives or as part of system engineering processes. While knowledge has been recognized as a critical resource and a growing body of literature is dedicated to researching its management, in many of these discussions, knowledge remains a somewhat elusive entity in that the focus is put on conceptual characteristics rather than its content and functions in the system processes. Chapter 1 and 2 discussed some of the issues around knowledge in the aircraft maintenance system as it exists: the tacit quality of critical knowledge and the reality of informal practices, amongst others, creating bottlenecks for its systematic use. Access to this knowledge is currently mediated by what people know and how their interactions facilitate its exchange. What can be stored in IT systems is information which graduates to knowledge when people apply it in a specific context to enable their actions and it thus becomes meaningful.

In realising the first rationale of the research trajectory, the research presented in Chapter 3 confronted these issues and developed and implemented a framework that provides a knowledge structure with the following characteristics

- Ecologically valid knowledge that incorporates both tacit and informal aspects
- Functional knowledge in its context
- Systematic integration of knowledge about different dimensions
- Knowledge that is defined in relation to process logic as expressed in technical and coordination activities rather than everything one could possibly know

Advancing the understanding of its application potential, this case study builds on the pilot study of its (limited) implementation in the design process in Chapter 3 and poses the question of how to leverage the knowledge at its core to realize actions that deliver changes into the system.

A HILAS general objective has been expressed as follows:

> 'The HILAS project will develop a 'system life-cycle model' in which knowledge generated about the human aspects of the system at the operational end is transformed into an active resource for the design of more effective operational systems and better, more innovative use of technologies'.

This single quote nicely illustrates the congruence of the HILAS project objectives with the thesis objectives. Turning knowledge into an active resource depends on having processes that can utilise it in a way that affects the outcomes. Shifting from a design application that envisaged a to be version of operational processes to an organisational change initiative for an existing maintenance system, the HILAS case study incorporates the framework from the very start and demonstrated how knowledge can be leveraged for delivering improvements in a real system.

4.1.1 Overview of HILAS improvement initiative

As part of the HILAS project (HILAS 2005–2009), one of the industrial partners, a large European aircraft maintenance organisation, set forward the following agenda to be covered as part of the project's remit: to improve the aircraft base maintenance check with the aim of improving efficiency (process and cost) and customer satisfaction while at the same time ensuring quality and safety. In collaboration with the research associates, an improvement initiative was designed, implemented and evaluated, delivering to both project and organisational objectives.

The timing of the HILAS project coincided with a strong corporate push of a central CI agenda across the group. The site (with which the HILAS project collaborated) was tasked to deliver improvements but retained the capacity to develop its own improvement agenda in response to the corporate targets. This afforded the HILAS initiative an excellent platform in terms of management support, resourcing and general support, and created a reality that pushed to collaboratively deliver change.

At the core of the initial roll out of the initiative was a series of checks, delivered to a single customer. An interesting opportunity represented itself in that the customer itself was a partner in the project. Although

partners in different project strands, the collaboration within the same project allowed for insights into the strategic agenda of both airline and maintenance organisation and extended considerations of the initiative's design into what it could deliver to both and how this created additional value for each of the organisations.

Improving the performance of the aircraft maintenance system had different value attached to it for the two partners: The aircraft maintenance organisations was driven by simultaneously achieving goals such as increased efficiency, improved quality, enhanced profitability, on-time customer delivery, improved safety, pro-active risk management, and overall the view to enhance the sustainability of a business relationship. The airline was driven by similar considerations, with a focus on receiving aircraft back into operation as planned in spite of the uncertainty of aircraft maintenance, remotely, but pro-actively managing quality assurance & risk control, and overall the sustainability of business relationship with a partner that was open to integrate these goals into the way they do business.

This strategic partnership between the industry partners in collaboration with the research associates, aimed to support the advancement of

- Strategic vision

  In an increasingly competitive market, the maintenance organisation was looking for ways to advancing a sustainable business model, delivering the excellence they were renowned for in a way that addressed the customers' requirements (e.g. cost, time, control). Collaboratively defining and implementing best business practices was regarded as a first step towards a sustainable business relationship with the customer. From a customer perspective, the requirement to outsource maintenance arose from their business model (low cost model) and as part of an overall risk orientated agenda in the airline had created sensitivity in regard to quality control, risk management and accountability in such a scenario. Therefore, entering a more strategic partnership with a maintenance organisation promised to open up the opportunity to address those in a comprehensive and sustainable manner.
- Process improvement

  Process improvements were regarded as driver of efficiency, e.g. cost reduction and time savings. This was to benefit both the maintenance organisation in terms of their overall cost model and the customer in terms of increased aircraft availability. Within the context of the HILAS programme, this initial take on process improvement was extended to include social aspects into the consideration of how the processes deliver value to both maintainer and customer. The result was a process improvement approach that escalated issues in the socio-technical processes of the operation to the business level and demonstrated the systemic interdependencies that affected overall outcomes.
- KPI and data management

  In conjunction with process review and improvement, a review of the Key Performance Indicators currently used in the organisation was defined as another objective. The aim was to ensure the use of meaningful indicators, reviewing and extending existing ones in the light of the

implemented changes. Again, the traditional perspective was challenged to look beyond financial and technical indicators into adopting a wholly systemic perspective that incorporated how social aspects contributed to delivering outcomes.

- Best practices for transfer

  It was emphasised that the implementation of the improvement initiative was not a local project, but designed as a process that could be documented, critically evaluated and transferred as best practice to other areas of the company or to external partners.

The improvement initiative was designed around three pillars: The process improvement that is at the core of this thesis was one of these while the others were build around environmental changes, realised through the lean approach of 5S (Sort, Set, Shine, Standardise, Sustain), and a strand of activities focusing on culture and team engagement that was central to communicating the initiative message and creating the capacity to engage, e.g. training staff or facilitating feedback mechanisms.

The rollout of the initiative was staged, within and across hangars: The customer's check line was run in a single hangar that was the location of the initial roll out. It started with overall communications (part of culture and training), followed by setting up the environment using the 5S methodology. When this started showing initial results and benefits to staff, the process improvement strand went live and the three iteratively worked together to deliver better operational results. After the pilot implementation it was extended to other hangars.

The overall initiative was run by the 'Improvement team': The research partner allocated two personnel: One researcher was based full time on site, a decision that was made to do justice to scale and timeline of the implementation scope, with another researcher spending time in situ for scheduled research activities. The organisation provided a dedicated staff member with a background in lean approaches to assist with the environmental management aspect in particular. This core executive group was complemented by the Organisational Learning Manager and the Base Maintenance Manager and was the 'Improvement Team' that managed the overall development and implementation of the initiative. As part of the implementation of processes other teams were defined within the workforce who executed the process activities as designed in the improvement initiative at different levels. These groups include: Hangar Improvement Team (HIT), working groups at management level, participants' in knowledge transformation workshops and others.

4.1.2 Positioning the improvement project in the thesis: research questions

The HILAS case study shifts the focus from the design process to utilising the framework presented in Chapter 3 to deliver improvements in the aircraft maintenance system. The framework continues to define implementation choices: in its application in a dedicated report to monitor issues arising in the operational process, and their subsequent analysis and resolution, as well as in designing the overall change management process that bases actions on the newly established facts. Introducing the framework in form of a tool into the operational situation defines a knowledge baseline that allows exploring the role of coordination and relationships in making effective use of it.

The initiative's overall goal was aimed at improving process performance. Within the HILAS remit, performance is discussed at a system level, considering it in the lifecycle context. Chapter 2 has argued that in a socio-technical system the overall performance is a result of the complex interactions of various elements, including people, technology and information. As discussed before, the process gives access to these aspects and provides a platform to address their impact in an integrated way since it delivers the outcomes that underlie system performance. In order to improve the process outcomes, the issues have to be identified and analysed in their system context, addressing the complexity of interdependencies to develop sustainable solutions.

Adopting a process baseline to address systemic issues helps with some issue around the data perspective in performance management. Events and occurrences that are collected to shed light on performance dimensions require a system context to fully appreciate their meaning. Many existing reports have specific objectives and targets (e.g. quality and safety) and fall short when it comes to establishing the actual operational context of the report item. The complex reality of operational issues is often only expressed as 'anecdotal complaints' such as: "we never have xyz and that messes up the whole check". In order to provide a legitimate basis for management to action changes, people's experience as expressed in these comments and remarks needed to be captured whenever they occur, and be backed up with a systematic exploration of the operational situation (including both technical and social aspects), e.g. how often, what was the effect not only locally but wider system, where did the issue originate, etc.

A large amount of operational data is available in existing systems but organisations face the challenge of selecting, integrating and interpreting it. While trends can be compiled, the challenge remains to explain where the underlying issues originate and how they are perpetuated within the maintenance system. In the current situation, the disconnect between formal and informal system practices limits a full understanding of how the system functions and thus reference system are inadequate to make proper sense of data. Even worse, existing data on the system's performance can be in conflict with people's perceptions or at odds with other data streams.

An example: In a check with low recoverability, staff complained about systemic supply chain issue as being a major contributor, but when reviewing the data it showed that service level agreements (SLA) were met. It could be argued that this proves that all the problems reside within the operation itself, but looking more closely at the reported and observed issues shows the residual variance, which is allowable when implementing Service Level Agreements (SLAs), created issues in the operational flow, which were more or less effectively mitigated within the check process. The SLA parameters are not sufficiently aligned with operational reality and thus resulted in the observed divergence between operational outcomes (as reflected in Key Performance Indicators (KPI) like recoverability) and support (as reflected in SLA achievement). This is an illustration of the limitations of basing processes and their outcomes on formal system descriptions and highlights the lack of insight into the actual operational practices.

Another example is the use of NRC discussed in Chapter 3. High numbers of NRCs raised indicate a lot of extra work that has to be billed to the customer, having the potential for creating a nightmare for the contract department when re-negotiating how those are paid for. Often, these high numbers have no

such implications, but are solely a symptom of people raising NRCs to better manage their process. In addition to their formal role in directing unscheduled task execution and managing the planning and accounting for additional work, they are also used informally to deliver other functions that are not well supported otherwise.

Without a systemic perspective of how all components of the maintenance system, e.g. all the business units (including roles, tools, technologies, processes etc) work together, one cannot leverage the situation and data remains inconclusive or misleading. In order to make sense of the data from different sources it requires an ecologically valid understanding of the functioning of the system. This is even more important when problems are to be addressed because the quality of a solution depends on a comprehensive assessment of the underlying system configuration, i.e. how well the problem is understood to begin with.

Chapter 2 has discussed the contradictions that arise in aircraft maintenance from the disconnect of formal system descriptions such as procedures and informal practices that people adopt to manage their daily work. These pose a challenge to accessing the relevant system knowledge and result in the same knowledge issues that were discussed and addressed in chapter 3: relevant knowledge about how the system works is hidden from scrutiny as it resides in informal practices and with large parts of it being tacit in nature, it is difficult to access. In addition to this, the knowledge is distributed across the system, requiring the consolidation of local perspectives into a bigger picture. People's local expertise and understanding of a problem is critical to solving it. However, only by integrating it with other stakeholders' knowledge can it provide a full account of the interdependencies and can be transformed to develop sustainable solutions.

In the context of this case study, issues around relative inaccessibility of relevant knowledge manifest themselves in a lack of transparency and shared understanding in regard to the how process activities influence and depend on each other within the wider operation (between teams and hangars) and the support processes such as planning or material supply.

In aircraft maintenance there are reports mandated by the regulator as well as voluntary reporting schemes introduced by the organisation to monitor certain aspects of the system and to uncover issues or investigate incident. Reports are a means to access knowledge and create a shared understanding of the operational situation. The effectiveness, with which they deliver this, is limited by people's perception of their objective and usefulness. Staff reported that they perceived existing reporting available to the operation as being biased (e.g. Ward, 2005) and offered examples around the following

- Perceived or real "blame" culture at operational end
- Rationale is driven by external department role/"agenda", e.g. quality, safety, planning
- Means of reporting makes it more likely for certain roles, e.g. technology capability

This reluctance to report is exacerbated by the dominant social structure that emerges in aircraft maintenance as a response to the disconnect of formal and informal practices and the knowledge thereof. While management and to a large extent the support processes make decisions and operate based upon the formal description, the operational staff implement these formal accounts as part of processes that require additional activities. In the operation, strong professional cultures manage adverse circumstances

(blockers) as people that work on an aircraft (or zone) feel responsible for getting the job done together – a pattern that is expressed in WIPIDO (McDonald, Corrigan and Ward, 2002).

This situation creates a feeling of 'them versus us' in the operation, where people feel challenged by having their processes impeded by support processes and management decisions, while on the other side those in support functions suggest that the operation cannot fully appreciate the constraints they operate under. In absence of an integrated picture of the actual interdependencies across the system processes, the extent to which the issues are managed depends on how well people that represent these functions relate to each other and the rapport they have established, over time, working together.

Local groups (e.g. trades, hangars etc) have ways of dealing with issues, 'work arounds' that are using relationships within and outside the operation; these relationships have their basis in the formal system description but the way they are enacted goes beyond these and reflects how these formal description are realised in an operational setting.

Coordination has been discussed before in regard to its role in the process transformation logic but is also key to managing all sources of uncertainty in the system. Unscheduled maintenance items and their consequences are the source of 'expected' uncertainty which is acknowledged in rules of thumb that leave 20-40% of check effort unallocated in planning phase. In addition to this, issues can arise around scheduled items that create additional uncertainty. Those result from the economic constraints of running an operation that deal with complex tasks and technology. Going back to the Friedlander argument in Chapter 2, conditions are never perfect, even for scheduled items.

In summary, the effectiveness of interventions in an improvement initiative relies on a good understanding of the issues to be addressed. In a situation as described for aircraft maintenance it requires access to all the relevant knowledge, including new data streams that are dedicated to a systemic perspective on the operation and the resulting improvement targets. Such an integrated perspective provides a shared reference system that is true to different stakeholders' experience with the system and thus has the potential to increase transparency to counteract 'suspicious perceptions of each other'. As a shared understanding benefits the operation in maximising coordination effectiveness, an integrated perspective on how the operation works - or not, if affected by 'blockers' - lays the foundation for the improvement initiative.

This leads into **Research question 1**: How can the knowledge structure designed in chapter 3 be deployed to identify and analyse operational bottlenecks (i.e. blocking process progression) in a systematic way?

Like many organisations these days, the aircraft maintenance company in which this case study was conducted had a long history of improvement initiatives. They varied in terms of scale, focus, people commitment, and other characteristics which all posed challenges on their own (some of which are documented by Ward, 2005).

When introducing the improvement programme objectives and drafting staff to get involved, staff commented on previous programmes in the company. The issues as perceived by participating staff centred on the following themes:

- Impact

  In cases where the programmes delivered positive outcomes, they targeted 'low hanging fruit' instead of addressing complex issue that potentially would have required profound and radical changes.
- Sustainability

  Issues were reported in terms of the sustainability of both, solutions and initiatives. Proposed solutions were either not implemented (for various reasons) or if so, not sustained, e.g. with adequate resourcing. The track record of initiatives showed that there were many attempts that did not result in new organisational processes to sustain the programme.
- Role of Management support

  Both issues were linked to management commitment and their degree of freedom within an organisation which fostered an internalisation of departmental effort by giving each business section has its own set of targets which were not necessarily well aligned. (see the earlier example of operational KPI and SLA).

From a management point of view, a lack of motivation and commitment was perceived to be prevailing in the work force. The perception was that good will was not acknowledged as such and that the changes that were implemented as part of the programme rarely did deliver the outcomes that were expected.

The respective assessments of the change programmes mirror the disconnect that exists in the understanding of the operational system, i.e. formal versus actual system, and indicate that the organisational change processes are not designed in a way that would allow to bridge this gap. The delivery of maintenance (with its system dependencies) as the core business is key to driving an effective change agenda that can deliver internal targets and direct value to the customer, e.g. shorter maintenance down time for aircraft. If the target system or key parts of it are not fully understood, any change process designed to improve it cannot meet the expectation.

Based on the material presented in the thesis so far, the argument is that the lack of an adequate understanding of the functional logic that underlies the operational situation is central to accounting for the perceived lack in regard to impact and sustainability, even if it may not explain all of it. Monitoring the issues in a systematic way that reflects how the system actually works as called for in research question 1 can be seen as a first step in a process that has to be designed in a way that can bring to bear the systemic knowledge base of the organisation.

Being unable to draw on the full picture, the knowledge available to even the best-intentioned management results in attempts to change or support the wrong version of reality. This does not only result in ineffective change but as a consequence of that negatively impacts in the relationships between management and operational staff. For example, trust as concept can be unpacked into several dimensions, including belief in the future and open communication (Ward, 2005). The situation as described above does not foster these, which in turn affects relationships.

Management support is being discussed as an important factor in successful initiatives. Based in the discussion in this thesis lack of support may not be intentional but based on an inadequate understanding

of the situation. So what staff may perceive as lack of commitment or even ill will may be largely explained by lack of mutual understanding. Even if conceptualised as a misunderstanding, the consequence however are the same as they would be if those suspicions were correct: including no effective or sustainable changes and poor quality of relationships, amongst others. This leads into a vicious cycle where the quality of people's relationships negatively affects the knowledge exchanged in interactions and thus reinforces the existing gap between formal and informal practices.

Having a functional knowledge base that is created collaboratively and identifies the interdependencies in a system, as expressed in both formal and informal practices, is a critical foundation to leverage effective interventions, However, it does not aspire to account for everything that goes on in a complex system. The effectiveness with which changes can be introduced into a system is mediated by many factors, some of which go beyond the socio-technically based functional logic captured into the proposed framework, and include for example political dimensions such as industrial relations, national cultures or personal dispositions.

In summary, while change is a complex matter, a key to designing an effective change process and being able to transparently manage it is a better understanding of how the system works and what is required to support the interdependencies between its parts. Such transparency also fosters better interactions which as a consequence build up relationships of a new quality. While not addressing all the challenges that an organisation or an industry is faced with in a change situation, it provides a major step towards better outcomes.

This leads into **Research question 2**: How can the proposed framework enable a knowledge based process for delivering effective changes in the maintenance operation?

4.2 Case study arc: The HILAS case

The HILAS case study is the second part of the case study arc introduced in chapter 2. It builds on the results of Chapter 3 and has a stronger emphasis on the deployment of the conceptual framework in an active knowledge process.

The improvement initiative was part of the HILAS programme of change, delivered by an action research agenda. This agenda was implemented in collaboration between industry partners and academic researchers, spanning design, implementation and evaluation. The author was part of a HILAS team dedicated to deliver the improvement initiative together with designated staff at all levels in the organisation. While contextualising the research in the HILAS programme, the case study is focusing on research activities that the author took main responsibility for.

The overall improvement initiative was built around three pillars:

- Environmental changes: 5S
- Process improvements in the operation
- Culture and team engagement

While the programme presents an integrated approach that was delivered collaboratively, there were particular responsibilities allocated within the improvement team, based on background and expertise.

The author of the thesis took a lead on the process aspects, building on the research in TATEM that preceded this. A black belt member of staff supported the environmental change component that was built on the lean concept of 5S. The full time TCD staff took a lead on training and cultural change, building on long-standing relations with the company based on a series of earlier research collaborations. This extended into a lead in managing the HILAS research trajectory within the company, giving the HILAS research support for the initiative a face as a constant presence in the organisation's daily operation. Staff at management level provided inputs in all these activities, based on their respective expertise, and supported the positioning of the initiative in regard to the organisational agendas and strategic goals within the organisation and the wider corporate group.

4.2.1 Action research

This case study is build around a strong action research agenda. The HILAS project as a research project was specifically designed to have a strong focus on implementing change in the real world, i.e. collaborating with industry partners' to effect change in their organisations.

The participatory aspects of action research were put at the centre of the initiative, aiming to bring everyone in the organisation on board. Staff at all levels in the organisation were invited to shape the programme in various ways in which they felt comfortable. This instilled a sense of ownership amongst operational staff in base maintenance where the initiative was first rolled out and facilitated receiving their inputs at every critical juncture of the implementation. While process focused interventions were based on a strong conceptual base developed in maintenance in the research in chapter 3 (which was iteratively validated with participating staff here), staff provided practical guidance on the implementation such as language or presentational issues.

In the maintenance strand, where this research was located, an interesting opportunity arose as part of an existing business relationship between two organisations that were both partners in the project. As outlined in the introduction to this chapter, both organisations were in progress of realising their respective central agenda for change and improvement with the view to pursuing innovation and competitive advantage. The maintenance organisation was implementing their version of the central CI agenda that was driven by lean philosophy and the airline had a strong company wide a risk and safety agenda; both of which were brought into the HILAS project to drive the envisaged action research based implementations.

In this case, the agendas intersected productively, facilitated by the HILAS programme. CI aimed to improve performance to deliver outcomes that increase customer satisfaction. For this particular customer, the new programme also allowed for more transparency and innovative way of monitoring quality in an outsourced business function which promised to address residual issue re quality control and risk management.

4.2.2 Ethnography

Phase 1 made extensive use of ethnographic methods to develop the structure and content of the body of knowledge about the maintenance system. In response to the TATEM project requirements, a particular

operational focus was put on the removal installation use case, however, in its wider system context, including check operations.

Building on the outcomes of phase 1, ethnographic methods were employed to a lesser extent in this second case study. However, there was a requirement to update the existing knowledge and to ensure its relevance for the operational context in HILAS (i.e. check level). For those activities that involved validating existing knowledge and creating new knowledge ethnographic methods were used, similar to phase 1. Details on these will be reported later in this chapter.

4.2.3 Validation strategy

The validation of the research is informed by the strategies outlined in Chapter 2. The research builds on the first case study and validates results reported in Chapter 3 in a new application context and with a new set of stakeholders, advancing an understanding of the results based on a wider basis. Different data collections methods were used as well as different people were invited to contribute, iteratively ensuring the best representation of knowledge in the framework as well as effectively leveraging it.

In addition to the validation activities internal to the strategy of the thesis, an external evaluation of the change initiative was performed as part of the HILAS project (Ward et al., 2009). Evaluators who were not involved in the change initiative devised an approach that used different data collection methods (including both questionnaires as well as interviews), targeting both tangible outcomes and perception of staff and management. Ten members of staff with different background who all had been part of the change initiative participated in a two day workshop that was run by external evaluators who deployed the different data collection methods.

The details on the validation activities will be discussed at appropriate points in the following sections while the general outcomes of the validation strategy deployed here are presented in the discussion section of this chapter.

4.3 Section 1: Knowledge structure

This section addresses **Research question 1**: How can the knowledge structure designed in chapter 3 be deployed to identify and analyse operational bottlenecks in a systematic way?

The development of a process performance report implementing the framework proposed in this thesis will be outlined.

4.3.1 Background

The improvement initiative that provides the context for the research presented here is set against a CI backdrop that is informed by lean philosophy. The performance monitoring aspect of CI was implemented and conceptually advanced by developing a process performance report that translated the conceptual framework that is at the core of the research in both case studies. The following gives a summary of the relevant areas.

4.3.1.1 Continuous improvement

Many organisations are adopting Continuous Improvement initiatives or similar quality processes in one form or the other.

"Continuous Improvement has been praised to be imperative for the success of an organisation, enabling it to optimise their operational, and as a consequence, their safety and financial performance. The requirement to improve is driven by (a) the need to adapt to changing situations in an industry that continuously evolves (e.g. technically, operationally, regulatory) as well as (b) the need to maintain the relative stability of the system to deliver the best possible product or service on a daily basis. Operational systems usually operate with less than optimal resources and support since total availability at all times does not constitute a sound cost benefit scenario." (Morrison, Ward and Gaynor, 2009)

A popular continuous improvement initiative is the KAIZEN approach which was adopted in other business units in the partner maintenance organisation. Kaizen is the Japanese word for improvement and a umbrella term for continuous improvement initiatives in the tradition of the Japanese school as represented by Toyota. The principles that it is built on are generic to many CI approaches and include:

- Building on workforce knowledge
- Motivate people to revise and improve their performance
- Measure (local) performance
- Incremental changes
- Iterative cycle

Its target is to improve the performance of people in the process. It is achieved by allowing them to introduce incremental changes that in their understanding of the work situation can contribute to improving performance. It has a performance monitoring component in that it measures the outcome of changes in the local process where the intervention occurred.

Processes are usually used as a baseline for identifying improvement potential or in the tradition of lean philosophy, wasteful activity. Originating in the manufacturing sector (e.g. Toyota producing cars) the process notion is a fairly sequential one, which focuses on incremental improvement along a value chain. Even when extended into the supply chain, the underlying assumption is that local improvements add up across the process. In contrast to this, the systemic notion adopted in the KSM framework starts in a local process only to explore the socio-technically defined interdependencies within the system. It is this bigger picture that, while built up from the operational base in Chapter 3, allows for a top down approach in its application to integrate change efforts, compared to the incremental build up and alignment with prescribed targets in traditional CI. While the knowledge that the improvements are based on originated in the work force, its incorporation in system models extends its relevance beyond the local groups that CI typically uses.

The knowledge base for improvements in the HILAS case study being systemic and functional offers to address issues about impact that have been recently raised about lean approaches. In the Harvard Business Review (HBR) professional blog by Ron Ashkenas (08 May 2012) and the ensuing discussion with his peers, the argument transpired that reviewing the performance of the big US companies that are

champions of lean showed limitation of its methods such as six sigma or kaizen. While those were capable of dealing with existing systems and their efficiency in a beneficial manner, they did not deliver creativity and innovation capability, which are seen to be crucial to the success of entering the next generation of enterprises (as also Chapter 1, on incremental versus radical change).

Translating the framework into a process performance monitoring tool positions the trigger of the improvement locally in the operational process, but its design extends into a system perspective: not only in providing a conceptual platform to address socio-technical dependencies within the overall system but also in defining requirements for a management process to correspond with it (see second section of this chapter).

4.3.1.2 Reporting on performance

Reports on performance aspects were part of the organisational processes in the partner organisation. At the beginning of the HILAS case study aircraft maintenance engineers had a number of self reports that they could submit. Each of these reports focused on a unique aspect of performance and safety (airworthiness and personal):

- Task Card Amendment Form: This report was for reporting on any suggested amendment to the Task Card. This report went to the Planning and Commercial Department.
- Quality Discrepancy Report: This report was for reporting on any issue that was seen to compromise the quality of the aircraft or the work being carried out. This report went to the Quality Assurance Department.
- Accident / Dangerous Occurrence Report: This report was for reporting on any personal incident, accident or near miss. This report went to the Safety and Security Department.
- Forward Driver Report: This was for making any suggestions for change or improvement that would yield a financial return on investment for the company. This report went to different allocated 'Drivers' in each department.

There was also a company confidential and voluntary error reporting process which did not have a report form attached but consisted of calling a confidential phone number or writing a free text letter / memo to the safety manager.

A common feature of all these reporting opportunities is that the reports are owned by processes other than the operation and are designed as an input into those, thus arguably creating value outside the operation. Their agendas and targets were based on the formal system and thus reporting did not promise to create actual value for the operation. Rather the opposite was the case: a challenge with these reports was grounded in the disconnect between formal system descriptions and the complex socio-technical reality of daily operations. It created a situation where staff were reluctant to report as the double standard between how tasks 'should' happen and how they do happen held the real possibility of system vulnerabilities being misconstructed as procedural violations and attract negative consequences for them.

Having staff as key partners in the initiative provided the opportunity to address these shortfalls of existing reports in the development of a new report, which was contextualised by starting with the very idea of it as part of the system model to implementing and evaluating solutions based on this data.

The new report and its use in the improvement process specifically addressed issues that staff raised in regard to existing reports as follows

- The report and its data were owned by operations, i.e. base maintenance department, in contrast to others.
- The reporting was based on an account of people's shared understanding of how a check as part of the maintenance system works rather than using formal descriptions as reference point.
- There was an agreed and transparent process of dealing with the data and delivering outcomes to the reported, including intermediate feedback.
- Within the process forums and dedicated activities were designed to deliver the aim to improve collaboratively and share responsibility rather than laying blame.

Its objective was to enable sustainable solution to process blockers and improve the performance of the check process, thus supporting the operation in delivering their outcomes and creating value in the operation and for the operation. This is a novelty as previous reports were part of other departments' value chains, even though it is the operation that is at the core of realising the overall business value.

4.3.1.3 TATEM achievements: Conceptual basis for KSM framework

The core achievement of the research presented in chapter 3 was to establish a conceptual framework to capture and organise relevant knowledge about the socio-technical system that is aircraft maintenance and present it in easily accessible representations. The key conceptual achievements include

- Modelling processes as a set of generic activities
- Integration of coordination as functional activities in the process activity modelling
- Extending the process activity baseline and how it delivers outcomes into a concept of socio-technical system dependencies
- Abstraction of the concept states and gates that allows organising socio-technical system dependencies
- Anchoring a perspectives dedicated to stakeholders and information in the process activity model

These characteristics and principles define the knowledge base that the models represent. It is driven by a system outlook and integrates technical and social aspects of that system according to their functionality in system processes delivering outcomes.

Generic CI principles are adopted, but refined and advanced by having conceptual framework that allows operationalising them and making assumptions about how they work (e.g. work force knowledge) and what to expect that they deliver. Integrating these concepts informs and delivers the methodologies used in this section

4.3.2 Methodology

There are two methodologies that are based on the modelling approach in the KSM framework: the process modelling approach applied at the check process level and a reporting tool that has been developed for this case study, to allow monitoring of process performance. As part of these, knowledge transformation principles are deployed, integrating knowledge into the model and selected the report

sections. Finally, a simple approach to quantitative analysis strategy is put forward to identify trends in the process monitoring data.

The core methodologies are linked to the framework, therefore they will be mentioned throughout the thesis, and discussed in the particular application context, which will emphasise one or the other aspect. In addition, methodologies such as the blocker report also constitute a result. The thesis design as outlined in Chapter 2, embeds the interplay of knowledge structure and its utilisation in a knowledge process in the system, deploying dedicated methodologies.

4.3.2.1 KSM framework

In realising phase 1, Chapter 3 has defined and implemented the KSM framework that provides knowledge structure with the following characteristics

- Ecologically valid knowledge that incorporates both tacit and informal aspects
- Functional knowledge in its context
- Systematic integration of knowledge about different dimensions
- Knowledge that is defined in relation to process logic as expressed in technical and coordination activities rather than everything one could possibly know.

It also defined methodologies for mapping core processes and their social and information space, which are inclusive of social as well as technical dimensions, integrating both formal as well as informal and partially hidden system knowledge about both.

4.3.2.1.1 Process system maps

The process mapping methodology developed in TATEM and presented in Chapter 3 was adopted in this case study. Here the baseline process was identified at check level. A process map and a stakeholder diagram were mapped out in a participatory approach that saw several iterations based on operational staff's input. As part of these activities the modelling parameters were introduced and explained to staff who validated their appropriateness in describing their work processes.

Building on ethnographically based research on different process levels in the maintenance production system conducted in TATEM, the check process was developed in collaboration with AMEs, crew managers, check managers and the live planner.

The process activity map included generic technical and coordination activities, associated stakeholders, and states and gates that organise dependencies.

4.3.2.1.2 Model based blocker report

Adopting the framework, a dedicated report was devised to collect data on the dimensions that had been identified as key to understanding of systems functioning.

The modelling framework is human centred and does not only capture technical activities but models those in relation to the human and social mechanisms that enable them. Staff was involved in developing the baseline process models, including all the aspects of their daily work that are not captured in formal

description such as technical manuals or standard operating procedures. The resulting models are a reference point for events that are reported on.

Using the framework and the knowledge incorporated in it for all stages of the improvement process, from data collection, analysis to identifying a solution and optimising its implementation, offers a systematic approach to dealing with system vulnerabilities that counteracts ad hoc solutions driven by internal politics or expiry dates. The report is only one piece of a puzzle that is building up a system view in a principled manner. It is an input into an organisational process that is designed to deal with "knowledge as an active resource" (HILAS, 2005) for system re-design.

The blocker report captures data from the individual and team, at the point of origin. People who perform the process are in the best position to report on it as they have access to the relevant functional knowledge based on their experience with the system, including tacit understanding that drives the actions that are reported on. It is a self-report and as such subjective. However, the conceptual design of the report facilitates it being a building block in a more objective picture of the status of the operational system. The report operationalises the conceptual framework, both in structure and pre-defined content options and this provides a reference point that allows a certain degree of standardisation of the report format. It was designed with the view to highlight process interfaces and related data streams to allow for systematically integrating relevant information, e.g. if a Query Note was raised to the engineering department on the same topic. In addition, defining a solution to the blocker was consolidated in a team effort and an agreed change was proposed. This allowed for further validation of the description and subsequent solution suggestions.

By reporting in the given framework the blocker report not only summarises a problem statement but at the same time positions it in the system. The configuration of the critical dimensions in the event enables a systematic approach to identifying additional information that facilitates analysis and guides finding solutions, and also puts a spotlight on those interfaces and relationships that are critical to utilising relevant knowledge. An example: The classification of a blocker identifies where to look for more information as well as who in the organisation can contribute to a solution.

The blocker report is not an error or incident reporting form but asks for accounts of operational processes being 'blocked' (or can be used to capture the opposite, processes being 'facilitated' outside formal parameters). It is an informal report, completely voluntary and anonymous if staff wish (staff can choose to give their staff identification number which facilitates integration of data).

The report is means of capturing data into an analysis and improvement process that informs the management of the organisation at different levels, from operational and tactical, solving problems to strategic, interpreting systemic trends and addressing them proactively. It identifies the main stakeholder, critical process activities as well as the impact on outcome and wider consequences in the organisation. All of this is captured against a model of the operation which reduces the effort in the reporting for the operator. In having a dynamic knowledge structure in the KSM framework, it the operational system scene is already set for the reporter and saves him general explanations outside the actual event.

4.3.2.1.2.1 Structure of the report

The categories of the report implement the framework as developed in chapter 3. Its structure or flow adopts the logic of a universal narrative. Combined, both these criteria ensured that although the report captures a snapshot with minimal effort, it is actually a comprehensive one. The scene is set and the activities described. Those are tentatively evaluated and reviewed in terms of outcome and consequences. This is reported against a framework that consolidated functional knowledge and this gives the context for assigning meaning to single reports as well as trends.

The structure also provides for identifying the point of origin of the report and the report status for further managing and integrating the data.

In the blocker report the data fields are organised in different sections:

Report section	**Content examples**
Identification	e.g. staff identification / aircraft registration / task card number / date & time / summary
Classification / Type of blocker	HF framework based initial classification of each blocker
Location in process	Process activity model
Direct outcome	(e.g. interruption / on hold /work around / extra steps / incomplete work / clutter workspace)
Consequences	to internal workflow / people / other process (e.g. re-plan shift / workload increase / delay to next process)
Stakeholder/Staff involved	e.g. AMA / AME / Crew Manager / Hangar Manager / Support Planner /Customer/ OEM
Impact	(e.g. high / medium / low and area of impact e.g. local / across areas / in process / across processes)
Suggestion to resolve the blocker	following discussion with the persons colleagues, team and crew manager)
Action taken	(following investigation with the Hangar Improvement Team)
Closing the blocker	(has action been taken / is initiator satisfied / is HIT satisfied / is area manager satisfied)

The section "Location in the process" uses a visual representation of the current process activity model. By indicating the location of the blocker and its consequences it immediately links the blocker report data to other relevant data attached to the framework.

'Wider consequences' and 'impact' as well as 'suggestions' are agreed in the team rather than being judged by the reporting individual. Here the report requests information that is more based in judgements rather than local observation. While the initial sections are mostly based on personal observations the latter more explicitly ask to make judgements, and what is more critically assess the consequences outside one's operating space. The team based review of these questions is meant to introduce a sense of impartiality within a subjective report. Even though it is a subjective report there are features that ensure greater objectivity than other self reports. Along with achieving some standardisation by having a model as organising principle, the team judgement broadens the knowledge base and increases the credibility and sustainability of possible solutions.

4.3.2.1.2.2 Design characteristics

The Blocker Report has been designed to capture data into the operational model and its analysis framework. Therefore the data fields relate to elements of the model.

The data capture is meant to be performed in the most efficient way possible to reduce the interference with the technical work staff is there to perform. The following features facilitate achieving this objective

- Overall length of the report

  All data fields of the report do not exceed two pages (back and front) while the content is legible and clearly structured in the pages
- Balance between free text and tick box options

  When possible items are managed by tick box fields that reduce the amount of free text staff has to produce. This not only reduces the time required to fill in the form but also addresses the sometimes pronounced reluctance to 'writing essays' in technical personnel. At the same time the free text options insure that the report is flexible enough to provide a comprehensive picture.
- Link to other data sources

  Fields such as task card number or sections such as the visual representation of the OPM are entry points into other databases to pull data to complement the blocker report for further analysis. This reduces the need for duplication of information already reported or held it the existing organisational systems.
- Presentation modalities

  The report was trialled as a paper version. However, there is an argument that criticises the accessibility of paper forms. This can be extended in including the updating of these forms. How can one be sure the form in this hangar is the current version? An electronic format was envisaged to be implemented based on the outcomes of the paper pilot as well as its continued use.
- Individual and team input

  As discussed above the report combines the benefit of first hand observations by the reporter and team based judgements that of approximate local expert judgements.

During the process of translating the framework into a report format, staff was consulted in an iterative process to review the overall usability of the report format as well as to assess from an operational perspective the conceptual integrity.

4.3.2.2 Quantitative approach to blocker data analysis

While the overall nature of the research strongly favours a qualitative approach that allows in depth analysis and participatory research as outlined in chapter 2, this does not exclude the use of quantitative means where appropriate.

Descriptive statistics, such as frequencies were used to manage the blocker data and provide inputs in the qualitative analysis. There is the option of extending the quantitative approach, e.g. exploring Bayesian networks to model system dynamics, especially in integration with other organisational data sources. Due to having an already extensive research trajectory in this thesis, this was not further explored.

The number of blockers collected allowed for identifying trends within the data and highlight areas in which the process was vulnerable.

4.3.2.3 Knowledge transformation

Model based knowledge transformation activities were designed based on the principles introduced in Chapter 3. The concept of knowledge transformation goes back to Nonaka (e.g. 1994, and is also discussed in Chapter 2) and has been extended in this thesis to allow for implementing it systematically as part of a model based process.

Knowledge transformation starts in the description of activities, here as part of the process mapping and collaboratively developing blocker solutions, and continues in a knowledge process that delivers system transformation. This will be further discussed in section 2 of this chapter. Its mention here only serves the purpose of highlighting the role of its successful outcomes in further validating the approach. The blocker report as a monitoring implementation enabled the identification of a critical system trend which triggered a KT event. Starting with the blocker information allowed for building a case that delivered the capability of deriving consensus solution in a KT set up to be suggested for implementation.

4.3.3 Research activities

4.3.3.1 Modelling the check process

The baseline process that was identified for this improvement initiative is the check level. A process map and stakeholder diagram was developed in participation with the hangar team. Based in initial interviews and existing research in TATEM a draft map was presented and iteratively refined in collaboration with staff. The core of the modelling took place in four workshops in which key staff participated, including hangar manager to crew managers to AMEs and aircraft maintenance assistants (AMAs), representing different work categories (e.g. sheet metal, avionics) and different zones of the aircraft (e.g. wings, landing gear, cabin).

The series of workshop identified the major states in the process and proceeded to detail the generic activities that were part of these. The later workshops explored and explicitly integrated the social processes involved. The maps were then presented back to all staff who had been involved in the process mapping and then subsequently to all hangar staff for further validation. Additional validation was done opportunistically, using interviews and small group exercises whenever an opportunity presented itself, e.g. after meetings, during task downtime etc. In addition, updates were put up on the hangar floor and staff was invited to note any comment they had on the map itself. Based on this a final version was agreed and used as basis for further research activities.

4.3.3.2 Introducing the blocker report

An initial version of the blocker report was designed based on the proposed conceptual approach. After introducing the initial concept to the staff, the blocker report underwent several iterations, more than 20, as part of iterative consultations and informal user test studies. While the core concept proved valid in these, the iterations addressed issues around wording and language, optimisation of representation of the process map, refinement of categories, e.g. outcomes.

The blocker report was implemented as a paper based system with the view of providing an electronic option going forward. The improvement team collected information initially, then it supported the reporting after meetings, until gradually the benefit became apparent and staff started reporting without this support.

Staff received introduction training in a class room setting, outlining the rationale and its role in the improvement context as well as a step by step instructive run through the sections of the report. In addition, written instructions organised around the report sections were available to staff, one copy put up on the wall where the forms were kept. It included short explanations of each step and its format and examples for illustration.

4.3.3.3 Blocker data monitoring and management

Blocker reports were available and staff was iteratively invited to fill them is. As part of the action research agenda improvement team members were taking part in operational meetings. If events were discussed in those which qualified as a blocker, this was followed up by the team members.

The collected data was transferred into a central data base, using Microsoft Office Excel, and analysed in SPSS.

Within the blocker report design there are elements that defined activities which instantiate social processes. Solutions are to be agreed within the team, as explained earlier in this chapter (e.g. to broaden the knowledge base). This can be regarded as a first step towards knowledge transformation. Reviewing the blocker gives a shared baseline understanding of the operational situation reported, and this is then collaboratively transformed into a solution suggestion that promises a better outcomes.

In the future, the data model is to be integrated with other organisational data stream to be able to more flexibly support wider change agendas.

4.3.3.4 Knowledge transformation activities based on blocker trend

The Knowledge transformation events are reported in detail in section 2 of this chapter (knowledge process), which shows their role as part of an improvement process. There were two dedicated KT event run as part of the process to resolve blocker. Both took inputs from the blocker reports in form of trends but only one fully implemented the model based KT approach. The other fell short of doing so due to factors outside the control of the improvement team.

4.3.4 Results

The following provides an overview of key results that the implementation of the framework into a dedicated report delivered. As discussed before, the blocker report as a dedicated methodology is a result itself and was introduced in the methodology section of this chapter.

4.3.4.1 Process maps

The outcome of the participatory approach to process modelling was a generic model of the check, including the interfaces with key stakeholders both during set up and actual work on the aircraft (see figures below). In contrast to the first case study that introduced technologies in to the process, the focus

shifted from activities themselves to the higher level of modelling: gate/states. The rationale for this shift was that engaging with the operational situation showed that interdependencies rather than technical details of the process offered access to vulnerabilities in the process. Once vulnerability was identified in the process, more details can to be mapped or discussed as part of KTWS.

The map shows generic activities at Check level with interfaces and pre-phase. Key are the phases and gates, those are in line with check milestones and critical path but include more information, not just task information based but coordination flow and representation of interfaces, leading into system. The new process maps are not meant to replace any check documentation that document aspects of the process flow, e.g. check milestones, but enable access to and support of additional functions which are executed today outside formal structures.

The coordination nexus in the maps gave access to wider system dependencies and at the same time identified key stakeholders for the improvement process that was to be designed to address the documented issues. The model of the process activities and its associated stakeholders grounded an integrated, systematic process that targeted system performance, and included the following functions: reporting; identification of escalation path and key stakeholders; solution derivation; KT activities, and feedback mechanisms (see section 2 of this chapter).

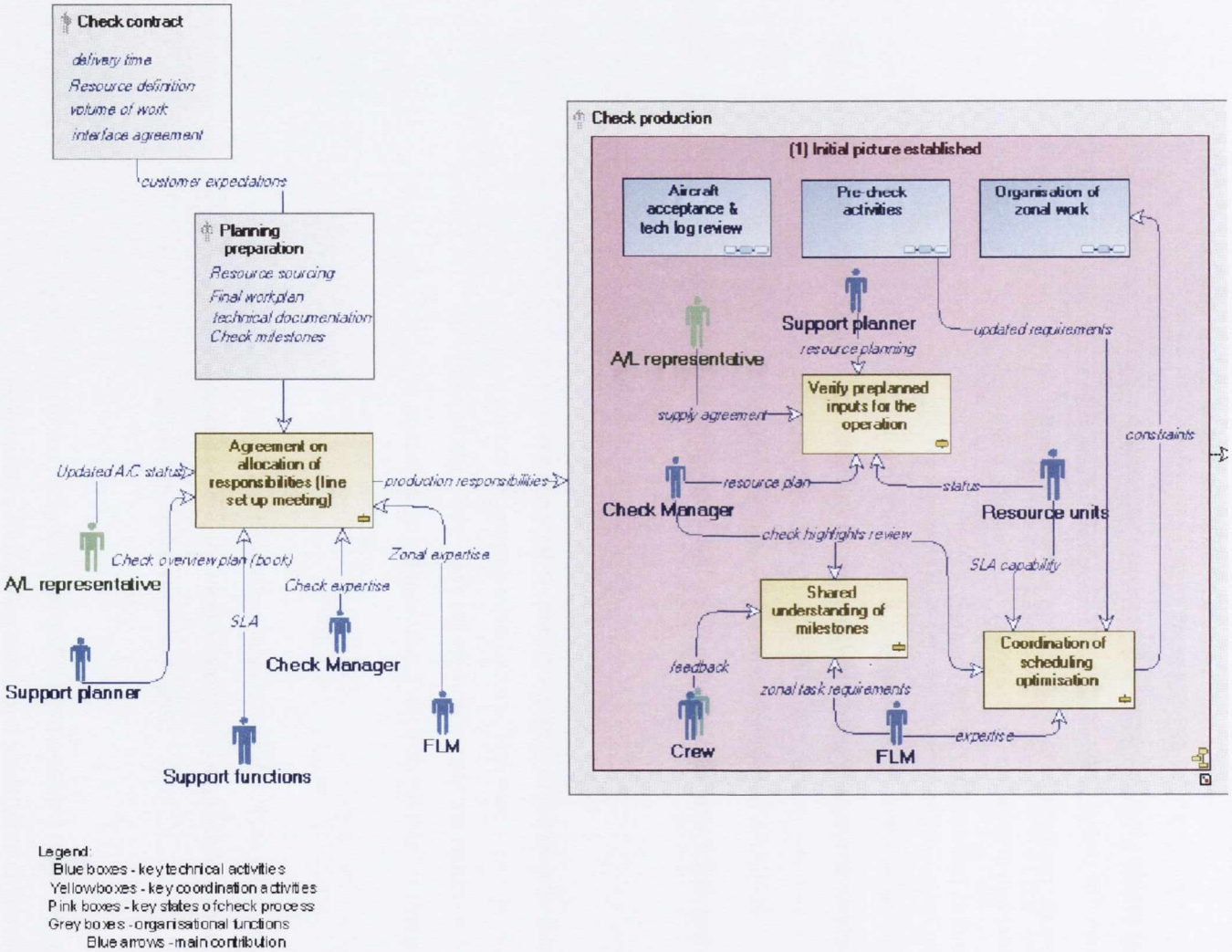


Figure 13: Check process activity model - Part 1

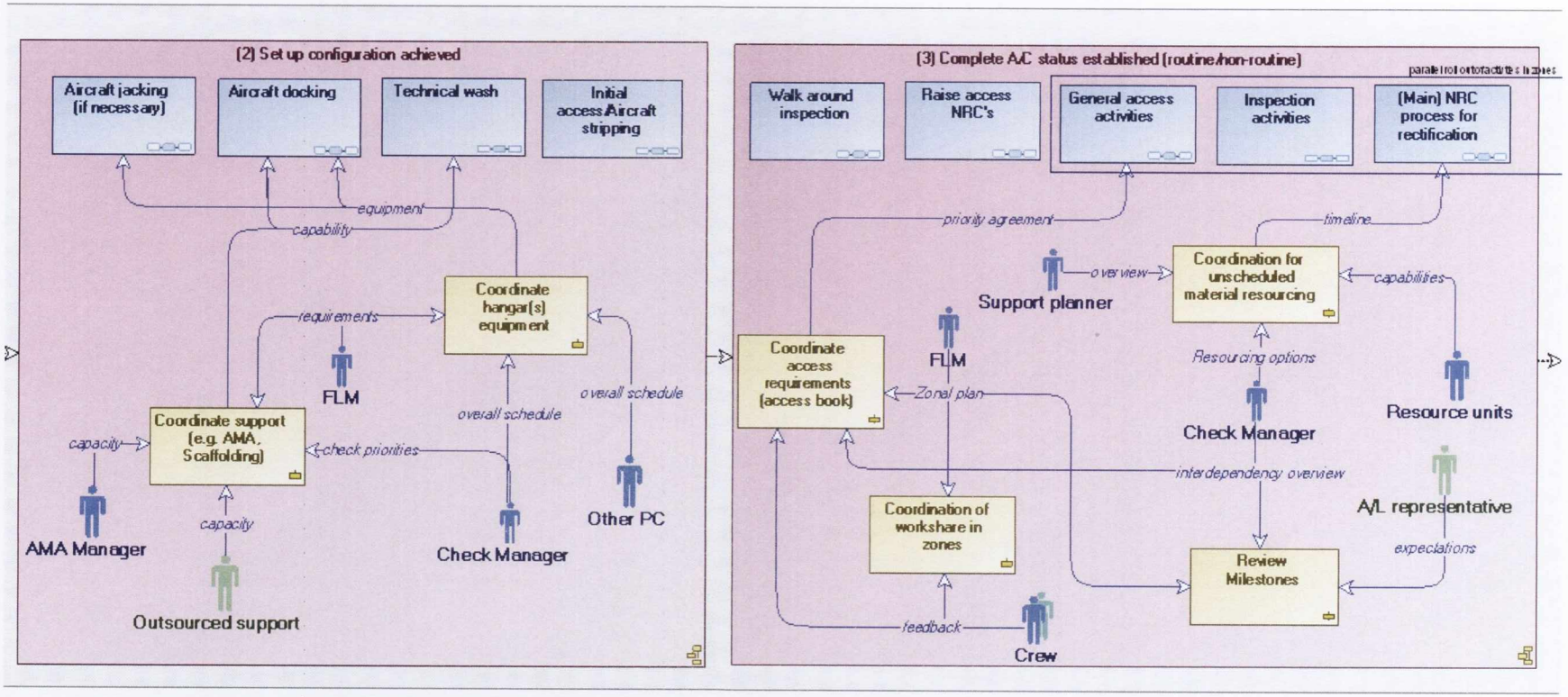


Figure 14: Check process activity model - Part 2

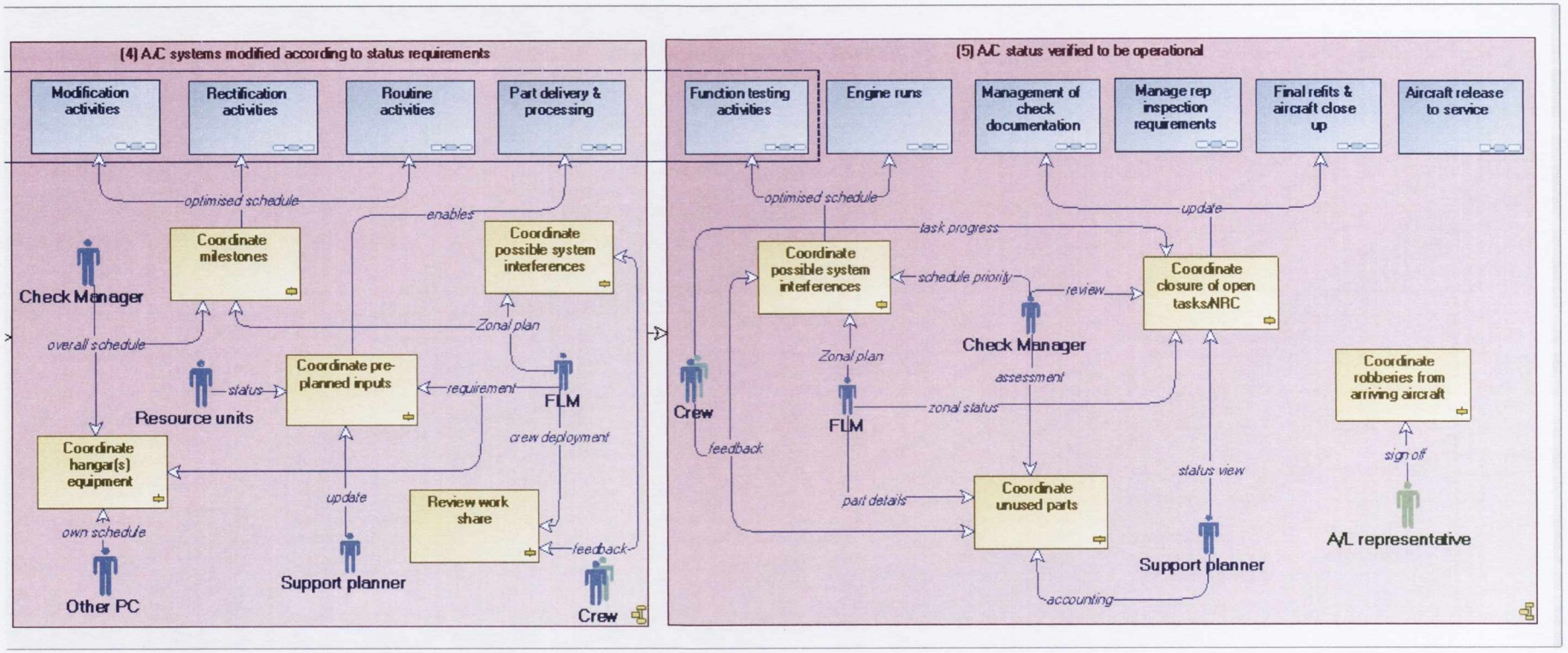


Figure 15: Check process activity model - part 3

4.3.4.2 Systemic issues in the maintenance system: Blocker trends

The analysis is based of the blockers gathered during the performance of check 1 to 10 on the HILAS case study check line. It shows trends in blockers to the operational process and their consequences as they have been documented during the check activities and their preliminary analysis.

The data used in the analysis are blockers collected in the wash up meeting of check one to ten on the HILAS case study check line (from Sept 07 – Dec 07), using the dedicated template to systematise and manage the information available per blocker in line with the proposed conceptual framework.

Results were organised around the following dimensions

- Frequencies in blocker categories
- Status of blockers
- Recurring blockers
- Outcome
- Blocker occurrences' location and knock on across check process

A total of 141 blockers were captured in the template. Table 18 gives an overview of frequencies in the different categories.

Table 18: Frequency of blocker per category

Categories	*Frequency*	*Percent*
Material resources incl.	**63**	**44.7**
Tools	1	.7
Parts/Materials	34	24.1
Equipment	28	19.9
People resources	**25**	**17.7**
Information resources	**10**	**7.1**
Process dynamic	**9**	**6.4**
Environment	**19**	**13.5**
Base Mx System/Contract	**3**	**2.1**
People system incl.	**4**	**2.8**
Team definition	2	1.4
Communication	2	1.4
Aircraft technology	**2**	**1.4**
- Not categorised -	**6**	**4.3**
Total of blockers	***141***	***100.0***

A summary of the results which are further detailed in the Appendix 2 shows that a lot of the issues occurred at interfaces with other process, when activating resources as inputs into the process.

The classification system adopted KSM categories such as resources, which attracted a high number of blockers, in particular parts and equipment. Figure 16 gives an overview of the status of blockers reported in each category, with three options, including fixed, i.e. the blocker was resolved, under review, i.e. the blocker was raised with the relevant stakeholders and a solution was being pursued, and open, i.e. it had not been possible to start a productive review process . An additional bar indicated the number of blockers where no data was available on the status. In combination with the status of the reported blockers it could be seen that it was also here that the highest number of blockers' was under review, rather than being resolved as it was in other categories.

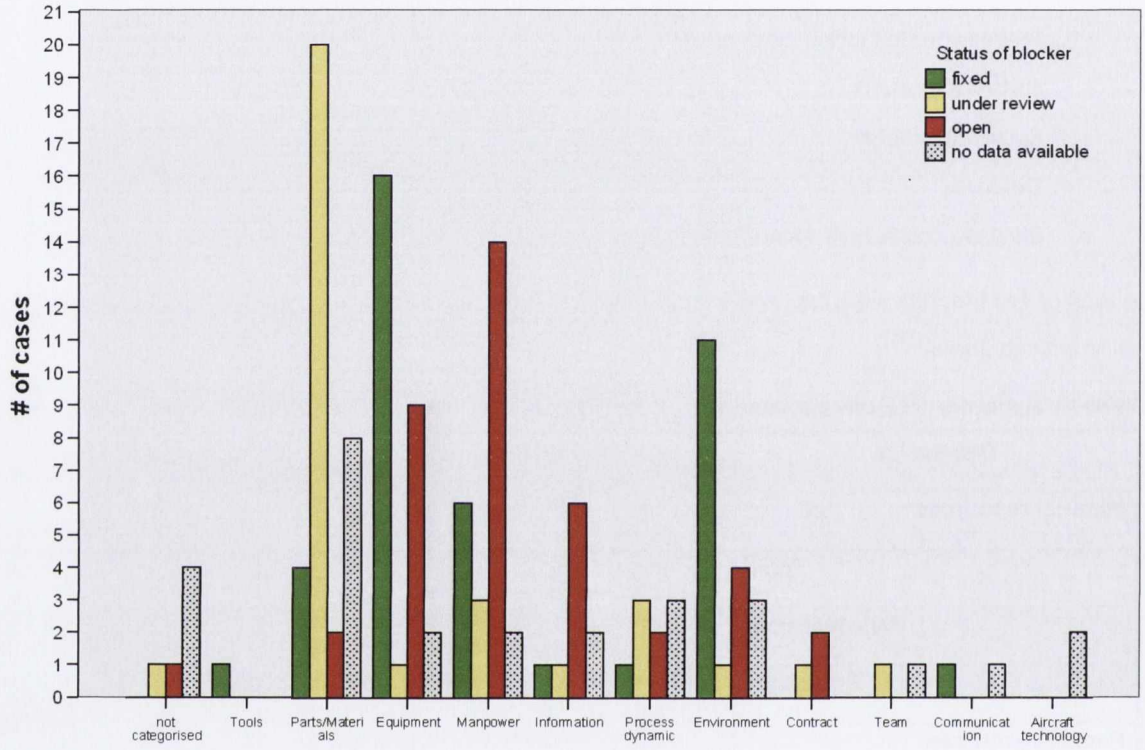


Figure 16: Frequencies in each blocker category, including their status (resolved, under review, open)

The impact that these blockers had on task performance was also measured. The total number (n=231) of reported outcomes of blockers was higher than the number of blockers reported (n=141). This is due to the fact that in some cases it was felt appropriate to report more than one outcome. In most cases the occurrence of a blocker resulted in an interruption of the task. The impact of this was usually mitigated by local rescheduling (one of the frequently reported consequences). Other outcomes included work-arounds (alternative way of progressing work) and leaving work in an incomplete state until it could be resumed.

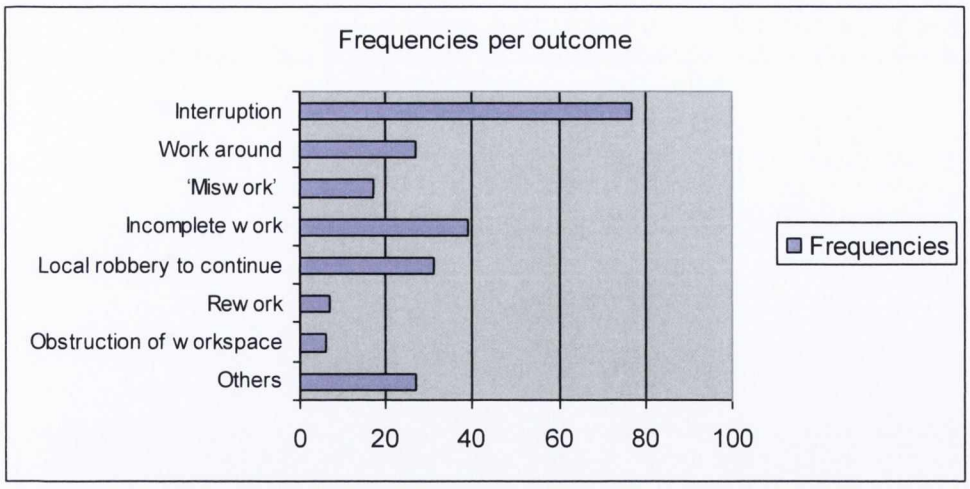


Figure 17: Frequencies per blocker outcome type

The blocker report data identified where in the process the problem was encountered and where it was expected to or already had knock-on consequences. The highest occurrence of blockers was reported in the routine work phase. This can be linked to the issues in regard to parts/materials provision into the operation. In general the rectification phases (routine and non-routine) as well as the close up seem to suffer the most from knock on consequences of blockers occurring during the course of the check. This matches the perception of staff as those being vulnerable phases, including the increased workload experienced towards the end of checks. It demonstrates that system dependencies have to be managed in earlier parts of the check or upstream from the check to reduce the down-time in later phases of the check process (a finding that would appear to be supported by Baranzini, 2009).

Additional results of the blocker data analysis can be fund in Appendix 2.

The blocker results also confirm results of case study 1 which showed a similar pattern of issues, based on the outcomes of ethnographic research methodologies; more specifically in regard to immediate task outcomes and internal rescheduling as well as showing the multifaceted criticality of set up phase and the vulnerability of the close up phase.

4.3.4.3 KTWS events

The KT events and their outcomes will be introduced in the next section as part of the process that is enabled by implementing the KSM approach and its operationalisation in the blocker reporting. Here they are referenced as a means to extend the validity argument started Chapter 3. The model based approach was validated in several iterations by subject experts, i.e. a range of operational and management roles, and by demonstrating that it is able to deliver a to-be version of the operational processes and relationships. Here the same framework is implemented in a different context, organisational improvement, and its basis operationalised in a reporting process. The success of the KT activities building on the blocker data and the application of the overall approach furthers the argument of its validity.

4.3.5 Discussion of results

Chapter 3 developed knowledge structure that systematises the operational knowledge about how the aircraft maintenance system functions, including informal practices and tacit knowledge that are core to

socially based functions. While in TATEM the models themselves were used as a platform for the resulting knowledge process, the HILAS case shifted the emphasis to an organisational application context. Key principles and dimensions of the knowledge structure were translated into an operational report that defined a new data stream in the organisation which provided a starting point for a new organisational process for operational process improvement.

4.3.5.1 Blocker report

The reporting format introduced here provides a novel way of addressing some of the challenges as experienced by staff in the maintenance system.

In its current application on the hangar floor, the place of production, the blocker report is a dedicated report to systematically capture operational issues for the sole purpose of improvement and better support of the operation and is novel in that it uses an account of the real system, including informal practices as a reference point.

The blocker collects data into an existing knowledge structure that is built on people's knowledge of the functional dependencies in their socio-technical system as it actually operates. This explicitly addresses the issue raised by Tuomi (1999) that identifying relevant data builds on an existing knowledge base that guides the selection. The definition of a data model underlying the blocker report is implementing key parameters of the KSM model base developed in Chapter 3.

The reporting outcomes provide a starting point that makes the improvement process which is build around is sustainable. The reports are linked to a systematic account of how the process that it reports on actually works. Integrating core conceptual dimensions systematically, it provides a rich picture of operational reality in which the blocker is positioned, and evaluated against, to deliver solution that are not ad hoc and short-lived but grounded in an understanding of system dependencies. Its conceptual structure grounds operational issues in their process context, highlighting knock on effects and what makes certain check phases more vulnerable. It then extends the account of them as a symptom into understanding the dependencies that underlie it, as demonstrated in the panel chart blocker resolution that triggered a change in an IT system at corporate level.

However, relevant knowledge is not sufficient in itself but to be useful in leveraging the situation it needs to drive a process that utilises it.

Throughout the process that uses the blocker data (starting with the population of the report and ultimately demonstrating the implementation of sustainable solutions) the KSM framework and its model base are anchoring the activities. In this approach the knowledge is made accessible but remains partially true to its tacit origins. It is represented in its functional context that encompasses the formal but more so the informal practices that are managing the inherent uncertainty of the system. The design of the blocker report based on the proposed framework and includes a process model as reference points and follows a generic narrative structure is another implementation of this.

The implementation of the blocker report as part of the check meetings and daily work allows for gathering blockers on an ongoing basis. This realises a core idea of CI as its associated process iteratively

resolves the blockers that are raised. Other approaches, e.g. Kaizen events as part of lean initiatives, take place once, with concentrated effort and are then followed up once or twice to evaluate implementations. After the event, new issues or 'waste' are not identified. Furthermore, the improvements are not only continuous but also sustainable. The two main reasons for this: solutions are designed in a collaborative model based process with management support and the blocker reporting would flag if there was any recurrence after the solution.

4.3.5.2 Data trends

Instead of anecdotal evidence and ill-perceived complaints, the blocker report creates a data stream that shows what hinders processes and how remote processes can have an impact on the operation. Following a systematic inquiry that positions the issues in its process context it allows for tracking the dependencies to develop a transparent and coherent argument for change requests.

The data captured in the blocker is process data, based on activities and how their support or lack thereof affects outcomes at different levels, rather than the traditionally employed KPIs that are linked to outcomes. The blocker data demonstrates where the system is vulnerable. A good example is the panel chart blocker. The analysis of the data showed a recurring issue that had the potential to create knock on consequences (i.e. improper close up) across the check which pose a threat to safety. Thanks to the new blocker data stream it was identified before it caused serious consequences, beyond additional workload in the check.

However, there are qualifying circumstances: the role of existing relationships and coordination. As discussed in many places in this thesis, informal practices are established that are crucial for making the formal system work. While the proposed framework has made them more accessible and systematised critical knowledge, this does not mean that they stop being used.

The differences in total numbers per category may be partially explained by the differences in awareness of blocking circumstances and the level of control through existing practices. In certain areas people have established routines that mitigate the effect of configurations that pose a potential blocker. One interpretation (based on knowledge accumulated about the aircraft maintenance system as presented in previous chapters) is that some internal challenges (e.g. process dynamic, information) can be solved on the spot and therefore it is less likely that staff would take the time out of their busy schedule to report them.

If that was the case, it would be useful to increase staff's capacity to report on those or to monitor their resolution to ensure the issues are optimally addressed rather than continue to be worked around. This defines a requirement for the wider improvement process. There are strategies which were adopted to address this. Firstly, the KSM framework and its modelling approach draw out patterns of informal practices and the blocker report gives access to reporting against them. This could be extended in the light of the origin of blocker concept in TATEM and ask for facilitators, one of which is a solution negotiated Secondly, implementing a transparent improvement process with effective data strategy is regarded as key to secure and sustain staff engagement. Having an overall education effort around the concepts,

merits and benefits of the improvement initiative and it processes aimed to demonstrate the benefit of those gradually becoming all encompassing. In other words, people would realise that blockers that are 'no bother' to fix on the spot can aggregate and the overall check benefits from addressing them with a permanent solution. Another facilitating element in this is the fact that many of those relationships which are utilised in fixing local issues are addressed as part of the improvement process and become better defined and supported.

Another way of completing the picture obtained by reporting could be to obtain data on interactions (ethically and responsibly), such as e-mails exchange, telephone calls, approximating a social network methodology to highlight areas of intense coordination.

However, even if not every blocker is reported the ones that are give new insights into the operation. The capacity to represent operational issues is transformed from a tension between anecdotal evidence and formal indicators to a systematic appreciation of the operational situation and its system context.

4.3.5.3 Conclusion

The main achievement was to operationalise the conceptual framework into a report that built on a model base incorporating hidden and tacit knowledge about the systems and thus, in aggregation, gave insights into how the real system functioned across the lifetime of the check line, with the explicit aim to create a return on people's knowledge investment. While it is incorporated into their daily practices it nevertheless required a small amount of extra work which, as part of a process, turned out to be a well placed effort and the start of creating value not only for the operation but also the organisation as a whole.

Within the blocker design the ground work is done for developing an analysis of dependencies, such as 'knock on' or interfaces but those have to be systematised in a follow up in process. Having relevant operational data and especially its analysis in system trends was a useful means for communicating with senior management. However, the blocker and its resulting data and information stream is not a means in itself. Without the 'meat' of blocker narrative followed up in its system context, it is insufficient (see also Tuomi's argumentation, 1999) and thus requires a knowledge based process to build towards sustainable solutions.

4.4 Section 2: Knowledge Process

This section addresses **Research question 2**: How can the proposed framework enable a knowledge based process for delivering effective changes in the maintenance operation?

It is going to outline the design and implementation of a process improvement process that manages the new knowledge generated by the blocker report.

4.4.1 Background

In the context of previous chapters, especially chapter 2 and the first section of this one, the following does not reproduce the existing review but highlights aspects that are salient when it comes to dealing with the implementation of an organisational process that uses the framework with the view to improve system performance.

4.4.1.1 Continuous improvement

Continuous Improvement was the driving force behind the central group agenda. In the previous section the generic principles of CI have been discussed and potential limitations have been highlighted.

Here the focus shifts from the monitoring the operational situation which triggers improvement activities to how those are designed and implemented. An organisational process is to be designed which takes data in from the operational reports or other inputs and follows a problem solving approach, i.e. a version of identify - analyse - plan - implement - evaluate. This is relatively easily translated in a series of process steps, which actual implementation depends on the conceptual basis adopted in the organisation, e.g. lean thinking or Total Quality Management (TQM).

In Continuous improvement approaches like Kaizen which originate in the Eastern hemisphere, a particular emphasis is put in the social setting in which people collaborate to improve their work situation. Compared to the problem solving steps, there is less clarity on how to translate these social aspects into activities.

The conceptual basis for the understanding the target of the improvements, the operational process, is establishing an account of how technical and social aspects are intimately interlinked in the actual practices of an operational system. The same principles apply to the organisational process designed to extend the capability of the operation process itself as well as the wider organisation to collaboratively drive process improvements. This directs how to deal with social aspects and knowledge in the improvement process design.

Traditionally, continuous improvement seems to be mainly concerned with efficiency. In the HBR blog (Ashkenas, 2012) and the ensuing discussion it is argued for a shift from efficiency to effectivity – a concept that strongly resonates with leverage. As argued before, leverage is realised at a system level, addressing interdependencies that exceed the local understanding of the situation and thus requires a knowledge base that represents a consolidated view on how the system actually works (compared to prescriptive formal accounts).

4.4.1.2 Social aspects

Communities of practice (CoP) have been discussed in Chapter 2 as a representation of a social structure that originates in shared practices which may or may not be part of the formal system accounts. In CoP, which are not defined by the formal organisational structure (though this may coincide), relationships between people are defined based on a common interest and create a shared knowledge base that benefits their work.

Brown and Duguid (2001) have extended this notion into networks of practice. This allows the transfer of core principles to a situation where people collaborate constructively without having the proximity that is implied in communities of practices. The advantage of not being constrained by formal procedures is preserved when creating a knowledge repository this set up.

Another approach to understand how groups of people work together in their processes is the work of Hackman and colleagues (e.g. Hackman, Wageman, Ruddy and Ray, 2000, Hackman, 2002). It defines the

condition for effective team work which includes: compelling direction; an enabling structure and supporting context; and available expert coaching (e.g. Hackman, 2002)

Ward (2005) has done a meta-analysis on three change initiatives and concludes that relationships and their qualities, e.g. trust, are core to effective improvement and change implementation. The quality of relationships has an influence on how well knowledge is shared and collaboration is effective in delivering the expected system performance standard.

These theoretical view points inform the design of process activities and the complementary re-design of the existing social structure by introducing new practices. New improvement practices are implemented and the engagement with those is fostered by dedicated effort in the team and cultural engagements strand of the initiative.

4.4.1.3 Change agents

The thesis approach in which transformation of systems is driven by knowledge adopts an interdisciplinary take on theory, design and methodology and through that delivers an integrated argument in its own merit. Change management is an umbrella term that gives a forum to discuss a variety of studies from diverse fields with little empirical research on its mechanisms (McDonald, 2008). Key concepts and arguments are taken up where appropriate (e.g. the role of management commitment).

A central concept from the change management literature is 'agent of change' which mostly refers to people driving change implementation, but can also include inanimate catalysts such as objects or programmes. Then again this idea is not exclusive to the change management literature. Brown and Duguid (1998) discuss roles with similar characteristics in the context of CoP in what they refer to as brokers of knowledge and translators.

This concept is especially applicable in action research which gains insights from intervening. In doing so, per definition, the researchers are agents of change who, due to the participatory nature of action research, are joined by staff involved in the programme. These can be characterised in two categories: external and internal agents of change who both have strengths and limitations.

4.4.1.4 Knowledge Management

In the knowledge management literature two main processes can be distinguished: knowledge creation and knowledge transfer. Chapter 2 has given an overview of how these can be further organised:

- Knowledge creation
- Knowledge storage/retention
- Knowledge transfer
- Knowledge application

These are addressed by various disciplines, but rarely in a manner that integrates these. Wickramasinghe (2003) did a review of the success of knowledge management initiatives in three major corporations and comes to the conclusion that while all have successfully built up organisational memory the actual knowledge management capabilities were less well developed. It illustrates that capturing knowledge is not an end in itself, but has to be effectively moved into utilisation of said knowledge; while the creation

of knowledge is described often the outcomes are then stored and not used, or at least not as effectively as one would have envisaged.

4.4.2 Methodologies

4.4.2.1 Action research elements

The action research was designed to be participatory at all stages. A key aspiration was to make theoretical concepts accessible in an operational context, from reporting to designing a process to new ways of thinking and feeling about change. This required an iterative collaboration between the different partners in this case study. Means that were taken included open communication, iterative clarification, addressing professional language barriers, feedback mechanisms, collaborative work settings (e.g. workshops, meetings) and others as appropriate.

The Improvement team acted as change agents, comprising external and internal staff. This concept was extended into the HIT which were designated to manage the improvement process locally as well as all participating staff who implemented the initiative and got involved in communications with future participants and had an impact by 'word of mouth testimonials'.

4.4.2.2 Organisational process design: Blocker resolution process

Blockers are interfering with process progression – the flow of the process or at interfaces. This functional logic of the process is defined by interdependencies. Coordination activities in the process manage those. A blocker described a situation in which a dependency (or many) is frustrated.

Transferring the logic of managing the issues in the operational process to resolving what blocks them highlights the requirements for effective coordination in the blocker resolution process. Coordination in adverse configuration is one version so coordination that constantly occurs around dependencies. The resolution coordination is therefore linked into the process, but formalised in new process. Also there is a requirement for transparent escalation mechanisms. Doing the same coordination function in wider system context, required access to those functions that are only indirectly linked to and thus only partially accessible from the daily operation.

The new process was designed into existing structures, mainly for two reasons. Firstly, it was practical in that it reduced effort in setting up new structure, workload for participants and time commitment in an already busy organisational schedule. Secondly, it highlights that the blocker resolution is not a separate process but an integral part of doing business effectively and safely as an organisation, not just in one department. In contrast, previous improvement initiatives which were perceived as falling short of expectations, were linked one department or designed as an extra, add on activity.

Going back to the Chapter 1 discussion of the importance of relationships to utilising knowledge in complex systems, this design decision also offered the opportunity of building on existing relationships. As part of a meeting schedule people who interacted regularly and had built relationships, were given new tools and inputs to more effectively respond to the operational situation. This creates the capacity to transform existing relationships.

4.4.2.2.1 Model based knowledge transformation

The model based knowledge transformation methodology in this thesis extends the approach developed by Nonaka and colleagues (e.g. 1994, 2000) as part of his knowledge creation process that is based on four modes of conversion in a structured social setting. The following principles are core to it:

- Model as reference point to establish shared understanding
- Framework dimensions to guide the areas of creation and transformation
- Requisite variety as defined by the model and redundancy in participants
- Agreement on target & objective
- Fostering constructive interactions, e.g. open communication, discussions in a directed social setting (model based knowledge exchange)

A critical difference to the Chapter 3 KT activities is the application context of the framework. In the TATEM case study the objective was to create a vision of a future operation of maintenance processes, which necessitated relying on assumptions in regard to operational, technological and social aspects. Here the application context was an existing system, with stakeholders in existing relationships with each other, mediated by departmental performance targets.

In an organizational application, there are different entry points into dedicated knowledge transformation activities which can be seen as spanning from tactical response to incidents to strategic innovation. Triggering dedicated KT events are the following:

- Addressing a specific case
- Dealing with trends in existing system
- Envisaging a future based on emerging capabilities

The participatory review of the KT principles as part of their design and their ultimate implementation into the process activities or even a dedicated event highlighted that the high level logic and the resulting interdependencies was the most appropriate level for engaging diverse stakeholders. Since it was at the higher level that the system functioning had to be understood, detailed process descriptions offered little initial leverage of the situation.

In addition to defining the appropriate level to engage in a review of systemic issues, it also proved to be the right level at which processes could be effectively communicated to each other among different stakeholders. People all had an initial understanding of the system which as part of the set up and the workshop itself was consolidated into a fuller picture. The re-configuration and transformation into a new shared understanding was done more efficiently and effectively at a level of generic dependencies and how those are managed in reference to process outputs. It enabled participants to share what their processes required, without entering a detailed discussion of all process activities which would have required technical expertise to fully appreciate it. Within the framework there is always the provision that more detail could be elicited, if required in any step of the process.

In the blocker resolution process KT activities are integrated in every step: starting with developing the model of the process that is reported against in the blocker which itself incorporates a KT iteration when it

is reviewed for the purpose of developing of suggestion in with all crew members to the activities in each escalation step, including dedicated KT events.

These always require multiple participants, and thus create a social situation. Every iteration was targeted to progress the optimal solution and was informed by the full picture of how dependencies are managed in coordination activities in the process.

4.4.2.2.2 DMAIC as problem solving methodology

DMAIC stands for Define, Measure, Analyze, Improve and Control. It is a generic problem solving or improvement cycle that is used in Six Sigma projects, though not exclusively (e.g. Womack and Jones, 2003).

DMAIC provides a formal structure that can be implemented as part of different conceptual context. It provides rigor in terms of structure for a process, but the quality of its outcome relies on the concepts which are used to realise the steps.

The blocker resolution process draws on this methodology and builds on its steps to implement a process that each iteration is informed by the model based knowledge approach to deliver solutions and makes use of KT principles as outline above.

4.4.2.2.3 Social structure

In correspondence to the process activities the social structure was re-organised. New teams were established and the remit of working groups expanded. Hackman's team characteristics (e.g. 2000, 2002) are one way of describing the features of the design. Implementing the process created real groups with boundaries, interdependence and differentiated roles. The improvement task that was at the core defined a collective responsibility for outcomes in the group. Within their organisational context, they manage relations with larger social system.

The implementations of conditions that are conducive for effective group work are summarised in the result sections and are organised around the three principles that Hackman promotes (e.g. 2002): compelling direction; an enabling structure and supporting context; and available expert coaching.

4.4.3 Research activities

Research activities were varied and followed the action research logic of iteratively review if impact was being achieved as expected (iterative action research cycle of plan – act - observe- review). The improvement process and its knowledge transformation components are two good anchoring points for giving an overview.

4.4.3.1 Improvement process

The improvement process was developed iteratively in collaboration with staff and management. The improvement team attended all types of meeting as part of communication and managing the agenda, but at the same time those offered insights in the functionalities and goals of each of those, spanning different levels: local to management. This facilitated the identification, together with staff, of the appropriate meetings to be included into the improvement process design.

The blocker concept gave a heuristic to systematise what relationships had to be established or managed differently to support all process dependencies and blockers that could arise from those. Relationships between the operation and support were established or re-defined to allow for direct blocker resolution capabilities on the shop floor, while the escalation of blockers was designed into the existing processes and organizational structures.

Integrating the blocker escalation into the existing meetings gave opportunity to communicate the approach widely before implementing it. In this it was attempted to convey the point that although the operation was as a baseline for the business and thus the focus of the initial rollout, the improvements would affect system performance and benefit the overall organisation in sustaining a viable future.

The blocker resolution process development was led by the improvement team, with participation of a selection of staff from hangar manager to crew managers to AMEs and AMAs, representing different work categories (e.g. sheet metal, avionics) and different zones of the aircraft (e.g. wings, landing gear, cabin). While it also supported the implementation and pilot run, an operationally based team (HIT) was established and trained to fully take over the process in the long term. As part of designing the HIT, needs for training were established to address the change in their job description and thus in the skill sets required. Those training elements included general change management context, continuous improvement, and specific tools and technologies, e.g. blocker template or DMAIC. In addition, project management and meeting facilitation skills were trained.

4.4.3.2 KT activities as part of the process

There were different types of activities that implemented KT principles as part of the process

1. Modelling the check

   As laid out in the first section of this chapter.
2. Blocker reporting & team suggestion

   As laid out in the first section of this chapter.
3. HIT team local blocker solutions

   The Hangar Improvement team were running KT activities when they reviewed blockers and collaboratively identified solutions with their designated contacts in the support departments (which was formalised and or established as part of the blocker resolution process). They were also trained in DMAIC to ensure rigor of their process and guide its documentation.
4. Meetings for escalating blockers

   As part of the escalation strategy of the blocker resolution process, KT principles were used in meetings that addressed blockers that needed wider input and decision power. Relevance (i.e. requisite variety) was ensured here, and possible redundancy of roles by inviting identified stakeholders (even if they were not regularly part of the meeting) and non-management staff with key knowledge.
5. KT events (workshops on complex issues)

   In addition to these regular activities, there were two major KT events. They were triggered by blocker trend data: one focusing in a persistent blocker that recurred several times across checks

and the other on a peak in blocker occurrence, with the qualifying characteristics that a large percentage of the given high total number remained under review and could not effectively be solved.

4.4.3.2.1 Building a KT case

In a first step the relevant operational models are identified and populated, building a knowledge base. This is an initial knowledge transformation itself as it sees the integration and consolidation of all key stakeholder viewpoints in one single account that focuses on the generic aspects and high level functional logic. The collaboratively developed check model was used to extend the understanding of the operational situation as reported in the blocker report.

The target in the process defines the group of people that is required to participate in the problem solving. It includes staff actively involved in executing the process activities as well as representatives of functions associated either via process interfaces providing inputs or taking the output or of parallel independent activities that influence or compete. If required it can also involve staff of the processes that are further remote but linked to the target process via a value chain. These second group of potential participants can – if required for practical or economic reasons - have a reduced involvement, i.e. called on as experts on certain aspects, either directly or indirectly, in person or remotely. Once the required participants are identified they are briefed on the objectives and presented with the existing information. It requires the facilitator to coordinate with the sponsor (senior management), the potential participants as well as their line managers to ensure their participation in the following process activities.

The model of the operation is the reference point for further activities. Initially it is validated with the group to ensure that as a reference it is current and matches everyone's experience of the current operational practices. Getting an agreement on the model establishes a shared understanding of the operational reality that is further worked on and subsequently modified.

Identifying the change requirements to meet the target/objective of the particular transformation process is facilitated by using the KSM framework. The process system which is frequently perceived as being mostly technical can only be understood by analysing its human and social dependencies. The KSM dimensions guide a structured discussion of the blocker and thus ensure that all socio-technical aspects are explored. The outcome of the participatory activities guided by the KSM framework is a list of requirements for change. Those can be translated into an updated OPM, including relevant annotations.

The requirements are shortlisted in regard to their expected impact on the desired outcome of the envisaged change (relevance and leverage). The change requirements that receive priority and then further discussed to develop an implementation proposal. Envisaging process changes is not restricted by anything – people should feel they have creative space. It is only here that organisational realities such as finance, politics and others can be taken on board. There is an option to develop a best case scenario and then create a caveat based on the knowledge of existing constraints (internally, e.g. limited finances or externally, e.g. regulatory constraints). Depending on the envisaged change the proposal may affect additional stakeholders (e.g. via new process interfaces) which need to be consulted. The implementation proposal should be very specific and practical, also outlining envisaged responsibilities for each

stakeholder. After being presented to the decision makers, the proposal based on an informed view of the problem is further reviewed in terms of the practicalities of its implementation as part of balancing economic realities.

4.4.4 Results

4.4.4.1 Blocker resolution process

In order to make use of the blocker data stream, processes that take it as an input had to be identified. Reviewing the existing situation in dealing with data collected from the operation, it became clear that a dedicated process had to be designed. Existing reporting functions that were related to improvement (e.g. task amendment form or quality discrepancy report) were all owned by other departments and processed there.

Putting the operation at the core conceptually was followed through by defining it as the driver of the improvements. Therefore, a process owned by the operation, sponsored by management was designed that interpenetrated existing organisational processes to enable escalation of issues. This was a key requirement as the distributed nature of interdependencies within the system resulted in many blockers that were at the face of it operational issues but required collaboration with diverse stakeholders, both internally and externally, to resolve them.

A process that became known as the blocker resolution process was designed around a series of meetings within the organisation. The improvement team collaborated with key management roles and staff in the hangar in developing the process.

Staff involved in designing this process set strong requirements for it to be simple and integrated in existing activities as far as possible. Aircraft maintenance as a set of people mediated processes is already heavily reliant on coordination for it to work, see chapter 2 and 3. These existing meetings and activities were built on in order to integrate the improvement task into the daily work practices and thus have staff see and experience it as a normal part of their jobs. In addition, a requirement was formulated that acknowledged the urgency of the nature of maintenance: empowering staff as locally as possible to resolve blockers rather than create extra work and time consumption in passing on information along the improvement process.

The blocker template included instructions to engage the team into identifying a solution proposal. As part of this step, staff through the crew manager had the option to use contacts in the support departments to suggest changes. If the blocker could not be resolved, it was addressed by the Hangar Improvement team (HIT). The HIT included the hangar/check manager, three crew managers (representing different trades - avionic, sheet metal and mechanical), six AMEs and an AMA (representing avionic, sheet metal, mechanical, and operative). There was an additional meeting introduced for the HIT which took place once a week for one hour. Within this group, the open blockers were discussed and possible solutions sought. The HIT team had dedicated contacts in departments that had interfaces with the operational process such as planning, shops etc. While informally relationships with these departments existed, they were

largely specific to people and their social capital in the organisation. The blocker resolution process formalised and standardised them following the interfaces identified in the check modelling.

Actions that followed from the blocker review were managed in a dedicated form which documented actions, their revision and timeline (expected, actual, closure) and also assigned owner to those actions. This was a critical tool for the escalation of more complex blockers.

The escalation that followed the inability to resolve a blocker or set of blockers at hangar level was managed in a series of meetings. The next opportunity to achieve resolution was the weekly meeting that involved the improvement team which had the base manager as key decision maker as a member. After that is was moved to the fortnightly meeting of the cross-departmental working group where operational departments met with support functions. The final step in the escalation of a blocker was to bring it to the attention of the Chief Operating Officer (COO) who sponsored the improvement initiative in a newly introduced meeting which occurred monthly between him and the improvement team. The COO had the capacity to action dedicated events in addition to the meeting schedule if a blocker was complex enough to warrant more attention that it could receive as part of any meeting.

The overall outcome of this process was the resolution of all blockers raised on that check line. They were resolved at different escalation levels and took different amounts of effort and time. A later section will showcase two complex blockers that were addressed in dedicated meetings and activities.

The data on the progress being made in addressing the blockers raised which was collected in this process was made available to hangar staff in the Blocker Countermeasure Sheet. This tabular chart was designed to be placed on a notice board in the hangar giving all staff a weekly update on the status of each blocker. It gave an overview of each blocker, including where it was raised, what its status was and which department had been allocated responsibility.

Information across all blockers was also shared with the customer. Before the implementation of the blocker resolution process, sharing of operational data was usually limited to a minimum as it was seen as exposing internal weaknesses and vulnerabilities. Here it was used to transform the relationship with the customer based on the communication of two key messages: Firstly, the blocker approach systematically defined the interdependencies with the customer processes and contract design, and made transparent the impact that the customer had on the operation. Secondly, it highlighted the commitment and more importantly the capacity for mitigation and improvement within the organisation with the aim to assure safety, efficiency and quality, all of which is in the direct interest of the customer.

However, while documenting the progress and making this information available is critical to ensuring the flow of the process and its transparency, it was the dedicated meetings (short, with focused agendas and clear outcome requirements) and the representation in the established company wide meeting schedule that became central to the initiative.

4.4.4.2 Social structure redesign

The blocker resolution process is designed around a series of interactions and thus did not only add new activities or transformed existing ones, but in parallel had an impact on the social relationships of those

involved in the process. The meeting structure as part of the process implementation defined a new social structure re-defining the scope of the existing relationships that were part of existing meetings and building new ones by establishing new working groups.

Within the overall improvement initiative, the HIT and the improvement team were designed as new working groups. Those were key actors in the blocker resolutions process.

The existing meetings, in particular the cross-departmental meeting, were extended in scope which redefined the relationships. This management meeting had shown characteristics common with an example that Hackman (2002) cites: an encounter with a group of senior manager that were regularly meeting but who did not perform as effectively together as the CEO expected (and they themselves) in taking on collective responsibility for the well-being of the company as a whole. Like the group of people in Hackman's example, here the different departmental heads had individual departmental targets that strongly influenced their agenda and actions. This is in Hackman's terms would define them as co-workers rather than an effective team.

The notion of teams is used to illustrate some of the changes in the social relationships that resulted from the blocker resolution process implementation. It seems appropriate as Hackman (2000) argues that real groups are pre-requisites for effectively working together and he defines those as having boundaries within which there are differentiated roles that are interdependent. Bringing the stakeholders together in the blocker resolution process builds in exactly those features: stressing the need of different roles involvement in solving an issue that result form the dependencies in the system.

The blocker resolution introduced new characteristics into the working relationships of the cross-departmental group which are in line with Hackman's conditions for effective teams, and which were also designed into the newly formed working groups such as HIT.

Compelling direction: The blocker resolution process purpose and associated activities were transparent to all stakeholders. It enabled defining a blocker which is a problem that manifested itself in the operation as a shared responsibility by identifying its system wide dependencies. The modelling bases allowed for goals directed discussion and eliminated the perceived anecdotal character and emotive content of previous complaints form the operational sector. It also gave a shared access point to engage with complex problems, which were the kind of blockers brought to the attention of this working group. The outcomes promised not only local improvements for the reporter but held the potential to become a template organisation of group wide transformation as in the panel chart example. The same characteristics applied to the design of the HIT which was dealing with another set of blockers.

An enabling structure and supporting context: All the key stakeholders required to address complex issued were assembled in the cross-departmental meeting. This is in line with requisite variety (e.g. Nonaka and Konno 1998) and Hackman's thoughts on the role of an enabling structure. However, there was room for optimisation. If the blocker was not related to their area some participants showed a tendency to lose interest. The meeting could have been configured to have engaged a subset of people in each blocker session and reports how the process worked to the whole group in the next meeting. The HIT

as a dedicated group had all the relevant involvement within manageable numbers. The context that the blocker process provided was supportive: it provided transparency in regards to outcomes and responsibilities, benefited from management commitment and delivered a dedicated approach to making information and knowledge available (as reflected in the independent evaluation outcomes).

Available expert coaching: This function was delivered by the improvement team who supported the implementation of the process, facilitated the blocker sessions and followed up on issues identified. The newly formed HIT was also supported in that way, and in addition received training in aspects of project and meeting management. This overall support was not limited to running the meetings but incorporated a steady presence of a dedicated HILAS improvement project representative in the company who disseminated the knowledge created in the process and continuously facilitated engagement with the process. Brown and Duguid (1998) advocate a similar role in what they call translator and knowledge broker (terms developed by the sociologists Susan Leigh Star and James Griesemer) in supporting the effectiveness of CoPs.

The activities in the third strand of the overall improvement initiative were instrumental in realising this social structure and energising its role in the blocker resolution process and the overall improvement initiative. Communicating the key messages and advocating the process merits was core to engaging all stakeholders.

The external evaluation showed that management was perceived as being supportive (Ward et al. 2009), which showed that the relationship had improved compared to the beginning of the programme where lack of management commitment and support was cited. Participating staff were asked about their general experiences and change in attitudes as well as outcomes and improvements that were achieved.

The HIT effectively engaged with contacts and were productive in collaboratively resolving blockers. The interactions grew more frequent and were defined by constructive exchanges rather than 'fighting ones corner', during which the HIT experienced new appreciation for their issues.

4.4.4.3 Knowledge transformation

In addition, the KT activities in the blocker resolution process meetings, two dedicated knowledge transformation events were called by the improvement team and supported by senior management in the face of complex blockers which were characterised by being cross-departmental, recurring and/or had strategic implications. Here both were based in blocker data trends: The identification of trends in the blocker data are a possible entry point in the KT activities. Other triggers can include severity of the blocker, e.g. a close call to a major incident, or a strategic decision, e.g. restructuring of a business area.

The panel chart workshops dealt with an information resource issue that recurred several times across different checks. The procurement event was triggered by the high frequency of material resource issues, and the high percentage of their status being 'under review'.

4.4.4.3.1 Panel chart workshop

The operational routine monitoring via the blocker template identified an issue with the quality of documentation provided for a set of maintenance tasks. The tasks could be done with the provided documentation but it involved several additional steps of information search and multi-referencing. This was perceived to decrease the efficiency (by consuming time) and increase the risk of work arounds (e.g. relying on memory) which could result in potentially harmful deviations. Attention was drawn to this issue by its frequency and recurrence in the operational reporting. No incident had occurred involving this particular documentation.

The panel chart is an example of a complex blocker that received the attention of a dedicated event. Its inherent complexity arises from the fact that its system dependencies span across organisations. Starting from the blocker manifesting itself in the operation, its follow up revealed that could be traced back from planning to a core IT based information capability of the group that was managed centrally.

It In addition to its inherent complexity, the blocker is also

- Recurring but not incident based (i.e. not warranting an official incident report)
- Targeting a function that is provided at corporate level
- Potential for change across the subsidiaries

In combination with its demonstrated operational impact that creates intensive aggregation of extra work, all of the aspects above justified a dedicated event which was sponsored by management. The decision was taken by management to support a knowledge transformation exercise on this target. It held the potential of an extensive benefit given that it affected a large set of maintenance tasks, amassing waste in the process.

Knowledge transformation activities were set up as part of the complex problem solving process that was built into the organisational process designed to resolve blockers. The group of participants spanned organizational departments, some of them liaising with external units to obtain additional information since it was not feasible for those staff to travel to participate in person. It was facilitated by the improvement team. The interaction started with briefing all involved staff and continued until the actual workshop event, building up a comprehensive picture of the challenge at hand which was presented at the final event. Staff involved broadened their perspective as a result and a possible solution was suggested in the final event, including the identification of roles and functions across sites that were in the position of carrying out the changes. The outcome was a change which implementations promised to improve the efficiency of the process, not only for the case study location but across all sites in the group.

Table 19: Panel chart workshop participants

Department	Role
Operational Area	VP Base Maintenance, Base Maintenance Production Coordinator
Planning department	Production Planning Manager
Engineering department	Head of engineering Manager Power Plant and Maintenance Programs

	Maintenance Schedules Inspector
Quality department	Head of Quality Quality assurance officer
Improvement initiative	improvement team, HIT representative

Description of the blocker

The panel chart blocker as an information issue was raised several times over the check. It was identified in the analysis as recurring, across several checks, with a solution still outstanding. Four reports were identified but in discussion with operational staff it became clear that it was more frequent but the motivation to report was diminished due to a multifaceted set of issues: the blocker had been a longstanding issue and was expected within the operational community. In addition it had not been acknowledged as a major problem yet nor been addressed by the blocker resolution process.

There were different aspects to the blocker:

It was associated with the inspection phase where access is required to determine the status of aircraft systems and as a result to identify additional maintenance work required. Crew managers were trying to mitigate the situation and as part of the organization of the work pack at the start of the check they went looking for additional information if there was time.

These additional activities were designed to make up for the fact that the information that was provided by planning was technically and legally correct but not organized in a way that supported the process logic of the work pack:

a) The panel charts were not organised by aircraft zone:

"For example, cards can come under; fuselage exterior, cabin door, landing gear nose, strut wing LH slat, wing fuselage fairings – but it cannot be identified what zone it refers to. The Copy Card given to each Crew Manager does not pick out all of the panels relevant to the zone. When staff removed an access panel (192E, 192F on the landing gear) they have to search through the Access Panel Cards to find it – these examples are located under 0008 Centre Accessory. Another example is under the category 'ALL' (0005) numbers 334HB which under the MPD is on the horizontal stabiliser, elevator hinge cover. Why is this in this 'ALL' area – why is it not in the 'TAIL' zone? All the 334 panels under 'ALL' should be in the 'TAIL'.

Another example in the LANDING GEAR NOSE section (0003) there are 5 panels listed, however there are 6 panels in this area (as per MPD 06–41–00 page 210). The other panel (114AW) is listed under FUSELAGE EXTERIOR (0001). There are numerous other examples of this." (Crew manager)

(b) The panel charts had no text descriptors and thus there was a requirement by staff for multiple cross referencing:

"On the Access Panel Cards there is no description of what the panel is. There is only a number given. You have to go into the MPD manual to find the descriptor text for what the panel is. Is it possible that the

information in the MPD manual is cut and pasted into the Access Panel Cards? We also need on the Access Panel Card the CARD Number that calls up that panel." (Crew manager)

As a result, extra time was spent on managing the shortfall which took time way from planned activities. In addition the information navigation and consolidation requirements required an increased cognitive effort in an already complex technical situation and, being a recurring issue, had a negative impact on motivation.

There was also the potential for knock-on effects across the check process, i.e. in close up:

'It is also a safety issue as if a panel is not in a zone then the refit of this panel could be missed when it comes to the refit of all the panels' (Crew manager).

Once the blocker had been identified in the trending of the data it was followed up by the improvement team. The following gives an overview of the additional information collected:

Staff perceived an imbalance between the efforts to fix this blocker at the planning stage which they regarded as once off time investment compared to the aggregation of their extra workload over a series of checks, in each of which this issue affected several tasks. It was regarded as another example of what they perceived as 'them versus us' and challenged in the relationship with support processes such as planning.

The further analysis showed that this was a recurring issue that crew managers were already taking into account when setting up for the work pack. Starting from the check process, the origin of the documentation was traced and the interdependencies of the operational blocker with other system processes uncovered. It emerged that planning at the participating site produced the cards but had no control over the set up of the IT system that created them. This was run centrally at the group headquarters.

Outcome: Solution proposal

A key outcome of the workshop was an appreciation of the complexity of the issue by all participants (operational and support staff), acknowledging both the profound impact it has on the operation, not just at a task level, as well as the distributed information management process that makes this a challenging one to fix, rather than an internal planning decision as initial assumed. The transparency in which the blocker was accounted for led to a constructive discussion and overall amicable feeling at the meeting.

In terms of solutions to the problem, in the light of the foreseeable effort to fully manage the distributed responsibilities around the blocker, the group identified two: a long term and intermediate solution were proposed.

The intermediate solution: The Planning and Commercial Department produced an in-house interim solution of printing the panel cards out directly from a current copy of the MPD and attaching the relevant page(s) to the task card as referenced on the work pack.

The long term solution: The reconfiguration of SAP tool to produce information in a format that facilitates the operational process flow and tasks.

Upon extended review at management level, the intermediate solution raised flags in the quality department as it was not aircraft-specific and could not be sustained. Thereafter, the implementation of the long term solution was pursued with more force. After 9 months of interventions by senior management and the improvement team a commitment from all stakeholders across all subsidiaries and headquarters was achieved.

4.4.4.3.2 Procurement meeting

The procurement meeting was called by senior management with similar intentions as the panel chart workshop. However, the differences in lead up and consequently the quality of inputs led to a very different outcome. The calling of an ad hoc procurement event when the opportunity presented itself as part of other business meetings shows management commitment but it also illustrates that good intentions are not enough and that, in situation such as this, the effort can be misplaced. Trigged by the quantitative blocker analysis that showed a peak in procurement related issues, senior management called a meeting to address the issues and advance a solution. The challenge was that there was no time to prepare it in a way that would have met the process requirements and KT principles. Therefore, the data trends were not complemented with a clear picture of system interdependencies that underlie the issues as experiences in the operation.

Overview of workshop

The procurement workshop was inserted into the meeting of global procurement staff at the participating site. In attendance were local staff that are presented the relevant supply chain functions as well as corporate representatives. Table 20 gives an overview of the participants.

Table 20: Procurement meeting participants

Site based staff	***Group representatives***
Chief Operating Officer	Executive Vice President Integrated Supply Chain Management
Customer fulfilment manager	Aircraft Services division
Senior Business Analyst	Group Procurement
Logistics manager	Group Logistics
Operations Purchasing Mgr	
Operations Procurement Manager	
Head of supply chain	
VP base maintenance	
Operations support	
Improvement team	

As part of the meeting there were two presentations given that introduced the participants to the challenges experienced by the operations when dealing with the supply chain. The first gave an overview of the blocker results in their area and positioned it in the wider improvement initiative. The second was a review of supply chain data that was performed independently as part of an operations support project and used data steams and indicators related to SLA.

The presentations were focusing on the local base without having had established an adequate view of the wider supply chain and central functions in the group. Given the short lead time of the event, the blocker data in the procurement categories was reviewed with check staff and organised around two main themes for each of which an initial narrative was developed.

Outcomes

An example set of blockers was organised around the supply chain for consignment stock. These are parts that are held by one party, here the maintenance organisation, without being initially purchased from the owner, here the airline. They only change ownership when they are used. Instead of holding consignment stock at the participating site where it was extensively used in a series of checks for said customer, the supply chain was centralised, holding and managing consignment stock at a UK site. In the case of the check series in which the blockers were reported, a commitment had been given to retain adequate levels of stock and operate a just in time delivery. However, the existence of high number of blockers suggested that the existing arrangement did not sufficiently address the operational dependencies.

While blockers were discussed and further explored, these discussions were constraint by limited implementation of the KT approach which included the lack of a shared knowledge baseline, e.g. different supply chains for different types of parts, tools and equipment. There was agreement on the problematic nature of the blockers though there was no consensus on what system dependencies contributed to them and what it would take to resolve them. As an outcome of the meeting, a set of actions were issued in relation to them and assigned to individuals, which implied further investigation within a department to achieve a solution. Issuing an action to an individual is contrary to the core of the KT approach to complex issues. While management meant well in doing so, this reverted back to highlighting issues out of context and instead of delivering solution options based on collaborative knowledge transformation, giving it to someone who by definition cannot have the right knowledge to fix a complex blocker.

In response to the presentation of a blocker experience in the operation, supply chain representative for internal delivery highlighted that operational practices created blockers for their processes. A key example was the fact that there were a lot of returns from checks; this scenario was backed up with figures after the meeting and highlighted the extra workload that the processing of return poses on the supply chain (especially stores) within the organisation.

In the second presentation, SLAs were discussed in terms of indicators, such as average delivery time; but without process context this does not have any meaning for better understanding how it affects operational performance. The discussion triggered by the supply chain data highlighted that the current indicators were inconclusive when it came to explaining operational blockers. As a result an action was formulated to review SLA between operations and supply processes.

Instead of advancing solutions, the workshops delivered further insights and extended the view from the check process into system dependencies. These included aspects that contribute to making supply chain management (SCM) a challenging task (as a large body of literature in SCM shows).The workshop showed that in the SCM implementation within the group (a) There are different avenues for different material resources such as different types of parts, consumables, tools etc and (b) Within that there are at least

two separate process phases: procurement and delivery, which are highly interdependent. These are organised at different levels in the group, with some of them centralised while others operated locally within business strategy.

4.4.5 Discussion

At the core of the improvement initiative was a set of processes: blocker resolution is the most prominent one but the other two strands also created new activities: the environmental change implementation that followed the 5S approach, a series of steps from sorting to sustaining activities, and communication processes that covered the overall initiative (as part of the team engagement and culture strand) which were mainly facilitated by the full-time TCD researcher acting as the main protagonist in a team of agents of change in the organisation.

The core of the thesis case study is the process improvement strand. Its core process was designed to manage blockers to the operation, incorporating model-based knowledge transformation activities across all its main steps. Implementing this process requires diverse stakeholders to engage in collaborative problem solving, that by virtue of being model based integrates knowledge and facilitates a shared understanding. In doing so, the implementation of the new process changes the existing social and knowledge dynamics. An illustration of how implementing the new process affects people's interactions and enables effective knowledge utilisation is the panel chart event. In contrast to the procurement event, it enables a favourable social setting in which functional knowledge was systematically transformed to deliver positive outcomes, i.e. agreed solutions to a complex blocker.

4.4.5.1 Blocker resolution process

The blocker resolution process delivered positive results, resolving 141 blockers across the check line and was taken on board within the operational departments and to a varying degree by support functions, as discussed below. Resolving all reported blockers contributed to delivering aircraft on time or early, leaving the customer satisfied and offering to renew the contract.

The blocker resolution process demonstrated how local tacit knowledge put into its system context can provide the basis to leverage operational issues. The model based approach fostered mutual understanding of each other constraints, extending into appreciation of factors outside the company, e.g. group functions or service provider. It enabled constructive engagement as it was based on a shared view on reality. This allowed for a re-evaluation of goals and how those are aligned between different sections of the company and for a review why formal indicators do not match up, e.g. SLA and KPI.

The blocker resolution process built on existing relationships which, in the current system, were utilised to maximise the benefits of coordination. Hangar managers and crews all had local relationships with other departments, usually the closer those were to the operation the more these were in place, e.g. contacts with the planning department via support planner or patterns of technical contact with NDT (non destructive testing) department was built on to coordinate task scheduling to ensure optimal support. As part of the blocker resolution process, these coordination interactions were actively designed and better supported which delivered short turn around for many blocker that were of bilateral nature. More frequent interactions in relationship with support function close to the operations proved to be a good

platform to resolve blockers. This was based on an initial shared understanding that was furthered in the new model based process activities.

If however a blocker involved various remote stakeholders due to its underlying complexity of dependencies, escalation was required. The relationships with remote stakeholders were often defined formally, e.g. by contracts such as Service Level Agreements which did not represent the actual dependencies very well. In the escalation, the functional knowledge of dependencies was a key resource in the escalation of blockers and advanced a shared understanding that until then was often limited.

Nonetheless, it is not enough to have both well-represented knowledge that is relevant to the system issue and an organisational process that uses it as an input. It is social processes such as coordination that enable processes and transform knowledge. The new approach has the potential to alter the relationships the quality of which facilitate or constrain how people interact. On the shop floor, there are several examples: crews collaboratively developing solutions in the blocker report, the effectiveness of the HIT team in coordinating with each other hangar staff, local management and dedicated support contacts, and a genuine appreciation for the role of management based on opportunities to interact with each other in an open and transparent way.

However, there were also limitations. Issues arose in the cross departmental meetings where some support department representatives engaged better with the process than others. While initially these meetings took place every two weeks, their scheduling was expanded to monthly events until those only happened on demand. There were several reasons that can be cited for this development; firstly, compared to dedicated events the meetings did not always have the space to fully appreciate the complexity that characterised many blockers which limited the power of the approach demonstrated in other settings (e.g. KT events); secondly, the engagement of support function representatives varied depending on shared history and on proximity of each department with the operation, and, thirdly, there was an imbalance in access to the improvement initiative as its first roll out was organised around base maintenance and did not extend into the support process that experienced their own blockers.

This situation was exacerbated by the fact that the structure of the company was organised in individual business units with their own internal targets, objectives and associated budgets. This set up was conducive to prioritising the internal logic of departmental processes over shared responsibility for the system performance which would have been a pre-requisite for fully appreciating the relevance of operational blockers and their distributed interdependencies.

Using the existing meeting structure and extending it where necessary, meant building on existing relationships. This was beneficial in that it allowed for utilising them for sharing new knowledge, but at the same time, it faced the challenge that these relationships were formed in response to the existing system with its inherent conflicts. A level playing field in terms of a full operational process picture to appreciate the blockers in their system context was the starting point for working together differently and had the potential to change relationships as a consequence of these new ways of working and affecting changes. Complex blockers attracted dedicated events to allow time and space for this. As part of existing meetings, however, the degrees of freedom were limited by practicalities.

In a similar way, a level playing field is required in terms of access to improvement processes. While the operation is the key reference point, each support process also faces internal challenges which could benefit from a systematic approach. The proposed framework is designed to be generic and can be extended to include all organisational processes. This allows for integration of all improvements towards a shared outcome, such as operational targets of releasing an airworthy aircraft on time.

These tensions show that a functionally sound programme that demonstrated its capabilities can be limited in its effectivity. While the implementation of a new organisational process is an achievement in itself, its outcomes are shaped by the ability to transform the social structure which enables it. Only then can relevant knowledge be created and exploited to its maximum potential. What has been demonstrated here, in the nexus of successful interventions and those that highlighted limitations as discussed in the next sections, is that the proposed approach has the potential to transform practices profoundly and as a consequence change relationships; but also that this potential can be maximised by rolling out in an inclusive way. Being a systemic approach it is only logical to aspire to extend it into the overall organisation, managing mutual interdependencies across boundaries of departments and management levels.

4.4.5.2 Discussion of KT events

Model-based KT is a core principle within the approach and is build into every step of the blocker resolution process; from the collaborative review of the solution proposal for the blocker to the HIT meetings across all the escalation meetings. Two dedicated events were run as extracurricular activities within the blocker resolution process to address complex blockers that cut across departmental boundaries and sites.

4.4.5.2.1 Panel chart

The complexity that defines this blocker, especially the distributed interdependencies and profound operational impact, makes it a prime candidate for a strategic management review. In addition to its potential for corporate wide impact, it is only at the strategic level that it can be leveraged. Senior management realised this and demonstrated commitment that was effectively channelled within the approach that underpins the improvement process.

In addition to its inherent complexity, the blocker is also interesting to management in that it is not incident or occurrence-based. When the issue was identified by the blocker data stream, it highlighted a systemic trend that caused inefficiencies which were mitigated at the cost of the operational staff. While it had the potential to compromise safety, the issue was brought to the attention of decision makers before it had safety consequence.

4.4.5.2.2 Procurement event

While it had a high profile group of participants, across the group, this event suffered from not having a proper knowledge base to begin with, for reasons explained in the introduction to this section. This only allowed for additional insights into the supply chain implementation rather than the derivation of solutions. In addition, key outcomes were the commissioning of a review of SLA and the commitment to

more proactively integrate of other departments into the improvement process, as they are dealing with their own blockers.

While the lack of the fuller picture was a challenge in itself, it also was off-putting to the external people who felt blamed. There was no common reference system to have a constructive discussion about and to get everyone on board as there was in the panel cart situation. Basing the meeting on quantitative trends shows the insufficiency of data, it falls short without the knowledge context that gives it meaning and relevance and allows for leverage.

The procurement meeting did not deliver solutions to the blocker, but gave new insights into the existing interdependencies. Unfortunately, the set up let to participants feeling blamed (a sentiment that was aired in the meeting and afterwards) and as a consequence reacting defensively. This had a negative impact in how willing they were to share and discuss. In terms of Ward's trust model (2005) the workshop instantiated unfavourable conditions: there was a lack of open communication and the as confrontational experienced situation confirmed existing resentments and perceived 'them versus us', which shows a history of mistrust.

4.4.5.3 KT event conclusions

Entering both KT events and their preparation confirmed the issue around tacit knowledge in distributed, informal practices as posed in Chapter 2 as both reflected a relative lack of understanding of each others' processes and their dependencies. Both events showed that the level of dependencies is appropriate for discussing the issues. Where required, technical staff offered more detail, but participants in managerial roles were favourable to the high-level approach as it is close to their daily engagement with the system. The difference being that in this setting they were offered a fuller picture that they would normally have (as discussed before in this chapter and others).

In the case of the panel chart, the lead up to the event allowed for the approach to be implemented more fully, and the outcome was positive. People gained new insights in to the bigger picture of the operation and its support as a system, and were able to use this to constructively engage in knowledge transformation that delivered a consensus solution.

The second event, the procurement meeting, was different to the panel chart workshop. The opportunity arose as part of a scheduled group level procurement meeting. The blocker presentation was called ad hoc, which left limited time to prepare and engage stakeholders in advance.

Both events dealt with complex issues and brought together a diverse set of stakeholders, both directly and indirectly. Their relationships were characterised by being remote, between stakeholders within the group and also speaking figuratively, within the participating site, and by having participants being responsible for departmental or group targets. In the procurement event more so than the panel chart workshop, relationships were also defined by a contract component in that departments had agreed SLA that framed their exchange.

Comparing the two events shows that the model is key to allowing for the complexity of blockers not being threatening but being dealt with constructively. The panel chart that implemented the approach delivered consensus solutions, while the procurement meeting did not.

The panel chart blocker event was prepared so that it presented a strong internal logic which could transparently be extended into the group and thus clearly identified the relationships to support required coordination of effort in resolving the issue, including the role of external IT support. The inputs into the supply scenario lacked this clarity on dependencies. Within the supply-chain related blockers that presented the highest occurrences within the different blocker categories the interdependencies were much more diverse, more closely linked to business strategy and economic models. While the research team appreciate the opportunity, in the actual set up, the approach was not given the chance to demonstrate how to manage this complexity effectively.

Contrasting the two events also demonstrated the inherent danger of using data without an appropriate knowledge context. Both workshops were triggered by blocker data analysis, but the procurement workshop did not have the knowledge base to systematically review the socio-technical complexity of the supply chain processes. It showcases Tuomi's argument that the hierarchy of data- information – knowledge is misleading and that knowledge is the starting point for capturing and interpreting data adequately (e.g. Tuomi, 1999).

Contrasting the two events and their outcomes can be seen as a further validation of the KSM approach. While the triggers were of the same kind (i.e. blocker trends) and the same generic KT principles, such as requisite variety based on the system dependencies, were applied in terms of event set up, the implementation differed in regard to model based content. The panel chart workshop that utilised the model based approach delivered positive outcomes such as shared understanding and sustainable solutions, while the procurement did not. At the procurement meeting a variety of key stakeholders across the group came together, bringing their highly relevant knowledge. The limited capability of the meeting to deliver widely agreed solutions reinforces the notion that having management commitment (by the COO) as a driving force and all the relevant people in a room does not automatically deliver an outcome.

4.4.5.4 Conclusion

The deployment of the blocker concept in an organisational process delivering process improvements built on the strengths of the ethnographic research encapsulated in the approach, giving hidden knowledge back into the operation and creating the capability of creating new knowledge for the benefit of the overall operation. The role of management commitment was critical to the success, delivering resources, decision and capacity to re-design organisational structure and processes. However, a qualifying comment can be made in regard to targeting the generally positive force that is management commitment. It requires an approach such as presented here to make a case based on system knowledge that is shared between all stakeholders. Otherwise, effort and commitment put into well intended opportunities can turn into stumbling blocks the improvement process, as the procurement KT event demonstrated.

Successes that validated the approach and also interventions that did not deliver are true to the case study being action research based. Having a theoretical basis allows for a grounded analysis of the reasons behind these and advances the concepts and overall theoretical argument.

4.5 Chapter 4: Overall discussion

The improvement initiative was set against the backdrop of an overall CI programme driven by the group's central CI department. The lean approach that was at the core of the corporate improvement agenda initiated activities across the group, including the participating site (e.g. it ran KAIZEN events). This gave an opening to integrate the HILAS project into the ongoing review of initiatives and upon management consultation the action research driven improvement initiative was rolled out in base maintenance, with lean programmes being run in other business units. The HILAS team successfully made the case to senior management that in dealing with complex systems such as aircraft maintenance, the lean approach has its limitations as discussed in Chapter 2 and offered an approach that was accessible to lean tools such as 5Ss while moving beyond its limitations with a human centred stance on system re-design. One can argue that the HILAS implementation benefited from a CI strategy being centrally advanced and that as a result, the HILAS implementation attracted management commitment and resources at a level unprecedented in a R&D project.

Pursuing an action research agenda in a climate of organisational re-orientation gave additional degrees of freedom, and more importantly the opportunity to not only intervene locally, but change management processes as it was demonstrated in the blocker resolutions process. This process extended beyond local activities and their follow up, and was a sustainable, with activities designed and implemented at different levels of the organisation. Implementing the model based approach created a knowledge base to appreciate blockers in their system context and enabled a shared understanding of their complexity which allowed for effective collaboration towards their resolution.

Introducing changes into an organisation necessitates a process that enables people to do things differently. Management commitment to improvement of change objectives is crucial but not sufficient in itself. It requires taking action in the organisation and re-designing the existing structure and processes as it was demonstrated in the initiative. However, this will only fully realise its potential if people engage with the new processes. The bigger picture of how the system actually works was at the core of the process improvement strand and enabled constructive collaboration based on a shared understanding (which was previously limited by critical knowledge being distributed or hidden in informal practices). Its underlying principles of transparency and inclusiveness were extended into how it was translated into an organisational application around blocker resolution and how this was communicated: having a system baseline, transparent process with clear responsibilities, feedback and outcome expectation. Having this defined, the team engagement and culture strand of the initiative was instrumental to communicate the objectives and processes, provide feedback and manage expectations. The full-time TCD staff was the central to this, being a steady presence in the company.

In parallel to the communication strategy, the role of relationships between key stakeholders was actively being addressed in designing new structure and activities: new social structures were implemented such

as new teams, e.g. HIT and its dedicated contacts, and new patterns of interactions were established in the existing management processes. These are examples that show the transformation of the social structure, which implementation was supported by the aforementioned communication, training and feedback.

Together the new process activities and interactions set the scene for capturing knowledge about how the maintenance system works and gives staff at all levels the means to utilising it for collaboratively designing solutions that are sustainable in that they reflect actual practices and are based on a shared, systematic understanding of the resulting system interdependencies. In doing so the approach created a capability in the organisation to deliver tangible improvements.

4.5.1 Overall outcomes of the improvement initiative

The overall improvement initiative was first rolled out in a hangar that was delivering 20 checks to the same customer. In summary, it delivered a range of positive outcomes and, overall, was considered a success by all stakeholders: staff and management in the maintenance organisation, their customer and the HILAS project representatives involved.

At the end of the check line the reported blockers had been resolved; some more timely than others, with solutions implemented both at a local level and, for complex blockers, the wider company and even group. The 20 aircraft were delivered to the customer either on time or ahead of schedule which improved aircraft availability for the operator by 136 hours (8.5 days) over the course of the check line. This translated into an economic benefit for the customer that was shared with the maintenance provider in form of a bonus payment – based on a delivery time based bonus/penalty agreement that had been written into the contract to incentivise risk sharing. During the course of the programme the customer was brought into the new process, getting insights in how the processes were run and what they achieved. It transformed the relationship with the customer and provided a transparent base for sharing risks in a business scenario that sees safety critical activities such as maintenance being outsourced. In constructive interactions the relationship moved beyond being purely contract based to a more collaborative attempt to optimise which was showcased in the customer complimenting the programme. In addition to the direct outcomes of the check line, it created a sustainable business relationship in form of a new contract.

The overall effect on the operation was also positive. The transformation of structure and processes did not only deliver the resolution of blockers but also had a positive effect on morale and improved the relationships with management. An evaluation of the HILAS improvement initiative was run by an external HILAS project team that was not involved in the research (Ward et al. 2009). A two-day evaluation workshop, including an individual survey, was set up. Ten people who had been part of the project and working at different levels of the organisation were invited to join. Its results showed that people were positive about the initiative, the support by management and confirmed the initiative's ability to deliver positive changes.

4.5.2 Dealing with blockers

The blocker report implements the framework and operationalises the structure proposed for functional knowledge about the system. In transferring the framework from the technology innovation context in which it was first applied in TATEM to an organisational initiative supported the validation of it. Staff in another application context validated the concepts and was able to use them to create positive outcomes. In contrast to TATEM, the framework application in HILAS extended its scope. Dealing with real issues in an existing operational situation (rather than building on a set of assumptions), the implementation of the framework in the blocker report and its resolution process enabled the formulation of the operational problem space in its systemic constraints/interdependencies.

The translation of key concepts of the framework into an operational report format represents a transformation of knowledge in itself. The in-depth exploration of aircraft maintenance as a socio-technical system delivered a systematic knowledge about functional relationships within the system. Organising it into a framework provides a platform to deliver various applications, including operational reporting as implemented in the blocker report. By doing this, knowledge that originates in the operation is given back to staff in a usable format, enabling a process that is directed towards objectives that they would like to see realised.

It creates a capability in the organisation to identify the socio-technical problem space, of which blocker reports are an instantiation, in a systematic way and enables to express complex issues that are defined by multiple interdependencies that span across processes or even organisations. Having this is a pre-requisite to collaboratively design solutions and sustainable ways to implement them. Therefore, this new capability realises relevance and leverage.

Staff engagement with the blocker report benefited from both relevance and leverage which were posed as criteria for systemic HF approach such as this. Staff recognised the concepts and content of the framework as a window into their daily operations and associated challenges, including those activities which are not accounted for or even taken for granted and 'not worth mentioning' by staff themselves until they see them represented as critical functions in the process. The data collected was relevant to the operational and to solving its issues. While the blocker reporting scheme was owned by the operation, their resolution was supported by a transparent escalation process within the organisation. The data base did not only highlight issues in terms of numbers, but also gave insights into the operational situation and its interdependencies. This provided a baseline for a strong operationally based argument and the reference point for KT activities that led to collaborative solutions.

Overall the HILAS implementation demonstrated the capability for change in the partner organisation, including the advantages of having a model based approach. After several unsuccessful change initiatives in the past (Ward et al, 2009), this one, while by no means perfect, was able to deliver results at various levels, as demonstrated in operational outcomes, an external evaluation and the customer response.

Adopting a system perspective in operational issues and implement it in an organisational process that escalates issues along this system trajectory proved to be a powerful approach. The environmental changes (based on 5Ss) that started before the first aircraft arrived showed that the company was willing

to invest in changes and when the concept of a blocker resolution process was introduced staff engaged to ensure that it met their requirements. As part of this, the modelling gave a new understanding of people's daily work and a means to communicate the previously hidden complexity of it. The resulting capability of tracking system interdependencies systematically created a new appreciation for how outcomes are shaped collaboratively; including constraints that affect all organisational processes (both in operational and support business functions). Prominent examples for this are both KT events, with one delivering a group wide solution, while the other did not deliver solutions per se, the (limited) case being made was powerful enough to drive an action to review SLA – which in the formal system is a core (but in its current implementation flawed) means of managing interdependencies.

As discussed before, in the conclusion of the second section of this chapter, as a systemic approach it should be rolled out across the system at hand, here the maintenance organisation. Prioritising the operation makes sense from a functional point of view, being the core business and as such revenue stream, but fails to fully do justice to the systemic perspective that the framework adopts. As interdependencies are defined within the overall system, the view from the operation only gives a partial picture. Other processes, such as support functions, have their own set of interdependencies, not only with the operation but also with other stakeholders. Targeting system performance, their blockers have to be attended to, too. In doing so, it further increases the capacity for realising the new support capability (i.e. targeted thanks to having a full picture of all operational activities and their interdependencies.) that is the result of operational blockers being resolved.

An example of a vicious cycle of uncertainty illustrates this point and the potential for further increasing the benefits of the approach: from a functional process perspective but also in terms of giving people equal access to improvement and thus makes them equal partners in an initiative that aims to improve overall system performance.

The procurement workshop did not deliver solutions but it provided new insights, not only into the dependencies with the supply chain but also in regard to the inextricable patterns of mutual dependencies. The operational staff had developed a pattern of mitigating resourcing issues by additional orders which resulted in items being returned. Data provided by the stores department after the KT event documented these trends which created additional work for stores, which took time from performing key support activities. During interviews and in following up blockers raised, people stated that one response to what they perceived as inadequate implementation of support in some areas was "trying to get hold off everything you can, just in case". Also in the TATEM research, people reported this strategy as a facilitator to their process. This is an illustration of the informal practices that arise in response to a formal system that does not add up. While those informal practices have been discussed as being critical to managing the operation, here their wider consequences are highlighted. It is shown how they impact on support processes in a way that even further decreases their capacity to support effectively.

On the face of it, the approach as it was implemented in base maintenance gave more control and influence to the operation. At the same time, it also facilitated process based accountability by having

more transparency via reporting and monitoring, which is not only directed towards the support functions but also the operation itself, as the example of the returns shows.

4.5.3 Role of relationships

As outlined before, the social structure was changed along with the blocker resolution process implementation. Getting people across the organisation on board and engaged in activities required intensive communication and demonstrations of the merit of the approaches that the overall improvement initiative was build around. This was managed by activities as part of the culture and team engagement strand, using the concepts, processes and knowledge that were developed.

Once people engaged in the blocker resolution process and its activities the outcomes that were delivered included not only resolution to blockers but it also transformed their relationships and the knowledge base shared between them.

There are examples in the research that demonstrate these changes. In the panel chart knowledge transformation event preparation, the improvement team took the lead in compiling additional information. It also made the summary information available in advance to the prospective participants. Having a shared reference point in how the operational issues were conveyed within the conceptual blocker framework, an ad hoc, constructive e-mail exchanges ensued between some of them which was not requested, but showed genuine interest in a problem that was now seen as shared responsibility. In these e-mails knowledge held by the respective participants was exchanged and provided additional inputs into finding a solution at the event.

Compared to this a follow up e-mail after the procurement workshops read more like a justification and was addressed to the whole group rather than people that were relevant to the particular set of issues addressed there.

Another example is the proactive use of external contacts by the HIT. Once those relationships were established in a formal way in the blocker resolution process and all parties engaged in the process, the interactions continued to intensify over the course of the project. Once benefits were demonstrated, operational staff felt more comfortable approaching support functions with their now well documented issues and intense collaboration ensued which was a major contributor to solving all 141 blockers raised. The process became more effective over time as both side gained additional knowledge in each others dependencies and how those could constrain actions.

The social practices that are created as part of the blocker resolutions process established new patterns of activities. In contrast to informal practices discussed in chapter 2, they are actively designed to manage relevant knowledge and overcome characteristics that pose a challenge in the current systems such as it being locally hidden, tacit and distributed. Thus, in what Oldham and Hackman (2010) call 'trickling up' (embedding them as daily routine practices) offers the potential of shaping common practices across the company and thus influencing organisational culture.

Another relationship that was transformed was the one with the customer. The customer representative was introduced to the initiative and informed about its progress in a series of interactions before, during

and at the end of each check. The new understanding of the operation and its system dependencies, combined with an increasing confidence that previously persistent issues could be resolved in the new organisational set up, allowed for communication with the customer to be more open than before. This enabled a more constructive collaboration within the risk sharing business model of outsourced maintenance and had a positive effect on the quality of the relationship, being a pre-requisite for trust (Ward, 2005). One indication of the mutual appreciation was the customer complimenting the initiative and its outcomes.

The results presented in this thesis are delivered by a research trajectory that seeks to integrate social, technical/functional and knowledge in applied research and thus can provide a contribution to building a research agenda that Oldham and Hackman (2010) advocate: "But circumstances change, and the time is now right for research that focuses squarely on the social aspects of the work itself (Grant & Parker, 2009). The reason [...] is that social interaction is now much more pervasive and prominent in contemporary work organizations than previously was the case." (Oldham & Hackman 2010).

4.5.4 Knowledge level

Chapter 1 introduced knowledge as being discussed as a key resource to secure competitive advantage in the future, not only within an organisation but even more so in enterprise models that span today's organisational boundaries. The emphasis of knowledge over information and data highlights the importance of the social space in which meaning resides (in contrast to data being the currency of technology).

The application of the framework in the case study presented here built on the knowledge structure developed before and made thorough use of the knowledge transformation principles that were applied at each stage from capturing the relevant knowledge into the models, its follow up and eventual transformation into solutions that define a new set of knowledge. KT principles sketch out a procedure which informed the process activities. However, it is important to appreciate that dealing with knowledge in action is a social process. Especially when it comes to transforming knowledge and delivering new insights as part of the dedicated KT events, the approach sees staff from different backgrounds engage in an intense social situation that is defined by access to a functional knowledge base and space to engage with it collaboratively and creatively but also a clear requirement to deliver a solution. Both, in the KT events run in HILAS and the routine activities in the blocker resolution process, a key achievement was that participating staff appreciated each others views and learned from each other in the workshop and its build up. It demonstrated the capability of the blocker template to identify issues in a way that was not only transparent and accessible to organisational staff but could be systematically positioned and explored within their system context, as part of the model based approach. The 'bigger picture' that the approach offers has two distinctive characteristics: system knowledge distributed across stakeholders is integrated and while hidden knowledge (by virtue of being informal and/or tacit) is being made explicit, some of its tacit features are maintained in modelling the functional context.

While the design of the blocker resolutions process, from monitoring operational issues to escalating until a solution is found, makes the improvement initiative continuous, it is the approach to knowledge, both in

terms of structure and management, that is key to making such a improvement process sustainable. Sustainability is fostered by having relevant knowledge to start with and a social structure that is conducive to its effective utilisation in process activities – this delivers better quality solutions which are being uphold in people's commitment to the process and each other. This type of approach can deliver continuous improvement which is characterised by local and incremental changes but also has the potential for supporting more radical changes that were postulated in Chapter 1 as a key challenge in the future (Keen, 1997). A recent blog discussion about the merits of lean echoes this assessment from a decade earlier and discussed that lean approaches are addressing existing systems, targeting local improvement that are meant to build up an organisational momentum (Ashkenas, 2012). However, there is doubt about how well it is equipped to deal with innovation and step changes. The approach that has been implemented here demonstrated that a systemic perspective allows for interventions to originate locally but extend across organisational boundaries. The complex blockers are key examples for this. At its core is a knowledge philosophy that is driven by relevance and leverage. The next step is to escalate this to the questions about expanding system notions in new virtual and extended enterprise models that were raised in chapter 1.

Implementing the blocker resolution process that was focused on delivering operational improvement and designing its complementary social structure provided the necessary means for utilising the relevant knowledge about the system. The baseline knowledge was organised in the approach and its models which as part of the process and its socially based interactions were actively used in knowledge transformation activities. Drucker (2003) defined knowledge as "information that changes something or somebody—either by becoming grounds for actions, or by making an individual (or an institution) capable of different or more effective action." (p.242) The HILAS case study operationalised this quote and implemented its implications, i.e. new processes and social structures, with the result of creating an organisational capability to deliver tangible outcomes.

5 Chapter 5: Consolidation

5.1 Introduction

In order to understand the dynamics of socio-technical systems in a way that gives leverage in design and system improvement, it is necessary to understand the human role in the system. Chapter 2 has described the complexity in socio-technical systems such as aircraft maintenance and identified four key themes around which the management of complexity can be explored. Arguing that a functional baseline is key to understanding system performance, it was argued further that the technology characteristics in combination with economic constraints introduce uncertainty that requires the implementation of social functions for it to be effectively dealt with. This positioned the human role at the centre of the thesis approach and provided the platform to address how knowledge and relationships are functional in delivering outcomes and value as propositioned in chapter 1.

The previous two chapters have demonstrated an operationalisation of this platform into a conceptual framework and its deployment in two different application settings: technology innovation as part of a system engineering project and an improvement initiative in a maintenance organisation. This chapter is dedicated to consolidating the findings and advancing a conceptual integration that moves towards a generic approach for transforming socio-technical systems.

5.1.1 Key achievements in empirical research

The research trajectory was implemented in a case study arc that combined two case studies in delivering the following

- Uncovering the relevant knowledge about how the systems work
- Organising this knowledge in a functional structure
- Delivering the socially based deployment of this knowledge

Building on a strong empirical and theoretical basis of research into socio-technical systems such as aircraft maintenance, the functional relationships in the maintenance system, including the ones hidden from formal scrutiny, were further explored and integrated into a framework which enabled the implementation of processes dedicated to utilising this new knowledge.

Such a functional framework is central to identifying, structuring and capturing the relevant knowledge, and then to show where this knowledge is used for what purpose in the processes. Building such a framework through empirical research embedded in the system delivers the basis for validating the claim for the resulting knowledge to be relevant – not only in its initial description but throughout the deployment of it.

5.1.1.1 Knowledge structure

Within the framework a structure to organise relevant knowledge was developed that encompassed parameters derived from the discussion of the socio-technical system complexity in Chapter 2. It integrated coordination into models of process activity and complemented the socio-technical picture of operational activities by adding a dedicated perspective on social relationships. Adopting a systemic

perspective, these representations were organised at different system levels, enabling the assessment of local effects in their system context. This was key to another shift in theoretical perspective which was established by enabling the abstraction of dependencies that are organised in reference to process milestones (states/gates). Within the framework, coordination is defined as managing these dependencies which are organised around milestones in process activity. This distilled the complexity of formal and informal elements that make up a maintenance operation, i.e. people coordinating potentially thousands of tasks, into a functional view that made it accessible for analysis and re-design.

Together with operational staff the framework was iteratively populated and refined to reflect their daily work experiences. It is instantiating a knowledge base that represents knowledge about how the system works. In both case studies, Knowledge Transformation Workshops (KTWS) and other activities validated the knowledge structure and demonstrated the delivery of effective system transformations.

In the first KTWS a recurring theme in the empirical research was reiterated by several people who had not been involved in the development process: "Yes, this is exactly what I do, but I was never able to express it" (NOTE from author: staff appreciated the process in its complexity and functional logic). People have an implicit understanding, however partial, of how the system works – it is reflected in all the activities that they perform, including those that are not formally accounted for. Organising and then presenting this knowledge in a framework that highlights the functionality of all their activities, was a major achievement.

Although this critical knowledge existed and was used daily in operational practices, it was hidden, partially even within the operation, but most definitely from stakeholders removed from the operational process, such as designers or support functions in the organisation.

Case study 1:

This is reflected in the relative absence of this knowledge in the design process and explains shortfalls of technology solutions in meeting impact expectations. Using the formal view on the target operation (as available in manuals or even from operators themselves) as a reference, only gives access to a partial account of the operational situation and fails to address the more complex issues.

In the first case study it was demonstrated that having an integrated set of knowledge available, enabled a constructive, more grounded exchange with designers about the potential of technologies in the operation and delivered a future version of the process. While this research was advanced into a proposition to the TATEM project of how to use the proposed framework and to deploy operational knowledge more systematically in the design process, this integration was not further tested because the project ended. Feedback from participating designers was positive and the new knowledge was used to adapt their prototypes and drive the overall narrative that provided the operational baseline in the demonstration of the project achievements, i.e. technology solution that delivered to the technical objectives.

The findings demonstrated the capability of technology to transform dependencies in the current system and highlighted that benefits are better understood in reference to overall system practices (including the hidden ones which are closely linked to social aspects of system). However, the characteristics of the

social situation created in the workshops which allowed leveraging the knowledge was not sustained and transferred into the wider project activities due to practical constraints (such as remaining time, resources and opportunity).Therefore, while the KTWS had an impact on finalising design decisions, it occurred too late to see the approach being extended into the wider research process of the project.

Case study 2:

As shown in the second case study, having the proposed framework can provide the platform for systematically identifying and addressing challenges in the operation, delivering direct benefits to staff and improving the overall system performance. It enabled operational staff to constructively think about what blocks their process, and moved their experience from anecdotal evidence to a systematic account of systemic issues, highlighting not only local effects but also their wider consequences.

Here the knowledge structure was implemented to monitor operational issues arising from the status of dependencies and incorporated in a process that actively utilised social processes to identify ways of improving system performance, i.e. the delivery of the system dependencies.

5.1.1.2 Knowledge process

Both case studies demonstrated that structuring the relevant knowledge and making it accessible is only the first step in a process that has to be actively designed for the knowledge to be effectively utilised. Dedicated processes were implemented as required that used the knowledge to leverage actions that transform the system towards the overall project targets: innovation and improvement.

Case study 1:

Case study 1 focused on the development of the framework, and in interacting with stakeholders valuable lessons about knowledge sharing in the industry and the role of existing relationships were learnt. The knowledge process was implicit in the research process in that it relied on communicating the approach during its development and building relationships that fostered common understanding and the willingness to participate in a workshop. A series of iterations had been envisaged implementing a process of which the KTWS is only a snapshot. Developing the models and their transformation into a future version were core to the delivery of the outcomes of the TATEM process.

Case study 2:

In contrast to the first case study, the framework was already available as an input into the research process of case study 2 and was built into the core of the process strand of the overall HILAS improvement initiative. In summary, the process included the following steps

- populating a process model of the check operation (which was the agreed target),
- monitoring the status of the check process by capturing data into a dedicated report,
- knowledge transformation activities to envisage possible solutions
- identification of the best solution and its implementation requirements

Each step was supported by the application of the framework in different ways, deploying the systematic knowledge about how the operation works. In addition to this an independent evaluation of overall impact of the improvement initiative took place.

Building on a generic problem solving approach, the implementation of the framework enhances each of the steps by having a reference; the systematic knowledge base defining the functional space in which the issue occurs guides every step from the identification of blockers to delivering solutions into the operation.

Resolving issues and improving process efficiency as well as safety and quality means to be able to effectively manage its dependencies. Knowledge and how it is used in relationships was therefore a key aspect of the improvement process design and implementation. All steps were facilitated by social processes that were designed to utilise the knowledge to maximum benefit.

While building on the research in chapter 3, it extended its scope as follows:

- The framework and its knowledge was in place and guided every step of the process improvement trajectory of the improvement initiative
- A model based improvement process was actively designed, implemented and evaluated to meet agreed objectives
- It produced a variety of outcomes such as KT meetings; several solutions supported locally, successful check (e.g. recovery, bonus) and strategic partnership with the customer through new processes, capitalising on social relations

Overall both case studies present a strong evidence base in favour of the proposed approach which this chapter seeks to consolidate and advance. Combining the conclusions and open questions from both case studies provides clear landmarks for situating this thesis' research achievements and sets a strong research agenda of future projects as discussed in chapter 6.

5.1.2 Overview of key conceptual advancements

Chapter 2 has given an overview of aircraft maintenance as a socio-technical system and based on previous research identified four themes (i.e. task logic, uncertainty, knowledge and relationships) around which constraints and opportunities for effective system functioning can be discussed.

In aircraft maintenance the aircraft systems themselves and their associated technologies are at the core of the system, being operated or maintained. They establish a baseline for activities that have to be performed when interacting with the technology, expressed as **maintenance tasks** in aircraft maintenance.

Chapter 3 has demonstrated that in addition to describing the maintenance tasks in isolation and deriving input/output requirements from them, they have different functions in the overall check, such as identification or rectification. In addition to their individual characteristics (such as certification level or tools required), their functional relationships define further dependencies that have to be managed when they are implemented in an operational process. This is emphasised by the fact that some maintenance tasks fall in more than one category. An example is the fact that removal/installation tasks can be performed for access or for rectification.

In the formal accounts of activities such as manuals the process context is not well represented. Tasks' interrelationships are highlighted in regard to their sequence, based on input/output relationships, rather

than their functional role in the process. This limits the basis for identifying wider system dependencies based on where they are performed in the process in what capacity, e.g. during set up versus close up, or routine versus non routine instantiation of the same task.

The concept of dependencies was introduced to move beyond input/output relationships that can be described on a task basis, to include qualitative characteristics about demand and supply, which are derived from the functional process logic. In addition, Chapter 4 garnered practical support for this conceptual shift by demonstrating that the logic of dependencies is an appropriate level to engage when dealing with system re-designing within an organisation.

The nature of the aircraft technology as expressed in tasks defines complex demands: it requires complex sets of resources, such as cost intensive, specialist equipment and parts that are provided by diverse supply chains or staff with different qualification and certification levels. In combination with the fact that by definition additional maintenance requirements are added based upon the findings that result from executing planned activities, this introduced **uncertainty** into the system.

Uncertainty as experienced in the operation is a function of the task logic (as defined by the technology) and the business logic (as defined by economic viability). Friedlander's argument highlights a business reality in which support processes such as supply chain are not viable if they aim to fully resource every possibility across a set of operational processes. This has implications for the implementation of the task logic into an operational process. Both case studies have shown that issues that are dealt with locally have a systemic context that has to be considered when identifying transformation potential that is sustainable.

These interdependencies that underlie uncertainty are not limited to within the organisation but extend beyond. KTWS #2 has shown that current challenges include the way people work together within and across organisational boundaries or the type of contracts or collaborations (e.g. outsourcing of maintenance) that are established as part of the prevailing business models (e.g. low cost models).

In response to the effects of uncertainty that people experience, people take extra steps and engage in informal patterns of activities which mediate a sub-optimal situation. This enables the system to work and as long as these practices deliver acceptable outcomes it is not picked up on. This poses a challenge for change or envisaging a future version of the operation. Investigations into adverse outcomes only come up with partial explanations as they have no access to the full operational picture. The same applies for proactive change management which is not triggered by adverse events but by strategic change or innovation. An example is provided in Chapter 3 where in KTWS#1 many future benefits of technology innovation were defined in regard to coordination activities (many of which are not part of formal system accounts).

With the existing disconnect between representations of the formal and informal system activities, the initial uncertainty is exacerbated because additional functional requirements, which result from it, are hidden from scrutiny and, thus, there is little opportunity for systematic leverage about them.

Many approaches that are developed to improve system performance focus on the certainties, as represented in the formal system. Uncertainty is either regarded as a result of poor implementation of formal systems or as residual variance in system performance that is not being accessible in a systematic

way. Business process modelling introduces the value chain and explicitly incorporates the supply chain and the customer when assessing process performance. Uncertainty, however, is not well catered for. The implicit assumption that underlies views on sub-optimal functioning such as deviation paths assumes that the mapping will give access to solutions that eliminate sub-optimal conditions. In that sense, one can argue that business process mapping is not concerned with managing uncertainty but eliminating it from the formal system. Assuming that suboptimal functioning can be addressed by designing a process version that delivers optimal work conditions has its limitations as it was shown that uncertainty is an inherent feature of complex socio-technical systems. An example is an improvement initiative that was adopted in the maintenance organisation before the organisation engaged with the HILAS project. Participants reported that it was based on modelling the processes and aimed to optimise the delivery of all the formal parameters. The outcome was a 'perfect' check. However, it was not viable as it interfered with the rest of the organisation, not per se eliminating uncertainty (or addressing how the informal systems manage it) but shifting it to other check lines.

Resilience engineering on the other hand acknowledges that uncertainty is an inherent feature of systems. The principle of approximate action states that in the real world, conditions for action and knowledge about them are always imperfect (e.g. Hollnagel, 2012a). However, there is no evidence that this uncertainty can be systematically addressed. In contrast, the principle of emergence implies that it may not be accessible in a systematic way.

This leaves a situation where uncertainty as a system characteristic is not well accounted for. The tension that stems from the overall system logic residing in formal and informal practices, accounts of which are not well integrated in existing approaches, exacerbates the situation. As argued in Chapter 2, an integrated approach would require advancing an understanding of how the technical features of a system set up the functionality of social processes within the operational context.

Based on the research presented here, this thesis comes to the conclusion that the uncertainty that is inherent to socio-technical system such as aircraft maintenance can be made accessible, at least in large parts, and can be expressed in terms of dependencies. Their status can introduce sub-optimal functioning into the operation as can the impartial understanding of their configuration. Rather than striving to eliminate uncertainty and achieve optimal conditions, the challenge is to account for it and reduce it by optimising the delivery of dependencies. Both case studies have demonstrated this: innovative technology changes dependencies or social processes resolve blockers i.e. transform how dependencies are delivered.

Defining the functional logic as a starting point, models of the process activity were an obvious choice. However, standard approaches fall short for many reasons, as outlined before. To address the issues a dedicated modelling approach was developed that incorporated all patterns of activity, the formal as well as informal practices, in order to express the total functional logic of socio-technical system of aircraft maintenance. Key features are:

- Functional task logic allowed for generic activities
- Coordination instantiates social functions in the process

- Both of the above enable the abstraction of the functionally driven level of states and dependencies

Dependencies are more than input/output relationships that are defined in workflow diagrams. They characterise a demand and supply relationship and its qualities within a functional context that e.g. defines how the input is best delivered or its relevance in the overall process that arises from the role of the task. Inputs are defined from a perspective of "what" a task requires. This is accounted for in formal systems such as MPD and the basis of SLA and can be described for each task in isolation, or in relation to the tasks that produce the required input. Dependencies move beyond the notion of input as it defines a demand in terms of the "why", i.e. its functionality in the process context which includes challenges based on uncertainty (both formal and informal activities are in process). It is on this basis that alternative and 'work arounds' in patterns of informal activities are established in the current system.

Mutual dependencies can be escalated in a critical path that spans across business units and can extend beyond organisational boundaries. The formal systems account for them in an abstract way, as inputs and outputs that lack the functional context of the other party. Each organisational unit such as HR or procurement and external function such as aircraft design and system integration is largely operating according to the local logic of their processes. Informal practices and tacit knowledge obscure critical interdependencies and only allow for a partial understanding of the operation as a key partner. Given the unavailability of hidden operational knowledge, designers tend to underestimate the uncertainty and work from the assumption that sub-optimal conditions are the exception rather than the norm. Support processes within organisations derive their internal logic from the business strategy rather than an assessment of all operationally relevant interdependencies and often manage their interfaces with operations through indicators based on formal system descriptions and business targets, such as SLAs.

As a consequence inputs systematically do not meet all the demands in the operational process and the overall system only adds up on the surface. Underneath the formal descriptions and indicators, the real system exists, operating informal practices that make up for the gaps.

Translating a process perspective that integrates both formal and informal practices into a functional view around states and dependencies is key to understanding the role of knowledge and relationships. The understanding of how dependencies affect the process and how they are managed to deliver the capability of progressing the process in a less than optimal situation. This is a knowledge function – knowledge as a resource for the process which is transformed utilising the social structure that complements process activities. Knowledge and relationships have been discussed in chapter 1, but their advocates yet have demonstrated how to operationalise their role in system performance.

Relationships are an expression of the social structure and offer an organising structure for social processes. The relevant knowledge about the system is created and held by people doing their work: building on explicit descriptions of their tasks and job roles, people respond to the functional logic of the system that they encounter when performing their tasks in a process context. Following the logic of CoP (e.g. Wenger, 1998, Brown and Duguid, 1998, 2001) it is argued that working together towards a common goal, people share knowledge and create a common understanding, very often locally. Their social

interactions such as coordination in the process are critical to the role of knowledge: it is in those exchanges that it is created, deployed and provides a basis for people to connect.

The coordination activities that are an integral part of a functional process, account for a large amount of the recurring patterns of social interactions in an organisation. In that sense, coordination is an instantiation of the social structure in the operational process. In contrast to CoP, the "common interest" is specified here as the system interdependencies as expressed in the process which define a requirement for people coming together to share and exchange knowledge about them. With much of it inaccessible/hidden, distributed and tacit, it is the social process that transforms it and delivers a common understanding that enables effective actions in processes. The social processes instantiated in coordination are not only social settings as advocated by Nonaka and colleagues (e.g. 2000) in Ba (social setting) to enable all knowledge conversion modes but actively targeted to enable a functional sequence of activities that transforms a physical entity such as an aircraft and deliver a specific outcome.

Thus, the social structure of a system emerges in response to the process functions, defining people involved and their role in managing the knowledge that the process realisation relies on. In these recurring patterns of social interactions of exchanging and sharing functionally relevant knowledge relatively stable relationships are established. Effective actions that deliver change (either as part of process transformations or at a larger scale transforming the system and its processes) are enabled by a shared reality that is relatively enduring, i.e. the social structure that complements functional processes.

Following this argument, social relationships are largely built on the basis of interactions that exchange functional knowledge to enable the system to perform within its given limitations. In a scenario of absolute certainty people could be utilised in the same way as other resources – assigned, deployed, and perform their tasks with minimal interactions such as two people joining forces to lift a heavy part. However, the uncertainty inherent in the socio-technical system such as described here defines a requirement for managing interdependencies by sharing knowledge and establishing a common understanding which results in various patterns of social interactions in the process.

Approaching uncertainty by defining dependencies between tasks which are both technically and socially determined and managed by coordination provides the basis to locate the issues discussed in this thesis at a knowledge level. **Knowledge** about how the system functions (functional knowledge) integrates social and technical aspects of the system into a single functional logic. This approach is different to business process modelling approaches, resilience engineering or knowledge management as, here, knowledge is described in functional terms and turned into a resource the role of which in the process can be actively managed (both in operational and change processes).

Both case studies have confirmed that issues originate in critical knowledge being largely hidden and distributed across the system, locked in local settings, which was discussed in Chapter 2. They advanced a framework and process to elicit the relevant knowledge in a way that makes it usable as a resource in both operational and change processes. How people experience the logic of the system and make it work constitutes the knowledge that is required to understand how uncertainty is managed to enable adequate system performance. Having the process framework established, both case studies demonstrated that

informal practices are not idiosyncratic but establish systematic patterns. Accounting for the socio-technical complexity expressed in these allowed the derivation of principles that were consolidated in the framework.

Chapters 3 and 4 addressed the operational complexity as experienced by people rather than documented in formal accounts. Both chapters showed how knowledge was systematically built up and demonstrated how it could be used to leverage system transformation. Knowledge is discussed as a key resource in recent business management publications. Considering this as part of a process notion, the question is: where does it feature as a resource? An attempt to answer this question shows that process descriptions which are based only on the functional logic that the technology imposes are not sufficient. Knowledge can be described as the currency of the social space and mediates how the social dimensions enable the functional logic of a given process.

The challenge is that knowledge as a resource works differently from other resources associated with the 'production logic' of the process. It is subject to the social logic of the process. A lot of knowledge is tacit – it is knowledge about how things work and how things are done based on previous experience and retained within people at a level that is not readily accessible. Based on shared experiences, such as working together in a system and being exposed to the same recurring patterns of activities and outcomes, people have common tacit knowledge, at least at a local level.

By integrating technically and socially based activities into a process framework delivers an anchor for systematically exploring the knowledge space of an operation and defining knowledge as 'material of production' in a social process.

5.1.3 Critical discussion of existing theories and approaches

In earlier chapters theories and approaches have been discussed that conceptualise knowledge creation in its social context. What is missing in many of these discussions is the functional context for knowledge and social relations.

Brown and colleagues

Communities of practice (CoP) as introduced by Wenger (e.g. 1998) and advanced in the organisational context by Brown and Duguid is one example of this tendency (e.g. 1998, 2000). CoP approaches advance an understanding of the overall (operational) situation between people interacting in the system which is the basis for the system working effectively in sub-optimal conditions as outlined in Chapter 2. They provide strong concepts of the social structures that enable practices which in turn creates core knowledge. It is focused on what people do rather than what is expected of them and thus grounds knowledge in how the system actually works. However, the functionality of practices in the system is not further explored. Practices are contrasted with processes (Brown and Duguid, 2000) rather than integrated and remain hidden and local. Sharing practices and knowledge is facilitated through social mechanisms without mediating the knowledge creation by introducing a functional baseline as shared reference point. Except for a shared interest, there is little discussion of the nature of the system that people are part of which in a work setting by default defines the reasons for people coming together in CoP.

In contrast to the approach taken in the thesis, CoP do not define an explicit functional reference system. Brown and Duguid (1998) mention business processes in the context of CoP, using them as an example of boundary objects which allow separate communities to engage. However, instead of exploring the functional logic that they (partially) represent and its role, the discussion moves to emphasise the social components. While the points about the social deployment of knowledge are valid the opportunity is missed to discuss what the core concepts and functions are that should be represented in those to create new practices and knowledge that can transform the system.

Therefore, the demonstrated usefulness of COP concepts is limited by a lack of definition of relevant knowledge, and thus effective interventions are not targeted but a by-product of organically occurring social interactions. These social relations can be facilitated in the hope of positive effects without a more detailed review of their function in the system. This limits the opportunities of leveraging knowledge in a way that is systematic and targeted.

Nonaka and colleagues

Another example is Nonaka's approach which is highly influential in the knowledge management literature and beyond (e.g. Nonaka, 1994, Nonaka, Toyama and Konno, 2000). In short, it delivers knowledge conversion within a social setting. The tension of tacit and explicit is conceptualised and thus caters for incorporating currently hidden aspects of relevant knowledge. Nonaka sees these conversions modes deployed in a knowledge spiral which spans from micro to macro, and thus can be regarded as a system notion. Knowledge is created in a social process. Therefore Nonaka defined a set of social settings that are conducive to the conversion modes he postulates. In Japanese tradition, the social is a driving force in the theory and parameters are set in concepts such as Ba (social setting), requisite variety and redundancy (e.g. Nonaka, Toyama and Konno, 2000, Nonaka and Konno, 1998).

Nonaka and colleagues discuss BA as the context necessary to have knowledge rather than information. In this social context shared understanding exists and provides a reference for the knowledge creation. While this is making a valid point, it falls short in defining the relevant knowledge and how it is used in response to the functional system people are part of, i.e. there is no clarification of what the shared understanding is about

Similar to the argument made about CoP, opportunities of leveraging knowledge in a way that is targeted and systematic are limited due to the lack of specification of the knowledge content. While the knowledge creation process is outlined in conceptual detail, integrating social components with iterative conversions at different levels, it is not anchored in a functional reference system. In addition to lacking a knowledge structure, it also does not allow for grounding social principles such as requisite variety in their functional context. Arguing from the point of view of dependencies, it is not individuals that have to be presented but a configuration of people that represents the relevant relationships.

Hackman and colleagues

More insight into the social structure that is created in response to the processes people perform tasks in is offered by Hackman's seminal work on effective teams (e.g. 2000, 2002). It is a well advanced framework to analyse the social structure in a work situation such as an operational process and

transparently unpacks how a social structure such as a team is designed and enabled to deliver effective performance.

Social relations are addressed from a perspective where the job is defined and a focus is put on within the team or the interactions with other teams. While Hackman's concepts offer generic principles that are critical to understanding how effective collaboration between people is established and supported, they do not well address the functions that social relations provide within the system. Hackman and Oldham (2010) conclude that a shift is required in understanding the performance of socio-technical systems such as organisations and state: "That is, rather than specific jobs it is the often-fluid relationships among people and their various work activities that are most in need of empirical research and conceptual attention."(p.476) The same article comes to the conclusion that "the time is now right for research that focuses squarely on the social aspects of the work itself (Grant & Parker, 2009). The reason, as several articles in this issue suggest, is that social interaction is now much more pervasive and prominent in contemporary work organizations than previously was the case." (Oldham & Hackman 2010, p. 467)

Having advanced concepts of teamwork around specific jobs, they do not claim to have addressed the overall functionality of relationships in the system and postulate it as a key area for research, thus implying its role in a future HF value proposition.

In addition, there is no strong focus on knowledge (only on job expertise) and how teams use it. It is acknowledged as being important and part of the social situation but within the team concepts there is no well advanced notion of how it is utilised as part of the social relations within the team.

5.2 Consolidation

The review of the explanatory capacity of existing approaches in the light of the thesis findings calls for a theoretical consolidation at a knowledge level. In combination, the outcomes of thesis have shown that by synthesising the two levels at which the findings in each case study were organised (knowledge structure and knowledge process) it is possible to advance the specification of the human role and social space in complex systems.

Both Nonaka and CoP stress the role of the social processes in utilising knowledge for delivering change and innovation (e.g. Nonaka, 1994, Brown and Duguid, 1998, 2001). However, without making accessible an in-depth understanding of the target system (i.e. what makes it work how, that is shared in practices in the social space) there is limited control about change implementation. In existing theories, change cannot be directed but occurs ad hoc as a natural property of people knowing. It can however be fostered by bringing people together in appropriate settings and it can be facilitated by the methodologies derived from those theoretical perspectives on knowledge; but it is not well targeted in terms of performance and outcomes. While an objective may be given as an input, the lack of functional knowledge content does not support a systematic process for tracking or actively designing how outcomes can be achieved differently in a future version of a system – the question about relevant knowledge content is more of a black box.

The social structure is normally relatively stable, facilitating a diverse set of system processes. It is established by sharing and exchanging knowledge in response to how people interpret their tasks in the

wider system context. Acknowledging and conceptualising the role of knowledge is very powerful in these theories, but the disconnect from functional knowledge content limits its leverage. The social space has to meet the core functional space (that is defined by technology capability and economic constraints in an organisation) to make effective (in the best possible way) organisational processes that are tasked with any type of transformation (whether operational process or organisational change).

In the HILAS case study, implementing the improvement initiative and more specifically the blocker resolution process did (re)configure social relationships. Defining these new or adjusted relationships was based on the integrated view on how the system works and what socio-technical dependencies have to be supported. Driving the restructuring of the social structure according to functional knowledge requirements links the social processes into the functional space. Knowledge is embedded in social processes; it is people who create, transform and utilise it. While people are key to performing these knowledge actions, when deploying knowledge in processes, it is the functionality of the system that they act within that defines the scope of the knowledge. Capturing this in a systematic way is a pre-requisite for leveraging an effective implementation of the processes that use it.

This is what this thesis has demonstrated and thus comes to the conclusion that knowledge is the key to understanding how the social and technical space in a socio-technical system link together to maintain relative stability of the system and deliver its outcomes.

The knowledge structure implements socio-technical dimensions that give insights into and promise leverage over uncertainty in the system and enables the organisation of the relevant knowledge. While the knowledge structure integrates social and technical aspects of the system, it is how this knowledge is used in knowledge processes that enable a better understanding of the critical role of people in managing the system. Dedicated processes implement its structure in a way that allows for managing knowledge in a way that is

- Highly structured
- Highly social
- Giving leverage and delivering value

Table 21 gives an overview of four key activities in the two case studies that were designed to leverage the transformation of the system, including the hangar improvement teams (HIT) as part of the improvement process, and the two dedicated events that were part of the HILAS case study as well as the two knowledge transformation workshops (KTWS) in the TATEM case study. While the details are discussed in the respective chapters, it can be summarised that those that had both a functional knowledge base (originating in the knowledge structure) and social relations adequately in place delivered better outcomes than those that did not.

Table 21: Overview of realisation of leverage in key case study activities

	HIT	Panel Chart meeting	Procurement meeting	TATEM KTWS
Knowledge about system dependencies	✓	✓	(✗)	✓
Social structure for utilising it	✓	✓	✓	(✗)
	effective in leveraging sustainable system transformation		not effective in leveraging sustainable system transformation	

The knowledge perspective on the case studies highlights an iterative cycle of making tacit/hidden knowledge explicit in a functional framework that then implements explicit knowledge in applications like dedicated reporting tools or the design of the improvement process, creating a new information flow. Both processes and tools are integrated into the operational daily practices and thus, in turn, update the tacit knowledge base.

5.2.1 Knowledge cycles

The baseline for knowledge creation and transformation are Nonaka's (e.g. 1998, 2001) four conversion modes: tacit – tacit; tacit – explicit; explicit – explicit; and explicit - tacit. He argues that those occur in a spiral that is facilitated by creating the right settings for the conversion to occur within social interaction. This offers an approach that can elicit the currently hidden knowledge and make it available for transformation into new knowledge. As such it establishes a means to acquire knowledge.

The research presented in the two case studies has adopted this approach, but advanced it by introducing a structure for the knowledge that extends into a heuristic for what to consider when transforming it. Based on the findings it is argued that knowledge is at the core of the successful operation and transformation of systems. Conceptualising the system functionality in terms of dependencies defined the functional role of knowledge and identified what is relevant to know when managing the uncertainty inherent in the system. Therefore, the thesis approach advances the understanding of knowledge as basis for action.

From the results of previous chapters, it can be argued that the management of dependencies was approached from two different angles in the two case studies: TATEM seeking to deliver process transformation through innovative technology, mediated by an improved information capability, reducing uncertainty at source, and HILAS seeking to improve by optimising dependencies within their systemic context (acknowledging the given techno-economic constraints).

From a functional perspective, this defines two knowledge cycles which include Nonaka's conversion modes but organise them in response to where the knowledge is created and used in the system (see Figure 18). Knowledge cycles are about how to action it in the socio-technical system that is the target of interventions.

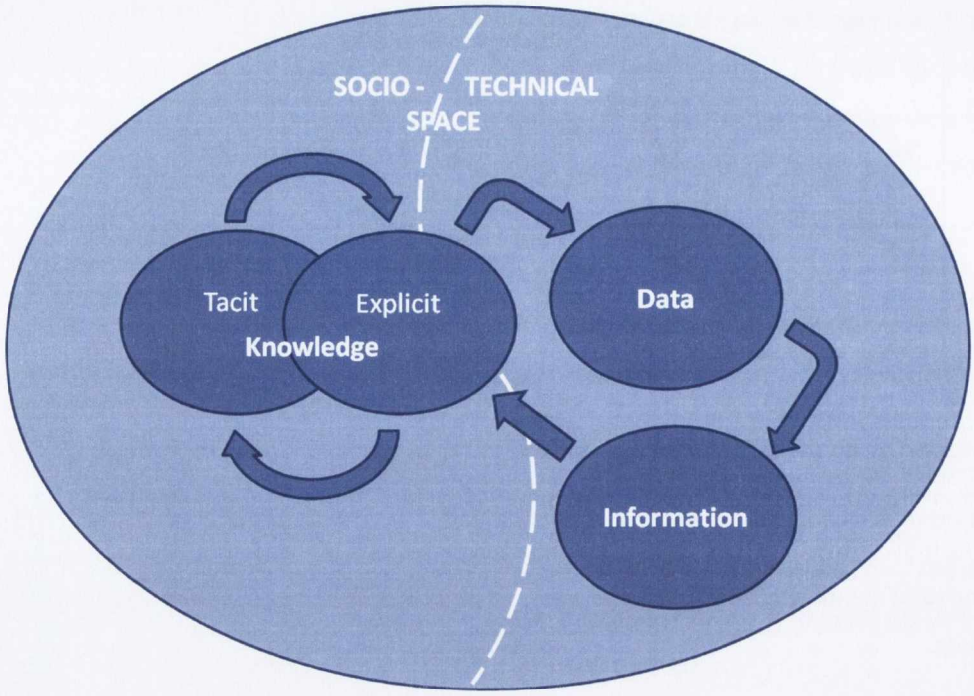


Figure 18: Knowledge cycles

Nonaka has highlighted the role of the social space in which knowledge resides in knowledge creation and transformation. The thesis argues to extend this role to appreciate the criticality of it in utilising the knowledge. While having the knowledge available is the basis for driving change, it is not sufficient in itself to drive action. Both case studies showed that the possibility of new design or organisational change depends on leveraging the knowledge by making it explicit, even if only temporarily.

Knowledge drives action, but leveraging it in a targeted way as part of planned interventions relies on making it explicit. This permits the directing of actions towards managing dependencies effectively, addressing uncertainty and tracing effectiveness to the functional knowledge that enabled those actions.

Managing uncertainty has been defined as a knowledge function. Uncertainty can be expressed in terms of dependencies: both status and configuration. Reducing uncertainty is realised by better knowledge of these, a capability enabled either via new data and information streams or by eliciting existing but hidden and distributed knowledge about them. As such it can be regarded as a knowledge function which underlies both the technical and social space of the system.

The challenge is that uncertainty creates ambiguity about opportunities for actions – what to do when the operational situation does not match the formal plan. In face of uncertainty, social interaction, such as coordination, creates knowledge that establishes the capacity to act.

This reinforces the argument that coordination (enabled by the social structure in the background) realises the transformation capacity of the process by providing knowledge that drives action.

In TATEM, new technology produced new data which, transformed into information and used as knowledge, reduced uncertainty. It opened up the possibility of transforming processes, both through the logic of maintenance tasks and the pattern of coordination, and delivering dependencies in a better way.

While possible benefits were envisaged in the KTWS there was a little room in the project design to implement the knowledge cycle and fully incorporate the future system potential in the project outcome.

In HILAS, improvements were identified and realised in a dedicated process which strongly drew on social processes for converting tacit into explicit knowledge. This allowed sharing a common view on the systemic nature of the issues and drove consensus solutions that addressed the complexity of the problem. In a process that is designed around social interactions with the requisite variety of stakeholders, the elicited tacit knowledge is further transformed into solutions that improve the capability of managing dependencies and thus reduce uncertainty.

In both cases the reduction in uncertainty allowed for an extension of the range of effective coordination. This creates a shift in local relationships which can become more routine due to less co-ordination effort. As discussed before, social interactions which are at the basis of building relationships are a response to the logic defined by technology and economic constraints.

In defining system dependencies the interpenetration of the social and technical space of the system is demonstrated as well as how functional knowledge links them both. Returning to the beginning of the chapter, it advances the argument why a discussion at a knowledge level is appropriate to consolidate the research presented here and allows for a discussion how knowledge and relationships create value, as proposed in Chapter 1.

In addition, it offers a new perspective on the debate whether on knowledge always has a tacit component. Brown and Duguid (2001) conclude "So, Polanyi' s and Ryle' s arguments militate against the idea that knowledge circulation involves explicit knowledge alone. From the idea that tacit knowledge is "non-tradable" and needs to be converted into explicit form to circulate, we come instead to the idea not only that conversion (if it involves uprooting knowledge from the tacit) is problematic, but also that tacit knowledge is required to make explicit knowledge usefully tradable or mobile." (pp.204-205).

5.3 Overall discussion

Chapter 2 discussed the uncertainty that is inherent in socio-technical systems such as aircraft maintenance. While based on technology characteristics, it is exacerbated by the economic reality that shapes the operational implementation. The social space has an independent role in delivering system outcomes, in response to the functional logic of the tasks and processes, people taking responsibility for producing the outcome. In a system where complex dependencies cannot always be supported in a perfect manner, coordination enables the process by optimising within the given constraints.

A reduction in uncertainty, enabled by proactive design and effective management of system interdependencies, is the key to leveraging the situation and effecting positive change. This is a knowledge function: knowing more or having better knowledge about how the system works and what its current status is creates the opportunity for acting more efficiently, safely and effectively.

As demonstrated in the thesis it requires both the relevant knowledge and a process that utilises it to realise this function. In today's system this knowledge function is approximated in the existing coordination where people manage the process within the given limitations by using experience (in tacit

knowledge and informal practices). In these largely local interactions people are creating knowledge, transforming knowledge, using knowledge about dependencies and their status. New technologies or organisational process change can deliver the basis for improving the capacity and capability within the system.

Grover and Davenport (2001) put forward the distinction between deliberate knowledge processes, (i.e. results of conscious organisational knowledge management initiatives) and emergent knowledge processes, which are tied to the work processes themselves.

Each of them follows the phases: generation, codification, transfer and ends in realisation which sees the resulting knowledge utilised.

While the authors argue for convergence of these two processes in "well conceived knowledge management", this thesis is proposing to put the emergent knowledge centre stage, with the deliberate ones being designed in response it. This is only possible if the emergent process is formalised. Having a formal model of the work practices, which elicits and structures 'emergent' knowledge in a systematic way, defines what needs to be known. It integrates the explicit, and more importantly, the tacit aspects of the operational knowledge. In such a functional model, dependencies are the basis for how knowledge has to be used and what needs to be supported by actions based on it.

The framework and its models do not function as an organisational memory in the traditional sense that sees best practices codified and stored (in different formats) to be called upon at the user's discretion. Instead of providing pre-packaged knowledge for consumption, the models are part of an active knowledge process. Defining a baseline against which system performance can be monitored or envisaged, they are actively used in a socially based process that delivers solutions (or an alternative future version) into this baseline. This grounds interventions in the here and now of the given problem statement or innovation scope, while anchoring it in a baseline that reflects the overall functional logic of the system, as embedded in all activity patterns that realise the operational situation, and thus gets closer to designing the operational reality.

The maintenance operation is the basis for the emergent knowledge process here. This thesis argues that 'getting a handle' on this type of knowledge process is key because it defines what the relevant knowledge is and what the knowledge needs to do. The functional logic that underlies the different tasks, which are organised in a process system, is defining the transformation of the subject of the process (here the aircraft and its components).

Deliberate knowledge processes are then using the framework (based on emergent knowledge process) to provide the context for transforming this knowledge base to envisage a future version of the system/process and design a new configuration of knowledge functions in the operation.

TATEM and HILAS designed and delivered (in TATEM partially) deliberate knowledge processes for the project: "design for operation" process and improvement process. Those processes were built on the knowledge structure and process of the maintenance operation.

The work in TATEM put a knowledge perspective on the design process, focusing on utilising the operational reality as captured to better understand how impact of technology innovation is realised by

affecting process outcomes. In that it bridged the gap between traditional technology design, which was focused on local interfaces with the technology (HMI), and the benefits expected in operating the technology. What mediated between the two is the functional logic of the process system, not from a local process point of view but including its systemic dependencies.

The work in HILAS focused on making explicit the functional reality of the operation, moving from local anecdotes to a systemic assessment of what impeded on the processes. It designed an improvement process that was build into the existing organisational processes, including the operation. This process was designed to extend local issues into their system context and had social mechanisms in place to ensure the collaboration of the relevant stakeholders for solving them in a sustainable manner.

5.3.1 Conclusion

Drucker (2003) defined knowledge as "information that changes something or somebody—either by becoming grounds for actions, or by making an individual (or an institution) capable of different or more effective action." (p.242).

The case studies of the thesis demonstrate that knowledge creates the basis for action and implemented a model based process that moves from its codification to what Grover and Davenport (2001) call realisation, the actual use of the knowledge to deliver outcomes in a different way. Knowledge being the basis for action is true at a local level, in the operational processes, but also in terms of interventions that span across system dependencies, allowing grounding emergent and deliberate knowledge processes in the same knowledge base.

The research has sustained two arguments that address the relationship of tacit and explicit knowledge. Firstly, the two knowledge cycles (tacit-explicit-tacit and knowledge-data-information-knowledge) are interlinked in explicit knowledge which draws together the social and the technical space of the system. This is the mode that allows anchoring the use of knowledge, such as in coordination activities in a process, even if it is only made explicit temporarily. Knowledge becomes explicit (if not so already) at the point of action; pragmatically addressing the uncertainties in the immediate dependencies that need to be addressed.

Secondly, using models of functional system parameters as a dynamic knowledge repository preserves the functional context of the knowledge and thus allows the retention of meaning. It is dynamic knowledge, as part of a dynamic process built around model-based knowledge transformation. Codifying this knowledge in a model systematises it for wider use. The model presents an abstraction from everyday patterns of activity and thus approximates the real system – formalising a deeper reality of constraints (functional logic in dependencies, uncertainty, and coordination) and the way things work, despite these constraints. This creates the possibility for directed interventions to change or redesign the socio-technical system.

5.3.2 Limitations of the research

In previous chapters challenges and issues that arose in developing and implementing the research methodology have been discussed as appropriate. Given its action research based nature, the research in this thesis was subjected to an iterative review of what worked and what required improving (either during the case study or in future research), for both conceptual and practical reasons. While this is

inherent to the nature of action research, it also is in line with the systemic approach adopted in the thesis: grounding the development and implementation in the actual system, appreciating existing constraints and managing interdependencies with the view to optimise how the actual system delivers outcomes.

However, there are two points that warrant a more general discussion of the limitations of the thesis achievements, specifically with a view towards future research.

(1)The focus of the empirical research is on aircraft maintenance.

As argued in Chapter 2, the aircraft maintenance system was chosen for a set of reasons, including the large body of empirical work that informed the conceptual framework of the thesis and the fact that it is not only a socio-technical system but also a part of a well characterised SoS, i.e. the aviation system.

However, the question arises whether the resulting framework is transferable to other industries and their processes. Demonstrating this is not within the scope of the thesis and defines a requirement for future research. Nonetheless, based on the research presented so far, there are a number of arguments to be made in favour of the likelihood of the success of such a transfer.

Firstly, the focus that the thesis puts on the aircraft maintenance system is on characterising it based on its socio-technical properties. While the research is grounded in the maintenance operation, the socio-technical properties are discussed at a level that is conceptually relevant to systems that share these social and technical components. It is not so much the technical details of aircraft maintenance but the functional integration of social and technical aspects from a system perspective. These aspects are described in a generic way and are shared with other industries.

As an example, the approach has also informed research in the flight operations strand of the HILAS project, taking a particular interest in the nexus between maintenance and flight operations. While reporting on the detailed results of this research is not within the scope of the thesis it can be cited as an illustration that the framework is transferable to another domain (e.g. McDonald and Morrison, 2006).

While this is the same industry as aircraft maintenance, other research seems to highlight that other maintenance operations shares similar system characteristics (e.g. Orr, 1996 as cited in Brown and Duguid, 2001) as does the health sector which represents another people mediated, high risk, highly regulated system. These are possible target system for future research to demonstrate the transferability.

However, the relevance of a functional perspective should not be disregarded for other industries that on the face of it seem to be very different in nature. It might be less obvious for other processes but a functional view can be adopted on everything, even teaching pupils. While other research topics may seem more pressing, the functional perspective adds value in organising knowledge with a view to affect system outcomes. This one can assume is of value for owners of all type of processes: understanding how actions effect outcomes.

(2) The cost-effectiveness of the proposed approach.

The research trajectory of the thesis as outlined in chapter 2 can be summarised as an extensive action research programme that is build around an in-depth exploration of how systems actually work. The

amount of time and effort spent on this has been immense, which in this form has only been made possible by the dedicated resources that an initiative such as an EU framework programme has to offer as well as the incentive of delivering a substantial piece of new knowledge in form of this thesis.

For further application, especially outside a research project, a critical question is not only as to whether it can be transferred (see the previous point in this section), but also how it can be implemented in a way that is cost-effective for the organisation.

Most critically to answering this question is the fact the thesis has performed the core of the development and provides a consolidated framework. This provides a platform to define implementation trajectories for different application contexts and focus efforts on implementation, i.e. where the impact is delivered. In the future, the proposed framework and new knowledge can be built on to advance standardised ways of implementing the approach in organisational or design processes in a customised way. Customisation can be seen as a requirement as the instantiation of the same functional logic can vary, for example across different organisational forms, such as the outsourcing of certain functions. Therefore, the implementation potential would benefit from modularising the proposed approach, defining functions and processes that can be integrated in the existing organisational landscape or system engineering approach.

It seem that key to delivering such a capability is support by information technology, i.e. dedicated applications that allow for flexible integration of critical knowledge into organisational or design processes. Current and future project are designed with this in mind and, referring to an example proposal, the role of such an IT capability is going to be further discussed in the next chapter.

6 Chapter 6: Conclusions

6.1 A new HF capability

The thesis started out from the premise that in transforming socio-technical systems in a way that meets the requirements of emerging business models, knowledge and relationships have to be at the core of a systemic approach. Operationalising these dimensions which have been postulated in the business management literature as being critical for the success of future operations (e.g. Post, Preston and Sachs, 2002) is not well addressed in current HF approaches.

In the previous chapters, the empirical evidence in support of the framework developed and implemented in the thesis research has shown that in order to deliver approaches that exert leverage over system performance it requires a shift in the core principles of existing HF paradigms: moving from local to systemic approaches that ground epiphenomenal based explanations in functional models that express the underlying logic of the system and allow for shifting the emphasis from contributing factors to core components of value creation.

Chapter 1 argued that in establishing system approaches successfully (an aspiration defined in the most prominent definitions of Human Factors (e.g. IEA, 2000) that has not been fully delivered yet (e.g. Harris and Stanton, 2010, Dul et al, 2012), Human Factors as a discipline can create an opportunity to move beyond delivering a support function by directly engaging in addressing issues of leverage and value. Going back to the themes identified in Chapter 1, this chapter draws conclusions on how the proposed system approach creates the capability of leveraging 'real world' issues (in affecting actual process outcomes) and thus poses a new HF value proposition for key system (or system of systems) stakeholders. Revisiting the propositions of the introduction to the thesis, the outcomes and conclusion of previous chapters are consolidated around three core themes: system, leverage and value.

6.2 Advancing a system approach

In contrast to HF approaches that are organised around human performance (previously at the core of HF definitions, e.g. HFES, 2012) and see people affected by the system and strive to explain the effect on individual performance, the system thinking advanced in this thesis addresses how people shape the system that they are part of with their actions and interactions.

6.2.1 Functional logic

Aircraft maintenance is an operation that is characterised by the complexity of the technologies it operates and is mediated by safety regulations. Maintenance tasks are technically defined and implemented in production processes.

The research has shown the functional role of tasks in the production system, demonstrating that it is not so much their internal logic that challenges safe and effective performance but their functional relationship in their operational implementation. Maintenance production sees tasks executed in parallel as well as in sequence, with their relationships defined by the role they play in delivering the processes milestones. Chapter 3 identified a series of process functions such as identification or rectification and

used this to re-organised task classification systems that were based on the tasks internal logic/content such as removal/installation. While executing the internal logic of individual tasks is core to ensuring quality, safety and efficiency, the outcomes of the overall process creates the ultimate value for the customer. Therefore, how the tasks are organised and resourced within operational processes is equally important for managing performance, including safety. The functional logic of the system and its processes can be expressed and organised at different levels, escalating from local task execution to managing a work pack to the business logic of the maintenance operation.

Having established the functional baseline as being the technology systems as implemented in operational processes, this allows for understanding the role of people in realising it. While a superficial review of maintenance as a system gives the impression that the technology is largely determinant of how the system works or not, the in-depth research in this thesis was embedded in the system and demonstrated that it is the interaction between people in coordination that is at the core of sustainable system.

The thesis adopted Crowston's definition that coordination manages dependencies between tasks rather than people or business units (e.g. Malone and Crowston, 1994, Crowston and Osborn, 1999). This allowed for grounding coordination as an activity in processes and consolidated traditional transformative views of processes with those that adopt a coordination perspective.

6.2.2 Dependencies & Uncertainty

Technology systems define a functional logic that underpins how resources are transformed into the ultimate outcome, here an airworthy aircraft. This can be expressed as a set of dependencies that exists between tasks within maintenance production as well as with other processes that support it, such as supply chain or planning.

Chapter 2 discussed how this set of complex dependencies in combination with economic constraints and regulatory constraints introduces uncertainty into the system. Uncertainty about status or configuration of dependencies requires their active management in social processes such as coordination. The research presented in the thesis showed that this extends the functional logic at the core of the system and defines additional social and knowledge functions.

Expressing the functional logic in terms of dependencies within and between tasks and processes enabled another conceptual shift: from detailed process activity to a generic description that encompasses the basic logic that underlies various instantiations (e.g. RI) and the organisation of this in a series of states and gates. While still focusing on the activity (both transformation and coordination), this puts the functional logic at the centre of the approach to system analysis and transformation/implementation.

In addition to being conceptually grounded, it is also an efficient way of dealing with the complexity of the socio-technical system. The models can incorporate detail in the background, and can be called upon or specifically implemented when needed in an application context.

Both case studies demonstrated the transformation of dependencies. In Chapter 3, a technology project delivered an integrated technology solution based on IVHM, the foreseen implementation of which promised the capacity of transforming the operation as envisaged in the KTWS. Starting from a

maintenance task process, the scope was extended to envisage changes along upstream processes. The outcome was a shared understanding of possible benefits, not only of the envisaged interfaces at maintenance execution level but the potential to leverage system dependencies. The KTWS#2 identified challenges that were defined by business models and the current way of collaboration between organisations. This marked a transition from the project's cost benefit analysis (CBA) baseline of reducing maintenance requirements to save time and subsequently money (i.e. TATEM project aspiring cost reductions in direct maintenance cost) to where in the system this allowed the creation of value for different stakeholders. While cost is a driving force, business models such as risk sharing in outsourcing may like to balance this with those elements that allow for better control and quality assurance, potentially saving money in different places.

In Chapter 4, the process improvements were anchored in a representation of a generic check process. This was used to anchor the effects on the process that arose from dependencies being sub-optimally supported and to track system dependencies in a critical path that escalated the issue to the system level at which a solution could be sustained. While the previous case proactively explored the transformation capacity of emerging technology and as such took a broad sweep at the system and its processes, the resolution of blockers was driven by the outcomes of the monitoring of process performance. While all blockers were addressed, the ones that were defined by a complex set of dependencies spanning system levels attracted more resources as part of the resolution process. These core resources were people and their relationships that represented the critical path and thus the knowledge that was required to identify the best possible solution (taking into account everyone's opportunities and constraints that are defined by the dependencies of their respective processes).

6.2.3 Knowledge and relationships

Managing dependencies and thus mediating the uncertainty inherent to the system is a knowledge function. It relies on an understanding of how the system actually works, which is largely based on a set of tested expectations. Anchoring dependencies in activities puts the functional logic as expressed in the processes at the core. People learn about the system as part of doing their job in it (including various modalities: observation, instruction, single and double loop learning and others) and experiencing different outcomes in different process configurations. From which they built up their understanding of the system's functional logic that informs further actions. However, individual knowledge is limited by factors such as experience, exposure and locality. As both case studies have demonstrated and Brown and Duguid (2001) observe, there are boundaries between groups that exist in organisations, even between seemingly similar roles. This limits the knowledge that can be acquired and shared. As a consequence knowledge is partial and hidden due to its characteristics of being local, informal and tacit.

Therefore, its effective utilisation of knowledge posed a demand for having a mechanism of validation that is built into the system. Having a model base is the first step as it creates a knowledge resource that organises knowledge around the system functions, hence making it functional knowledge. As discussed in the case study chapters, iterative validations were involved in refining and populating it. These were based in social interactions. The social structure that complements the functional logic of production

interconnects people and their knowledge. When knowledge is deployed it is targeted towards an operational context which defines the appropriate social setting or relationships in which to validate and transform it effectively. Both case studies demonstrated that the functional logic defined the social structure that enables interaction for shared understanding and this optimises either dependency delivery within constraints or the transformation of these constraints.

In the thesis, establishing the framework and its models created new knowledge and made it accessible. While integrating functionally relevant knowledge (in socially based activities) creates a platform for change, actual leverage is realised by deploying it to change the situation. Its success can be measured in terms of how well its deployment leverages the system and its processes in delivering better outcomes. The HILAS case study in particular is a good demonstration of this (see Chapter 4).

Approaches such as Nonaka's knowledge theory (e.g. 1994) and Communities of Practice (e.g. Brown and Duguid, 1998, Wenger, 1998) address the social component in a knowledge process but focus on its role in the knowledge creation. The implicit assumption is that having the relevant knowledge allows for its effective application. The thesis extends the argument of social setting into the application of the knowledge. The CoP approach has an element of this; however, it is not actively designed. The COP is a social structure against which all knowledge processes are set, including knowledge application. The application of knowledge cannot be targeted as neither its content is defined nor the relationships that can sustain solutions. Instead, only overall social conditions are mediated with the aim to influence the outcomes.

Creating the capacity for implementing knowledge more effectively (facilitated either by technology innovation or organisational transformation) changes dependencies and thus reduces uncertainty in the system. The current patterns of fire-fighting that rely on interpersonal interactions for effectively coordinating dependencies are replaced by routine activities. Better control allows for transparent, more even distribution of a series of decisions around the critical path of system dependencies that come together in delivering the expected system outcomes. Therefore coordination can extend its range and encompass uncertainty upstream. Relationships are no longer local, but follow the critical path into the system. This trend of shifts in coordination requirements and responsibilities was demonstrated in the case studies, most detailed across the levels of KTWS#1 target processes (as presented in Chapter 3 and the Appendix). Moving interpersonal coordination further upstream also extends the knowledge base of these relationships, extending the scope of knowledge transfer in the system. In this scenario, more complex dependencies can be addressed which allows for effective knowledge use to create leverage at higher system levels and align goals, purposes, objectives between previously remote, largely independently run processes and their stakeholders.

The TATEM case study demonstrated that introducing technology innovation into the operational system has the potential to transform existing dependencies. As discussed before, reducing uncertainty is a knowledge function. TATEM technologies enabled a new information capability that promised to broaden the knowledge base by improving the characteristics of its information inputs and also by connecting critical stakeholders, (re)defining relationships and extending the knowledge creation capacity. The new

IVHM capability delivers better data and information about the system and thus reduced the uncertainty. As outlined in Chapters 3 and 5, it changes tasks and patterns of coordination in the process and transforms dependencies by allowing for better delivery or by making them obsolete.

The HILAS case study demonstrated the reduction of uncertainty by deploying the framework for eliciting tacit knowledge so that it could be transformed by model based KT into solutions that allowed for a better delivery of system dependencies. This was not delivered by major technology innovation, but by actively designing a knowledge process that was built around social interactions that were conducive to knowledge exchange and transformation. As part of the process design and implementation, relationships were transformed and new ones established in way that complemented the functional logic of the operation that the model revealed. More so than the first case study, the HILAS case implemented an appropriate social context that was functional for knowledge deployment and demonstrated the capability of the approach to deliver changes, creating outcomes that were of value to stakeholders at different levels.

6.2.4 Escalation to SoS based enterprise models

The thesis has shown that the reduction in uncertainty at local level increases control and shifts decisions and responsibilities further upstream, both within and outside the organisation. In this situation, dependencies (and the associated uncertainty) are dealt with across organisational or system boundaries and defines a requirement of transforming the relationship. Addressing dependencies in the system can shift responsibilities for change and innovation, and transform relationships by creating accountability to each other based on shared process understanding and outcome expectations. This is the functional basis that underlies these new interactions which establish new relationships.

By introducing a means to leverage knowledge and reduce uncertainty, system dependencies can be addressed at the appropriate levels and create a capacity for effective coordination between originally more remote stakeholders to deliver additional value to them. This was demonstrated for design and operation in TATEM, and within and between organisation in HILAS.

The reduction in uncertainty extends the range of interpersonal coordination mechanisms into the wider system, allowing previously remote and only partially connected stakeholders to form new relationships. In these new relationships new goals and objectives are defined that extend the scope of system dependencies that they can manage and define new value creation opportunities not only within an organisation but at a system of systems level. In the aviation industry, new business models emerge as owners of technology and information seek to reconfigure the social/organisational space to optimise the share out of value from their point of view, such as manufacturers attempting to exploit the value in the information attached to their technologies by gaining control over associated services.

An example for this trend in the aviation community is a recent EC framework 7 proposal called ATOME that answered the call to integrate technology innovation with organisational re-organisation and a dedicated information capability to define corner stones for the implementation of an extended enterprise framework. Extended enterprise relationships develop as collaboration across the lifecycle of product and services begins to outweigh largely competitive relationships. In contrast to Harris and

Stanton (2010) assessing the aviation industry as a system of systems based in the independencies of units and clear boundaries between them, both structural as well as in terms of relations between organisations, the escalation of thesis findings to a system level shows that in the e business models it is the links and relationships between the elements of so-called system of systems that are important to understand for effectively designing their implementation (confirming the role of knowledge and relationships), thus turning it into an actual system that can be made a subject to the approach put forward in this thesis.

6.2.4.1 Information system capability

New IT capabilities supports realising the transiting towards new business models and escalating the functionality of knowledge and relationships in the system to the business level, especially the advances in information integration and interconnectivity; new technology and information based applications have the potential to drive organisational process integration and building relationships and knowledge and transforming dependencies.

IT capabilities have developed at a pace not seen before, over that past decade, and are offering a potential for realising the transformation of systems that previously were remote and disconnected and enables the design and integration of constellations such as extended enterprise models. Traditional data base and search functions have been outdated and information technology has evolved to be much more capable of real time exchange, informal use, high processing capability, data integration, multi media format and interactive navigation among others.

The thesis provides a platform to address how to target the deployment of this potential in future research, addressing a gap that already exists with today's IT based knowledge management solutions: giving most attention to the codification of knowledge when designing IT solutions and very little to the subsequent utilisation of it (e.g. Grover and Davenport, 2001). On the face if it, the newly emerging IT characteristics allow for better and more importantly integrated support of the two knowledge cycles postulated.

1. Data/Information transformation

   This type of transformation is the obvious one when thinking of IT systems. It comes back to Tuomi's (1999) argument that knowledge is the basis for defining the data and what to do with it. An example: The Blocker reporting and analysis was paper based. For the next generation of user, these can benefit from an IT based version. Pre-population of data saves time; automatic analysis and flagging, regular reports or flags for particular cases, such as defined for complex blockers; probabilistic models of dependency concept, and others. This enables more powerful exploitation of the data originating in the knowledge base. Within a conceptual framework, it can link up blocker data stream with existing ones. This enables large scale exploitation of data.

2. Relationship transformation

   Relationships can be enacted through social features of innovative IT capabilities and new social media formats; this is a new feature added to previous IT capabilities. Social media make social process transformation possible in unprecedented way as they approximate real time

interactions and maintain informal characteristics, e.g. having a chat or free association chain on twitter.

6.3 Leverage

Chapter 5 summarised the impact that was delivered by selected interventions (as part of the overall process) within the two case studies (see Table 21). It shows that having the functional knowledge about system dependencies that characterise a socio-technical system, in which the techno-economic logic defines requirements for social functions, provides a critical platform. However, leveraging this knowledge is the mechanism for delivering impact and creating value. The overview in chapter 5 shows that effective changes in the case studies were not only the result of having the right knowledge, but also required a social structure that is conducive to constructive knowledge transformation and that can sustain the proposed changes – and vice versa.

Escalating local issues into the relationships that are functional at the level at which the solution has to be sustained delivers changes both locally and in the wider system. Both case studies have demonstrated this and while the instantiation in the TATEM case study did not fully exploit its potential for the reasons discussed, the HILAS case study saw the implementation of organisational changes that operationalised knowledge and relationships, sustaining improvement initiatives to maintain value creation.

In her critique of the rational model of change, Dawson (1996) argues that any plans can only be fully translated into an implementation if certain conditions are met.

Firstly, she defines a requirement for people to be aligned with the goals along the process, either by building a consensus or exerting power. Either of these mechanisms is socially based and calls upon the relationships that the existing social structure supports. The thesis has emphasised the social nature of knowledge processes, from developing the models to utilising the resulting knowledge for implementing changes, and actively designed the social relationships to complement the functional logic of the system that the thesis approach targets.

Secondly, Dawson argues that effective implementation requires "complete knowledge" of how the system works. The thesis has build on a priori knowledge and validated and consolidated its main dimensions in a functional framework, integrating social and technical aspects of the system, and has delivered the capability of expressing an integrated set of socio-technical functions in the concept of dependencies. Having a functional structure defines relevant knowledge and creates the platform for devising plans for change and targeting interventions.

Thirdly, she calls for processes that exert control over the variables that influence the outcome, or creates a situation of stability. In the thesis it has been established that relative stability can be achieved in managing dependencies that underlie the system's inherent uncertainty. Both case studies have demonstrated socially based knowledge processes that transformed dependencies and increased control. Functional knowledge deployed in social relations leverages the dependencies in the process (even if some may not be fully within the span of control) to achieve business outcomes.

In summary, in the context of this thesis Dawson's critique can be translated into a recipe for leverage which has been demonstrated in the case studies: the ability to effect changes was successfully implemented in deploying the model based functional knowledge in dedicated processes that drew on social relations to manage system dependencies that underlie uncertainty in the system.

Dawson comes to the conclusion that those conditions are rarely achieved. When reviewing other theories in regard to their capability to deliver to Dawson's requirements, it becomes apparent that they fall short in meeting those in an integrated way. Chapter 5 comes to the conclusions that the theories that focus on knowledge management (e.g. Nonaka and CoP) are concerned with knowledge creation, or even its acquisition and exchange in social practices, but without defining what the knowledge is about or what functional logic the practices are a response to. Knowledge is turned into an abstract entity that is without its functional context. This disconnect is partially mirrored into the way social relationship are dealt with.

This defines a gap that does not only represent a shortfall or incomplete theory but effectively limits them in supporting change in a direct way. In the absence of a knowledge structure (as implemented in the functional models of the thesis) leverage cannot be supported as there is no systematic way of identifying the knowledge content that can define what needs to be changed. Therefore, passing the gate from knowledge creation to knowledge utilisation and implementation in a way that is transparent and reliable is not adequately supported. Referring back to Dawson, the theories discussed are strong examples for managing the social aspects, but in terms of defining relevant knowledge about the target system's functioning, they fall short and thus the impact they achieve is can only be validated post-hoc.

Recent publications by the main protagonists of these theories show an increasing awareness that the explanatory capability of their concepts is limited, especially when faced with designing new organisational scenarios that reflect business trends as discussed in Chapter 1.

Hackman and colleagues

Oldham and Hackman (2010) review where their discipline will go next and come to the conclusion that it will face dramatic changes in the light of how the business world is evolving and as a consequence this will transform peoples' jobs and their way of working together as teams. They conclude: "The next decade, we believe, will be an exciting time for research about people doing work in organizational settings. [...] the design of work is now inextricably bound up with the structures and processes of organizational systems more generally. That is, rather than specific jobs it is the often-fluid relationships among people and their various work activities that are most in need of empirical research and conceptual attention." (Oldham & Hackman, 2010).

In the same article the authors argue that "We also expect that future research on job design will give increasing attention to "trickle up" models of the relationship between organizational properties and how jobs are designed. Traditionally, job design has been dealt with, by scholars as well as by practitioners, as a top down undertaking: the way the work is structured is shaped and constrained by properties of the larger organisation within which the work is done. But it is at least possible that organization-level properties might themselves be altered by the way front-line work is designed and performed." (Oldham & Hackman, 2010). Chapter 2 gives an outline of how the uncertainty that results from operating complex

technologies in a business context is not well represented in the formal system design and support and subsequently is mitigated by informal practices that implement the social and knowledge functions that are required to sustain the overall system performance. This provides a definition for what has trickle up and be acknowledged as being functional in its own right, in order to design better socio-technical systems, systematically delivering the changes in organisational level properties that Oldham and Hackman envisage.

To achieve what Oldham and Hackman (2010) call for, it requires a functional perspective on the system, which integrates technically based functions with the social and knowledge based functions which result from operating the technology in a business environment. They talk about how people's experiences 'trickle up' which has to include knowledge of informal practices and how the system is shaped by what people do locally. The thesis has not only demonstrated that this is the case, but also shed light on the reasons behind it and actively dealt with it in the case studies.

Brown and colleagues

In their discussion of local knowledge in global innovation, Brown and Duguid (2002) make a central point: "In all, the networked economy is not just a technological network carrying digital information, but a social network supporting the creation of human knowledge." This reinforces the role of relationships in the light of new enterprise models as postulated in Chapter 1, even if those are enabled by introducing yet more technology.

"This vision of the future suggests less a polarization of society than a symbiosis. It does not turn around a simple distinction between old and new economy jobs (any more than around a distinction between material and informational products). Rather, the two may continue to merge into one, combining each other's strengths, rather than one trying to supersede the other." However, as no means is offered to address the functional logic of existing or future systems, it is not clear if it can be actively designed and implemented.

More recently Brown is concerned with innovation, building the extension of communities of practice into networks of practice and the role of creation spaces, promoting those over traditional tales on knowledge management (e.g. Hagel III, Brown and Davison, 2009). While the strengths of the original approach remain intact, its transfer or escalations to larger scale systems suffers from the same limitations. Questions raised and principles promoted such as new knowledge as a key resource or extension into global markets and networks resonate with the issues raised in Chapter 1 of this thesis. However, the core concepts such as social relations and practices are discussed in the context of globalisation and how IT capabilities in social media create conditions conducive to connecting people at this level, but still without addressing their functionality in a system.

Nonaka and colleagues

In a recent review article, Nonaka and Van Krogh (2009) responded to the critique that has been levelled at the knowledge creation process since its initial publication in 1994. While they clarify and ground the concepts in supporting publications, only a few extensions or new questions arise. They reiterate the explicit strengths of the approach that the thesis adopted, such as the relationship of tacit and in

knowledge conversion, the argument that knowledge is enabling action and problem solving, and the social component of knowledge processes and how it validates knowledge, among others.

However, two lines of argumentation in particular reflect the distance between the accomplishments in the thesis and the corresponding knowledge management concepts as advocated by those authors:

Firstly, while knowledge is defined in terms of allowing action and being useful, there is no functional reasoning how outcomes are achieved. In contrast to earlier publications, the authors explicitly discuss outcomes of the knowledge process which are defined as product or process innovation and increased capacity for action and problem solving, and thus highlighting the relevance of the implementation phase in knowledge processes. However, how the knowledge is implemented to support functions in the system that deliver these is not addressed; in terms of a structure for functional knowledge a black box remains between knowledge creation and its expected outcomes.

Secondly, they expand on the role of social practice and while favouring CoP approaches, they stress the need to expand boundaries to allow for innovation which is limited by the knowledge base within a community. In addition they argue that the knowledge conversion creates a social reality, rather than just being an enabling condition (such as BA), and "propose that social practices may evolve around knowledge conversion, over time providing necessary conditions of stability" (Nonaka and van Krogh, 2009, p.646).

6.4 Overall conclusions

In summary, the thesis introduces an approach that has been based on conceptual integration and empirical research strategies which in combination address the complexity of socio-technical systems in a way that allows for directing interventions based on functional knowledge about the system and thus maximises leverage.

Figure 19 consolidates the argument made in this chapter and provides a platform to conclude the chapter with a discussion of a value proposition.

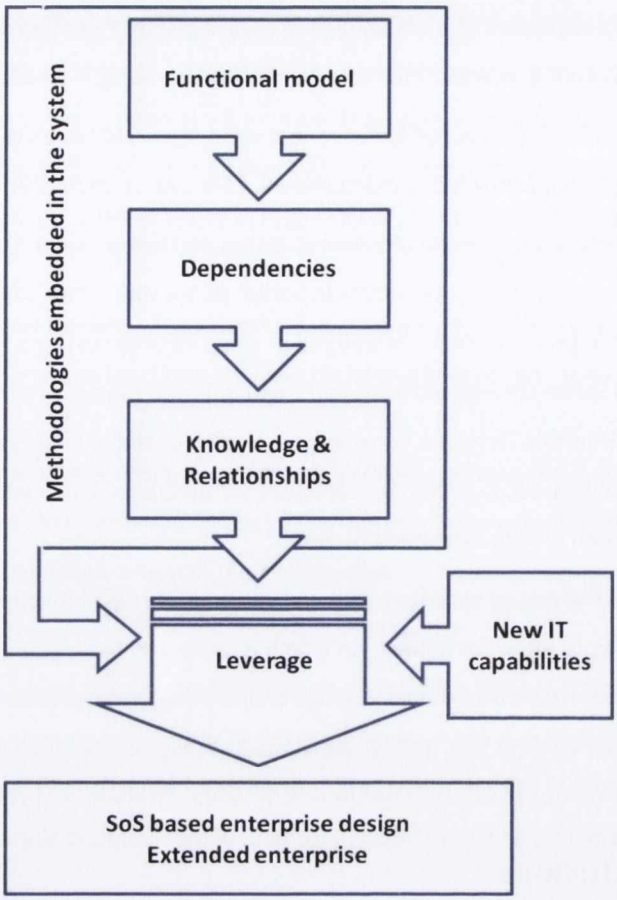


Figure 19: Overview of thesis conclusion

The functional model expresses the basic logic in the aircraft maintenance system. Based on the aircraft technologies, maintenance requirements are implemented in different work pack configurations and the resulting dependencies are managed by social processes. The findings in the thesis, especially in Chapter 3, have demonstrated that there are limited degrees of freedom in how maintenance requirements can be configured in a work pack. A generic functional logic that defined both sequential characteristics as well as the transitions between levels was established. Within this the vast numbers of tasks can be organised, and in combination with the economic strategy, ground the operational implementation. This provides a baseline for abstracting dependencies that span system levels. The status and configuration of dependencies underpins the level of uncertainty in the system. Previous chapters have demonstrated that coordinating the dependencies within and between system processes utilises knowledge as part of social relations.

The current system operates along these dimensions, with people approximating activities based on their largely implicit understanding of the system. This has been illustrated in WIPIDO (McDonald, Corrigan and Ward, 2002) which emphasised the role of local management of symptoms of sub-optimal operational conditions. The thesis has moved away from a worker centric point of view of the operational situation and devised a framework that addresses the parameters that feed local efforts and integrate them according to their functional role in managing the overall system.

The design of the case study arc was aimed to engage with the system in-depth according to these parameters. It integrated both ethnographic and action research paradigms. While these are approaching

the subject from different angles, in their implementation in the thesis they have in common that both embedded the research in the target system. Both engage with the system in an in-depth way: ethnographic approaches make observation on the everyday life as it unfolds in a given setting and consolidate those into a rich picture, while action research intervenes and reflects on the outcomes and consequences to gain detailed insights. Adopting a functional perspective focuses both of these and integrates their respective strengths around the analysis of system functioning.

Embedding the thesis research process into the system allowed the abstraction the underlying, partially hidden functional logic of the system and its consolidation in a knowledge structure which organises the relevant knowledge space that spans from local to global system levels and across diverse but functionally interrelated socio-technical dimensions (i.e. functional tasks and their dependencies, knowledge and relationships).

Having the relevant knowledge is a pre-requisite but is not sufficient in itself to give leverage over the system. In social interaction knowledge is exchanged and transformed and becomes a ground for action. These actions are part of processes that deliver outcomes. In the case studies, the thesis research was embedded into the respective process at their core: the design of innovative technologies and the improvement of check performance. As part of the thesis research design, a participatory approach was realised that worked with stakeholders in their processes to address the goals of these design and improvement processes, rather than defining the research process only as a set of inputs to the process. Both case studies have demonstrated that the relationships (either in the design process or as transformed by the improvement process), which were established through the implementation of the project processes were core to creating new knowledge and basing actions on it.

It was this combination of a knowledge structure and its use in a process, which created leverage and delivered the change outcomes in the case studies.

New information technology capabilities offer the potential to extent the scope of leverage that is delivered based on knowledge and social relationships. New capabilities such as social media applications and interconnectivity based on collaborative processes can be exploited in designing knowledge and relationships as they connect remote stakeholders and facilitate both knowledge cycles.

Increasing process certainty shifts the focus from local solutions towards global re-organisation. As part of this, relationships between organisation can be reconfigured or newly formed, expressing goals at business level that can be formulated with more confidence in the presence of increased certainty of system performance. An example is the extended enterprise framework that is favoured by key industry players in the aviation community. It is based on redesigning a system of systems by integrating its processes and relationships around a shared business goal that has value to all stakeholders but cannot be delivered by a single organisation; thus effectively designing a new system. Given the scale and geographical distribution of such systems, IT capabilities have the potential to support the re-drawing of organisational boundaries and the integration of processes to meet new business goals. How effective an IT solution is in delivering these benefits depends on whether its design choices implement the dimensions that make a socio-technical system work in the first place. Only then can it effectively facilitate

the processes that are core to the delivery of outcomes that are of shared value to all stakeholders in the new system. In fact the real opportunities for new technologies are to address functions which are currently being managed by informal co-ordination, as these tend to where the system is least well supported in achieving its functional goals.

6.5 Consideration of value

In order to make a convincing case for stakeholders to invest in new processes and information systems and in building up social capital, i.e. networks of relationships, the value proposition needs to address their respective expectations. Formulating a sustainable outcome or a set of outcomes that has a (possibly different) value attached for each stakeholder, which define the objectives of the collaboration, requires a shared understanding of how their respective organisations work and interact today and a transparent way to achieve a common vision of the future.

Pettigrew and Whipp (1991, as reviewed in McDonald, 2008) define the market environment as the driving force for strategic change (see also Chapter 2). This implies that a value assessment (re)directs business targets and defines the required changes that allow the organisation to deliver to those. Rephrasing their change factors in the context of the thesis, effective change relies on a functional reorganisation across system levels (strategic and operational change) and on social transformation, leveraging knowledge (HR and leadership).

In new systems such as extended enterprise, the business strategy is defined by shared values that one organisation on its own cannot realise and is implemented in both product (transactions) and people (relations) strategies, both of which contribute to value creation. The thesis has demonstrated the intertwined nature of two value chains: the transformative that is based on the techno-economic logic and the coordinative which is grounded in the social nature of knowledge.

New business models build on the same value creating mechanisms that delivered value in both case studies. Leveraging knowledge in social relationships is a key mechanism for implementing changes that will transform the system processes and the value chain those instantiate.

Transforming system dependencies and reducing uncertainty is a knowledge function that is enabled by having a functional perspective on the system and a socially based process for leveraging the derived functional knowledge. This allows value creation that is outside the limitations of current system functioning, which is reactively dealing with uncertainty, and allows for proactively designing a value chain, integrating both technically and socially based transformations.

6.5.1 Value creation in the case studies

Both case studies have shown reductions in uncertainty and how this extends the range of effective coordination. As dependencies are transformed, local relationships can become more routine due to a reduction in co-ordination requirements. Dealing with less uncertainty gives more control over the process and how it delivers its outcomes, both locally as well as in more reliable planning that occurs upstream. These conditions set the scene for a more assured value delivery.

In the HILAS case study, the overall improvement process was driven by performance drivers that represented value to the MRO as well as its customer: on time delivery within the cost allowed for recoverability for the MRO and (increased) availability for the customer. The HILAS project provided the context for exploring the intersection of their respective agendas and allowed the pursuit of new ways of working together. In the traditional relationships with a customer, the focus of the MRO was on the internal production logic while the customer sought 'more maintenance for less money'. While a collaboration which involved risk sharing and included sharing of operational data was rejected in earlier project meetings (McDonald, 2012), the constellation of HILAS offerings in combination with a push towards improvement in the MRO agenda and a risk focus in the airline created a unique opportunity.

The implementation of the initiative delivered to the value expectations, including a bonus payment for the MRO and increased aircraft availability for the airline as aircraft were delivered ahead of schedule. In addition, the new way of interacting and exchanging information and knowledge in pursuit of shared goals transformed the relationship between the MRO and airline. Not only was the programme complimented by the customer, they also entered a continued collaboration (as expressed in awarding another contract) and transferred the approach to other maintenance partners.

A similar logic applied within the organisation: operational staff saw value created for them in a joint effort, as did management and support roles who appreciated the operational outcomes. In a situation where relationships had suffered and trust was an issue, based on a series of programmes that were regarded as largely inconsequential to the workforce, this initiative delivered value at many levels (e.g. improvements of the work situation, meeting KPIs targets). Instead of managers promoting technical solutions based on formal accounts, aspiring to eliminate uncertainty, all stakeholders collaborated in a process that deployed their combined knowledge about the actual system to better manage uncertainty; implementing coordination and relationships that were functional.

In the TATEM case study, the capability of the approach to deliver value when integrated into the design process was demonstrated in the KTWS but not fully exploited in the project. There are several contributing factors to that, many of which come back to the role of knowledge and relationships within a system as discussed in Chapter 3. In summary, the approach was implemented late in the project as it required a knowledge process of its own to develop, communicate and operationalise it in a way that promised to create value for all the stakeholders that needed to be involved and to meet the project objectives. Unlocking technology innovation to deliver operational benefits relies on an active process of knowledge exchange which requires favourable relationships. In the absence of shared understanding of how objectives could be realised in a way that generated value for all parties, the required transformation of existing industry relationships to enable knowledge exchange about each others actual dependencies was limited in both scope and opportunities.

However, the project overall delivered to its technology focused agenda. As part of this, the approach and specifically the KTWS that it enabled demonstrated the value of integrating a knowledge process into technically driven system engineering processes. It delivered outcomes such as to-be models that highlighted areas for transformation, and thus savings, that were previously hidden, and informed a

narrative that filled some of the gaps that were left in the final demonstration of operational benefits delivered by the project solutions. The model-based workshop design accelerated the exchange and integration of knowledge and its transformation into a vision of a future operation; with these interactions starting to enable the transformation of relationships. From the experience in the project, it takes such an approach to overcome the barriers that are defined by the current relationships. Furthermore it was these outcomes that sowed some of the seeds for the more recent proposal on extended enterprise.

6.5.2 A value proposition

Abstracting from the practical achievements in the case studies as summarised above, the core argument of the thesis as consolidated in Figure 19 defines opportunities for Human Factors approaches such as this one to deliver value at different system levels. This offers a value proposition that extends the capacity for value creation beyond the local level, which has been described as the perceived limitation of current Human Factors practices by Dul et al. (2012) in Chapter 1, and integrates HF as a system science into the value chain.

Implementing the knowledge structure reconfigures the understanding of interfaces that people have with the system and thus the scope for local intervention at different system levels, while at the same time advancing an understanding of the role of people and their relations in the system processes that instantiate the value chain.

The functional role of knowledge in social processes emphasises the importance of the social space of the system. Social capital argues that value is realised by patterns of social relationships. While discussing the benefits of 'appropriability' (transferring the benefit of established relationships onto new situations or context, e.g. friendship to work) there seems to be little insight in how those benefits are realised in a process system that delivers tangible outputs. In a review article by Adler and Kwon (2002) of social capital as a concept, most of the studies cited are focusing on HR functions such as career development, turn over rates, rather than linking social capital into the traditional notion of value chain. The thesis findings demonstrate that the social space is equally important to the technical aspects of the system in delivering its outcomes. It enables functions that are core to system functioning.

Previewing the relevance of this for design at the level of new business models, supported by complex IT solutions, Smoliar (2003) discusses that for it to be effective, knowledge management has to be seen as interaction management: "Knowledge management thus requires moving beyond simplistic models of information exchange to more challenging problems of leveraging social interaction to the advantage of the enterprise." (p.337)

The way new enterprise models are aspiring to profoundly transform how business is done and organisations operate, puts knowledge and relationships at the core of their active design, as postulated by Post, Preston and Sachs (2002). Having demonstrated their role in the current system, this approach offers a capability to address the proactive design of new systems with the role of knowledge and new business relationships playing a central part.

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8 Appendices

8.1 Appendix 1: TATEM case study

8.1.1 Examples of narratives

The following are examples of narratives that were collected as part of the modelling of the removal/installation process.

Example 1:

Abstract – Summary	Different quality of work cards
Orientation – 'Setting the scene'	Operator, planning, mechanic State: Task card allocated and accepted
Complication – Situated actions and events	The mechanics receives a work card which allocates a task, the work cards can include very different information as well as require different sign off procedures, depending on the quality the mechanic is required to obtain more or less additional information, which takes more or less time that is not planned for
Evaluation – Comments & Judgment	The structure varies and does not necessarily fit with daily practices The complexity of the situation increases with navigation issues "NRC produced by BM are the best – upfront, clear and logical"
Resolution – Outcome	Task take longer than anticipated
Moral - Conclusions/lesson learnt	Standardised work cards that reflect logic/natural units could be beneficial Planning could take responsibility to standardise operators' input to a greater extent
Coda – Current Status	FG Base Maintenance

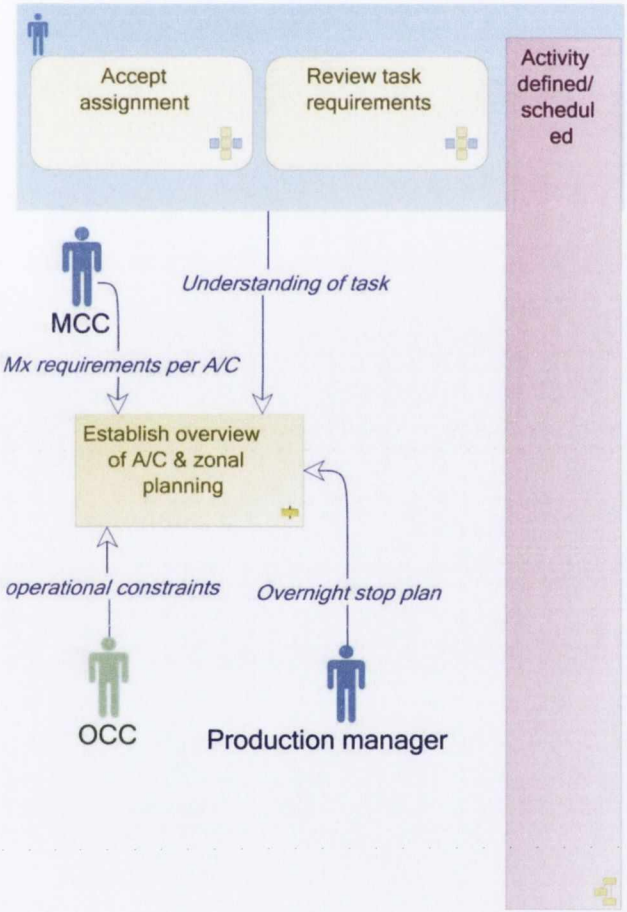
Example 2:

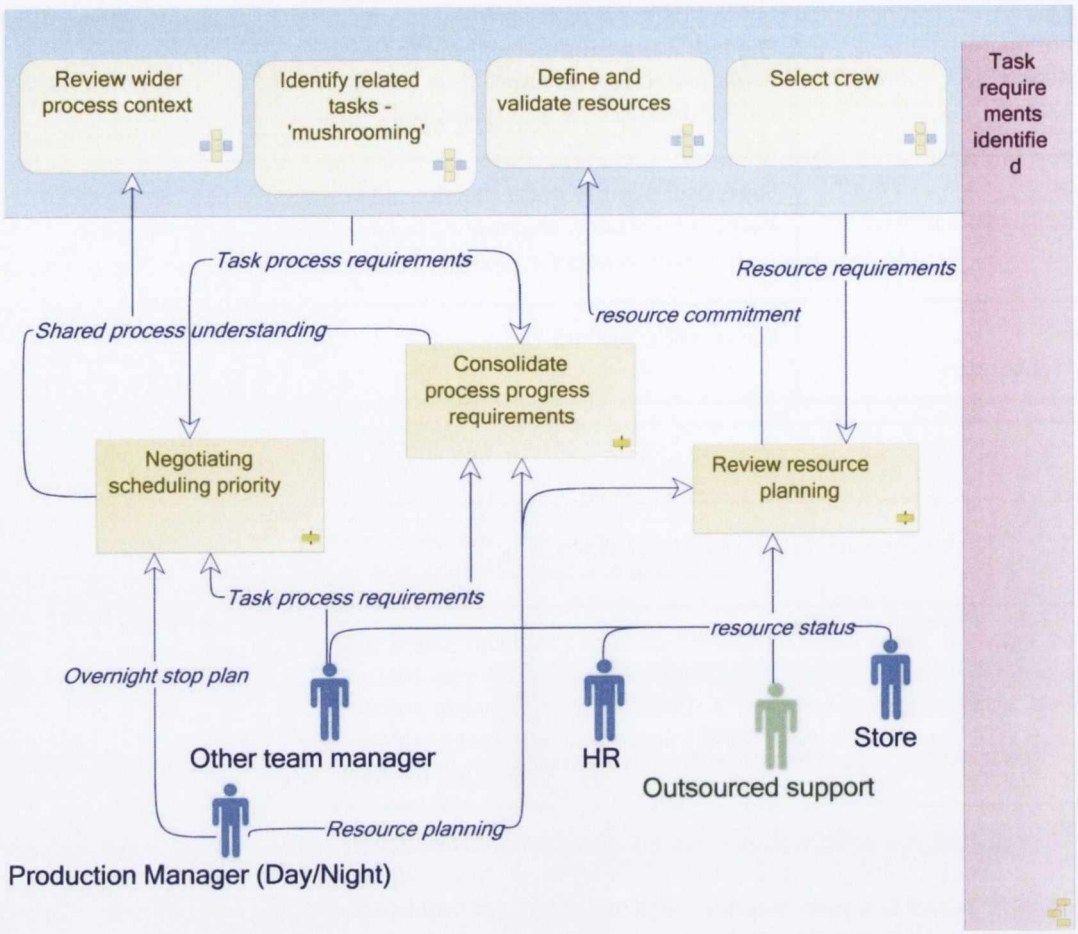
Abstract – Summary	Wrong tool
Orientation – 'Setting the scene'	Stores, supervisor, mechanics State: Part removed and stored
Complication – Situated actions and events	The tools were collected according to manual instructions, the thread protector for the wheel removal was applicable to all Airbus A/Cs, it fitted the thread but the wheel would not go off
Evaluation – Comments & Judgment	A special tool was referenced as alternative but this was not available in company Mechanics and supervisor spend time to figure out what the problem was, retesting the tool

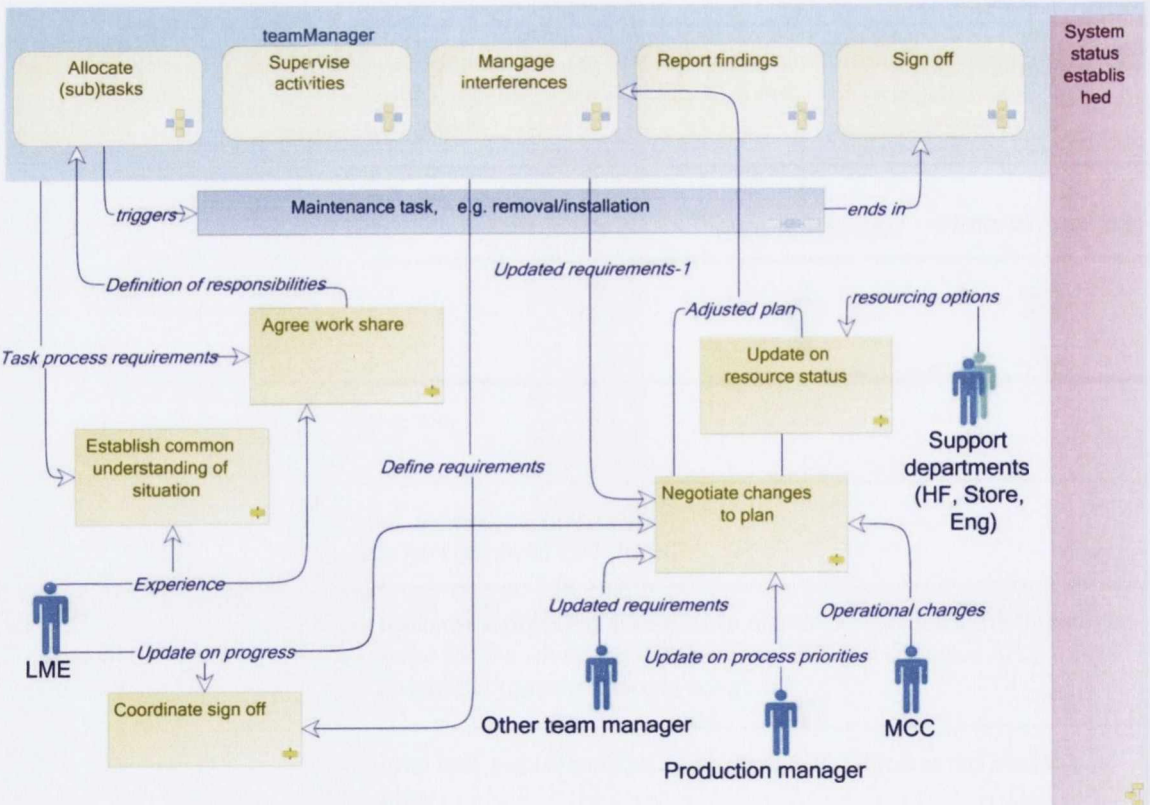
Resolution – Outcome	The task was performed without the tool It was tested several times, time was spend on figuring out the problem, talking to supervisor and stores and other mechanics
Moral - Conclusions/lesson learnt	Supervisor plans to order the alternative special tool, instead of raising QN because he expects engineering to come to the same conclusion
Coda – Current Status	Observation: BM, H6

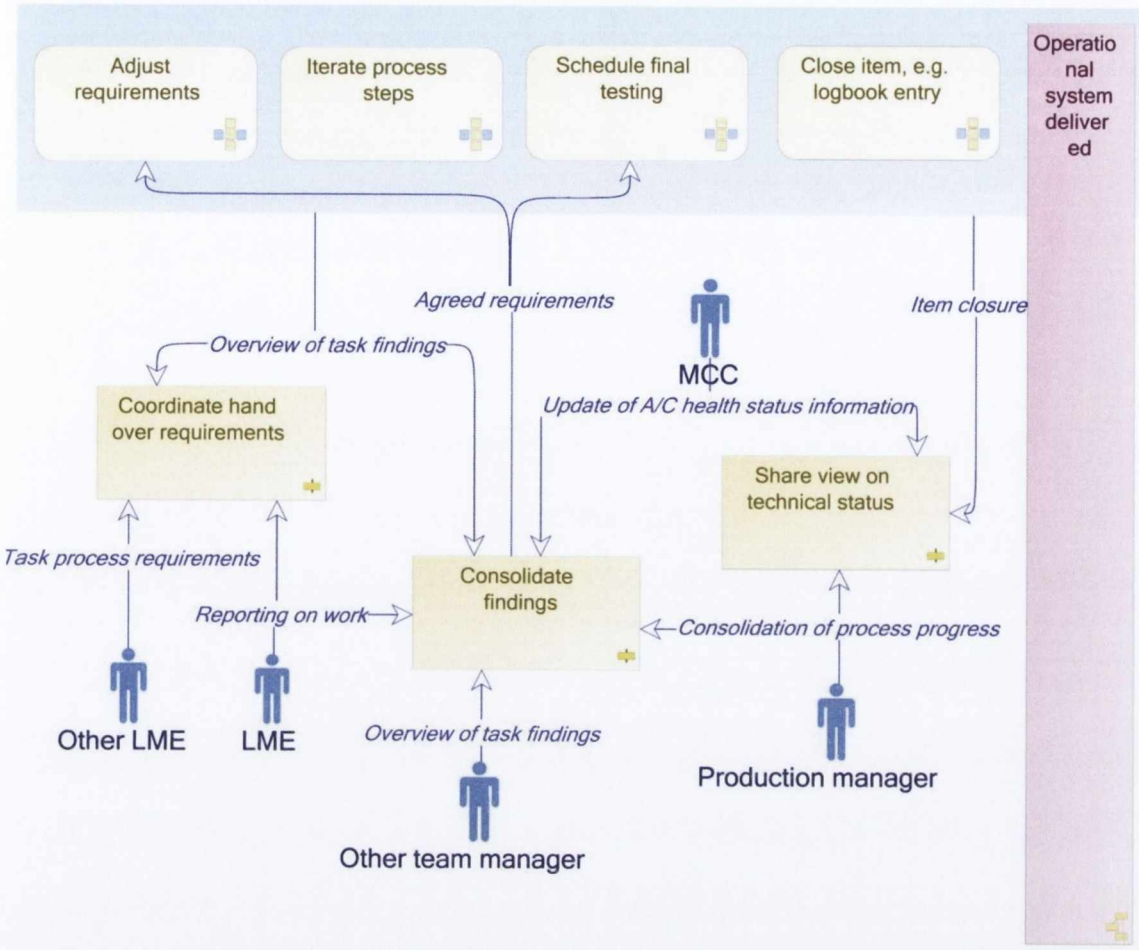
8.1.2 Task sequence level: results of modelling

8.1.2.1 Process activities

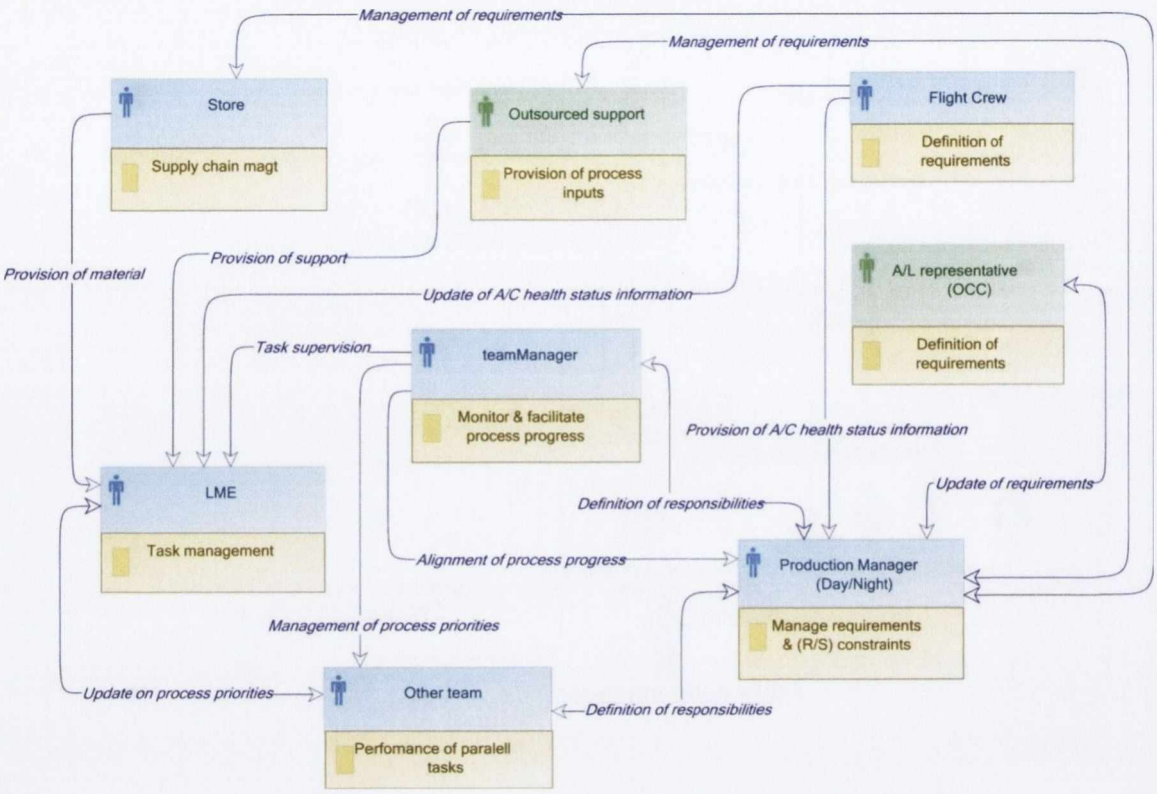



Review wider process context
Identify related tasks - 'mushrooming'
Define and validate resources
Select crew
Task requirements identified
Task process requirements
Resource requirements
Shared process understanding
resource commitment
Consolidate process progress requirements
Negotiating scheduling priority
Review resource planning
Task process requirements
resource status
Overnight stop plan
Other team manager
HR
Store
Outsourced support
Resource planning
Production Manager (Day/Night)


teamManager
Allocate (sub)tasks
Supervise activities
Mangage interferences
Report findings
Sign off
System status established
triggers
Maintenance task, e.g. removal/installation
ends in
Definition of responsibilities
Updated requirements-1
Adjusted plan
resourcing options
Agree work share
Task process requirements
Update on resource status
Support departments (HF, Store, Eng)
Establish common understanding of situation
Define requirements
Negotiate changes to plan
Experience
Updated requirements
Operational changes
Update on progress
Update on process priorities
LME
Coordinate sign off
Other team manager
MCC
Production manager

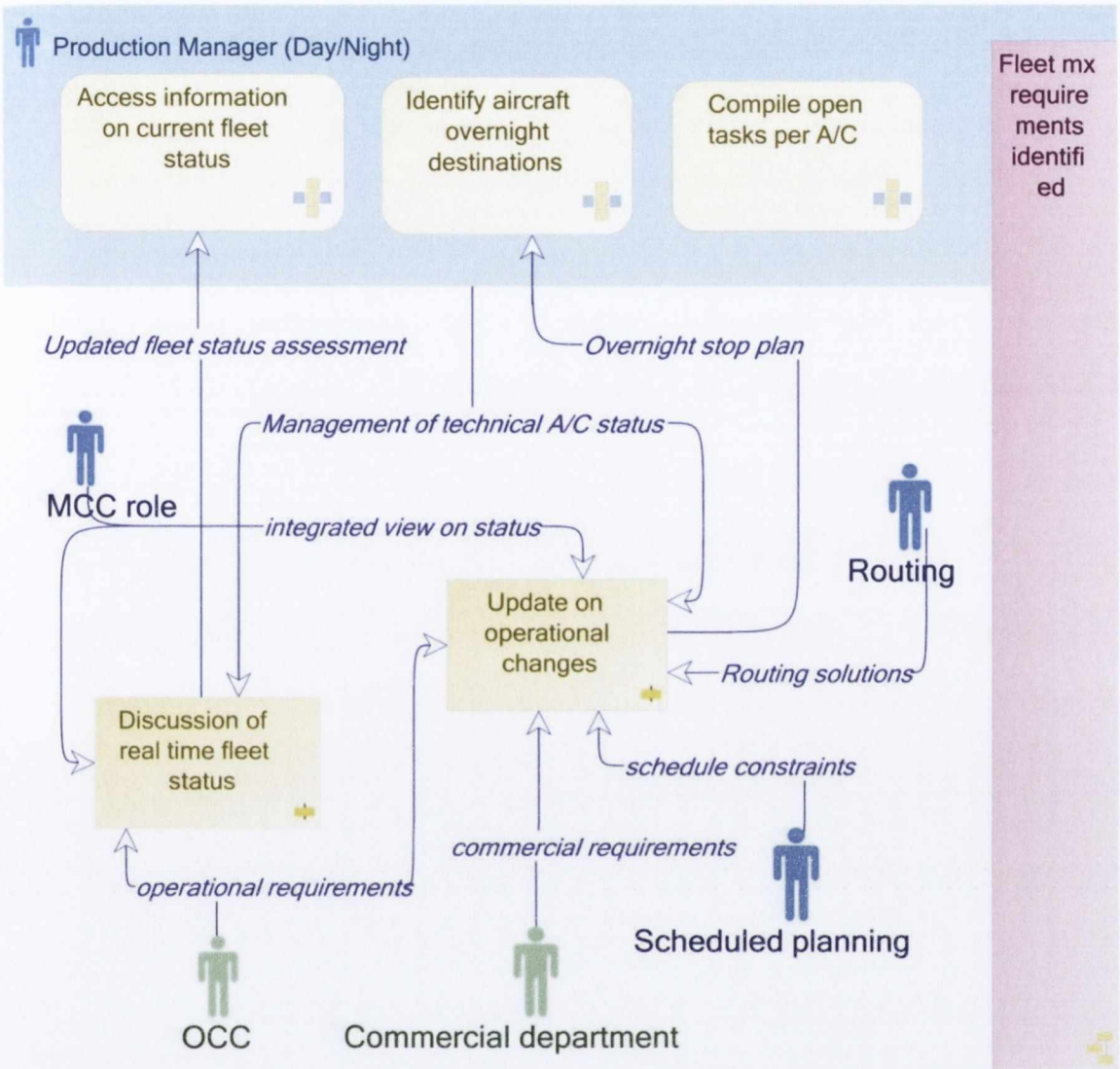

Adjust requirements
Iterate process steps
Schedule final testing
Close item, e.g. logbook entry
Operational system delivered
Agreed requirements
Item closure
Overview of task findings
MCC
Coordinate hand over requirements
Update of A/C health status information
Share view on technical status
Task process requirements
Consolidate findings
Reporting on work
Consolidation of process progress
Other LME
LME
Overview of task findings
Production manager
Other team manager

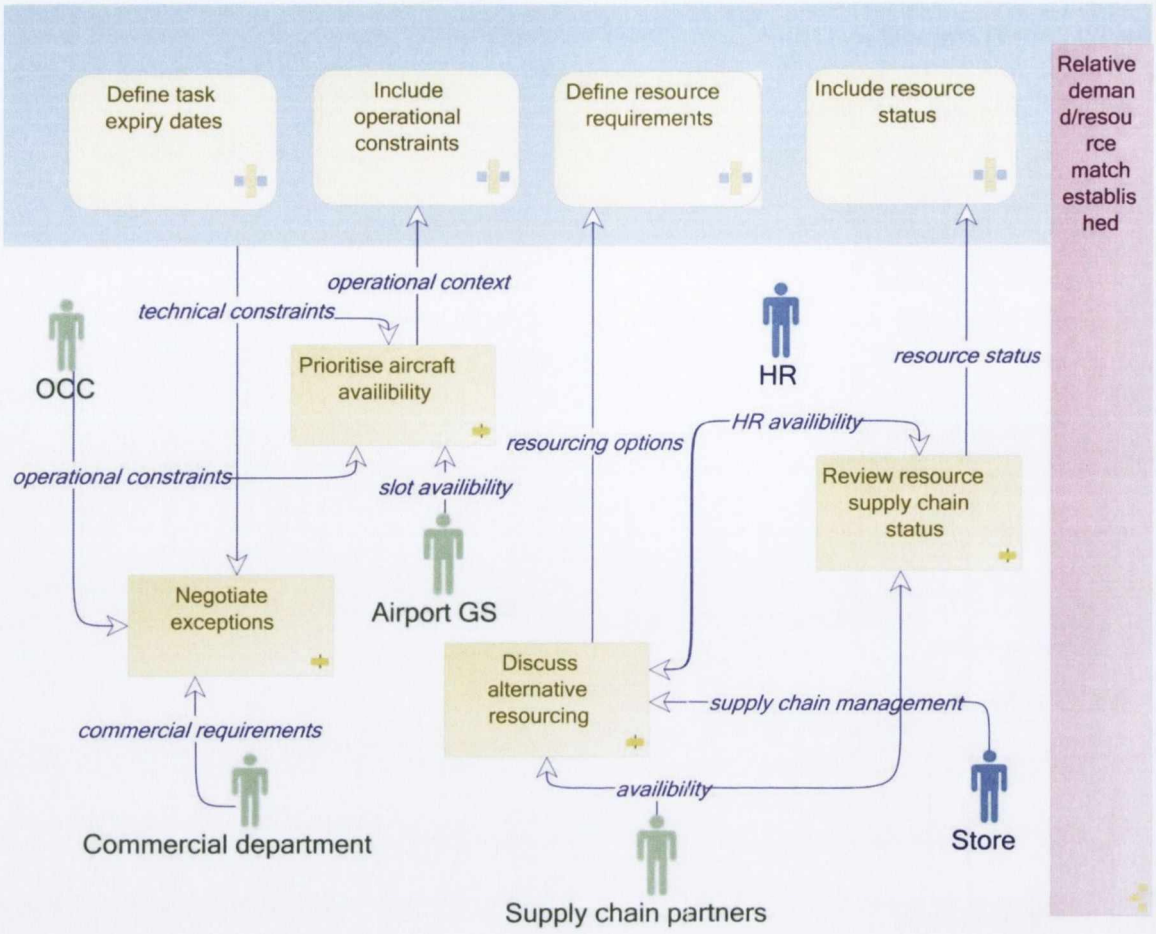
8.1.2.2 Stakeholder diagram

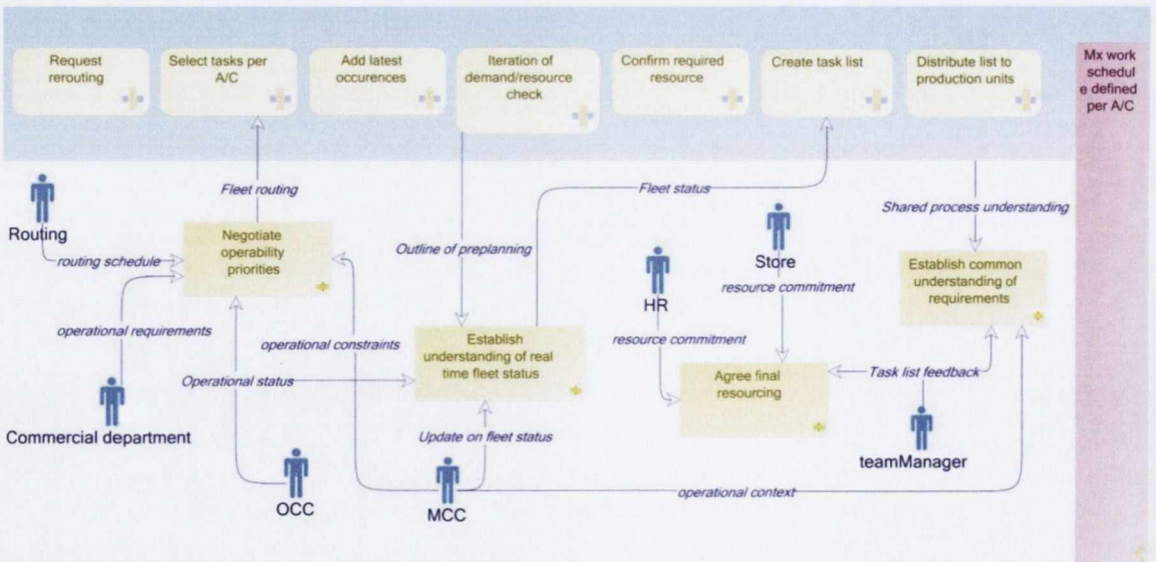


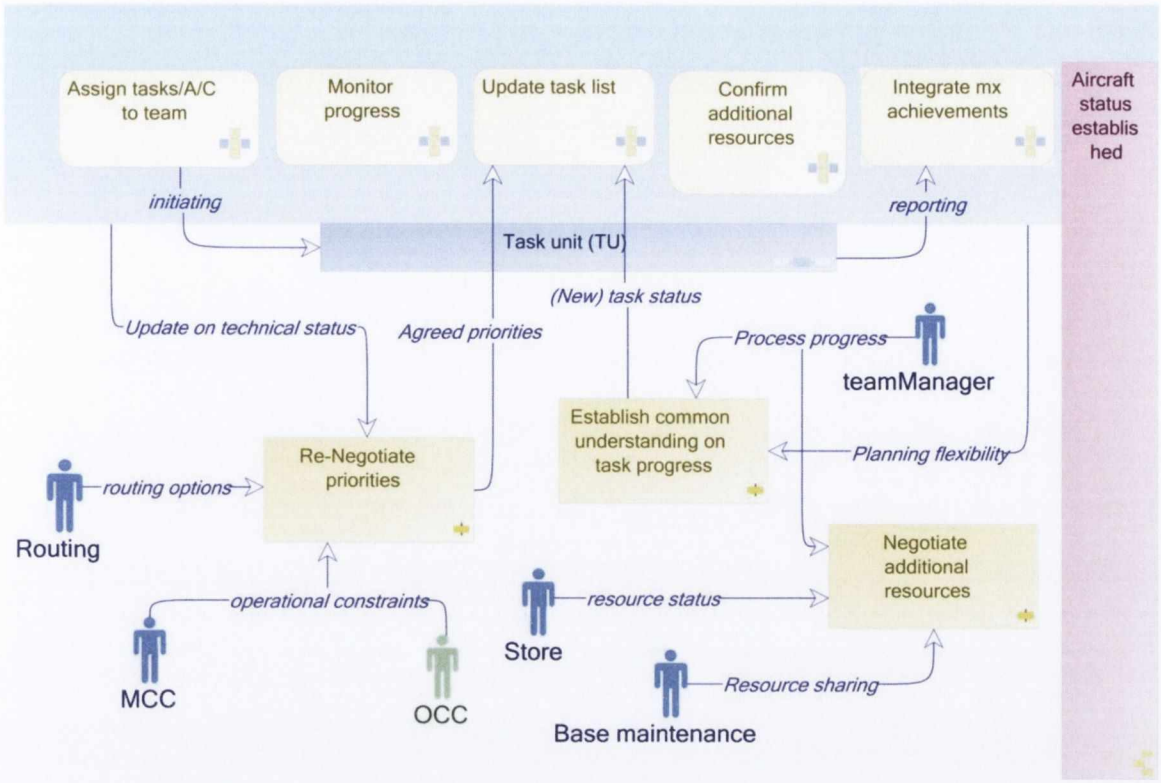
8.1.3 Operational level (Overnight): Results of modelling

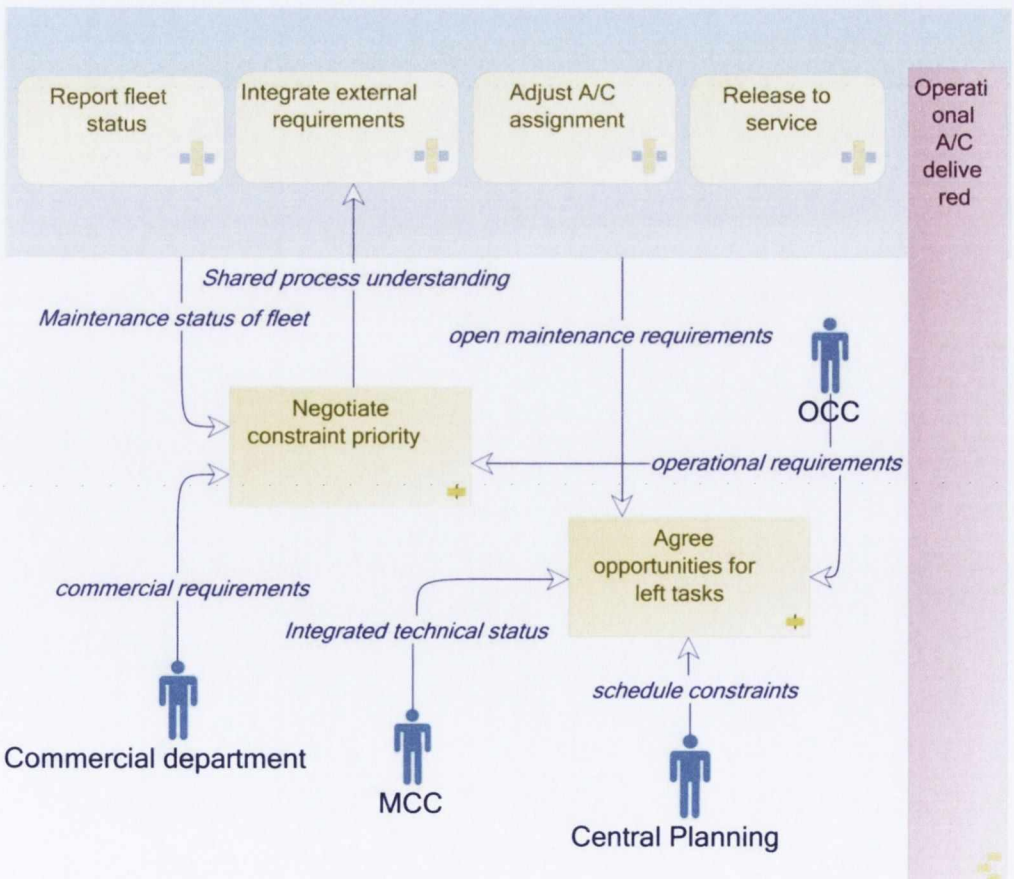
8.1.3.1 Process activities



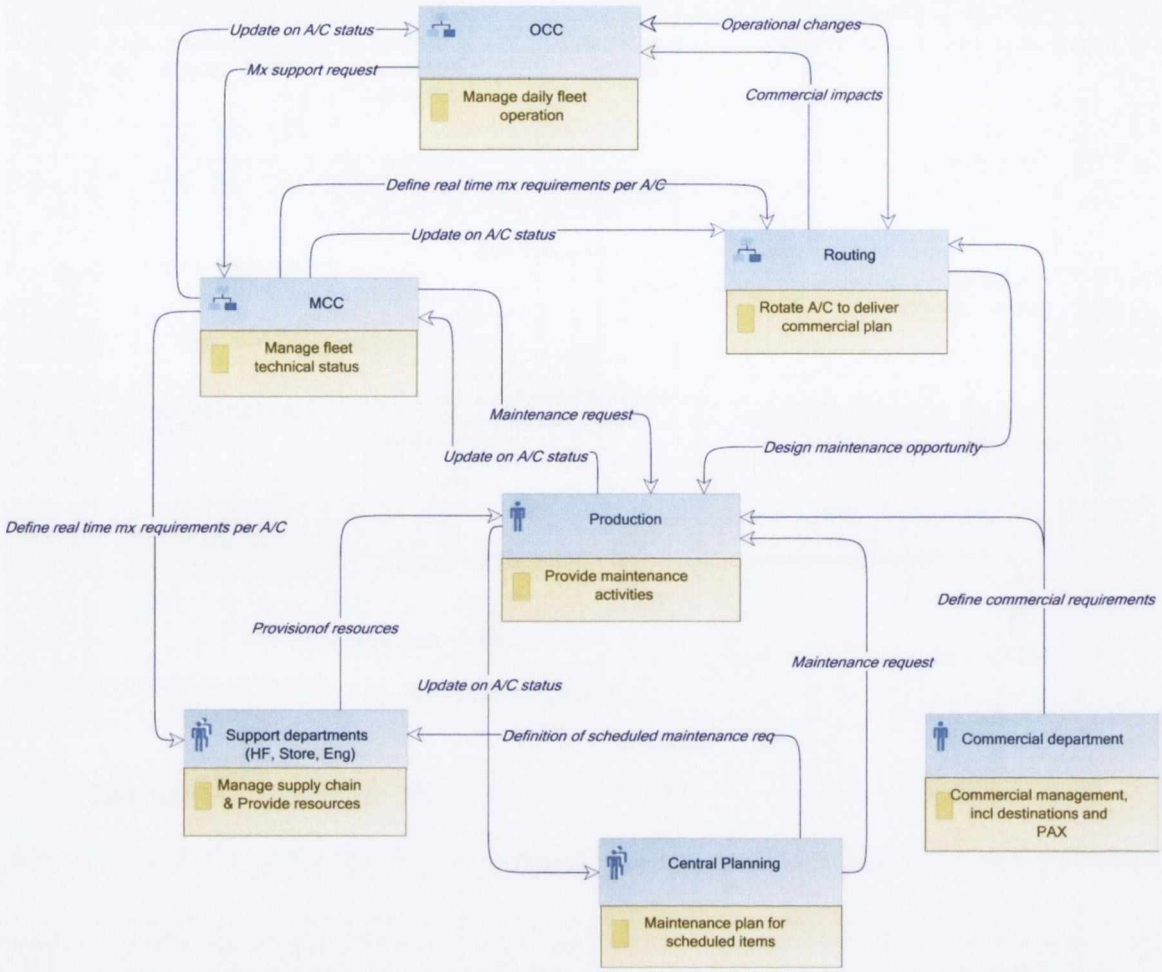

Define task expiry dates
Include operational constraints
Define resource requirements
Include resource status
Relative demand/resource match established
operational context
technical constraints
OCC
Prioritise aircraft availibility
HR
resource status
HR availibility
resourcing options
operational constraints
slot availibility
Review resource supply chain status
Negotiate exceptions
Airport GS
Discuss alternative resourcing
supply chain management
commercial requirements
availibility
Commercial department
Store
Supply chain partners


Request rerouting
Select tasks per A/C
Add latest occurences
Iteration of demand/resource check
Confirm required resource
Create task list
Distribute list to production units
Mx work schedule defined per A/C
Fleet routing
Fleet status
Shared process understanding
Routing
routing schedule
Negotiate operability priorities
Outline of preplanning
Store
resource commitment
Establish common understanding of requirements
HR
operational requirements
operational constraints
Establish understanding of real time fleet status
resource commitment
Operational status
Agree final resourcing
Task list feedback
Commercial department
Update on fleet status
teamManager
OCC
MCC
operational context


Assign tasks/A/C to team
Monitor progress
Update task list
Confirm additional resources
Integrate mx achievements
Aircraft status establis hed
initiating
reporting
Task unit (TU)
(New) task status
Update on technical status
Agreed priorities
Process progress
teamManager
Establish common understanding on task progress
Planning flexibility
Re-Negotiate priorities
routing options
Routing
Negotiate additional resources
operational constraints
resource status
Store
MCC
OCC
Resource sharing
Base maintenance


Report fleet status
Integrate external requirements
Adjust A/C assignment
Release to service
Operati onal A/C delive red
Shared process understanding
Maintenance status of fleet
open maintenance requirements
OCC
Negotiate constraint priority
operational requirements
Agree opportunities for left tasks
commercial requirements
Integrated technical status
schedule constraints
Commercial department
MCC
Central Planning

8.1.3.2 Stakeholder diagram



8.1.4 KSM assessment

The following table gives an overview of modules that were designed to add to the information in the models, advance an understanding of dependencies and guide suggestions for transformation. The summary overview reflects the status ate the time of the TATEM research

Module name	Module objective	Questions
Within task	The within task module examines the structure and activity within a task.	Are there certain root causes of "work arounds" and divergences between formal and normal? Are there conflicts between task elements over ... • Time or Resources or Attention? Is there a requirement to act despite conflict / ambiguity as e.g. ... • Check deadline • Task output is expected as pre-task for others • Lack of special tools in company Is there an opportunity to review operational problems as they arise?
Coordination	The Co-ordination module examines all the activities which link that task to other tasks in the sequence, to parallel tasks, and to the outputs of previous processes	Are co-ordination mechanisms appropriate? Evaluation and feedback mechanisms • Can these be understood as a way to resolve problems? Quality of communication in the team • Is the communication open and clear? • Are there issues that cannot easily be spoken about?
Team system	The Team system module examines the extent to which the participants in the task and co-ordination form a team, and how well its characteristics are supported by the organisation.	In how far is there a clear and consistent membership to the group? Is the team concept shared throughout the process? In how far is there a collective responsibility for outcomes? Which activities support team formation and training? Which activities resource teams most efficiently? By which activities is team maintenance monitored and calibrated? To which degree are team support programmes embedded in the operations?
Competence	The Competence module defines the knowledge, skills and abilities, the understanding of the work and the performance and evaluation dimensions which are derived from the Within Task and Co-ordination modules	Who are the actors in the process and what are their activities? How is the task understood? What are the KSAs? Are there discrepancies?

Social relations/Trust	The Trust module is built around a number of dimensions which influence the development of mistrust, as well as some which are important in fostering trust.	What are the relationships? Are they affected by the following, fostering trust or mistrust? Lack of trust • Formal versus normal • Incompatible goals • Performance requirement • No open communication • History of mistrust Trust • Belief in future • Genuine support • Personal relationships
Operational system	The Operational system module examines the interrelations between tasks and processes from a system perspective.	What is/are • Status of process: Formal / Normal / Non-normal • Requirements for and outputs of each task • Functional logic of process sequence • Roles and goals of agents at interfaces Is the process functionally coherent? What are the discrepancies?

8.1.5 Additional outcomes of KTWS#1: Task sequence level

8.1.5.1 Process Activities

Current	Description of process transformation	Future
State 1: Activity defined / scheduled		
Trigger from overnight process level / Accept assignment	Quantitative	Trigger from overnight process level / Access overnight plan
	New process step replacing another one; time savings possible, because Team Mgr receives accesses plan on PSS (?) instead of directly coordinating with other stakeholders	
	Qualitative	
	Removed: tbd Change: The PSS concept formalises the triggering process. No or reduced communication between central management functions and team manager is required if plan (based on HM scheduling) is accessed via PSS. Shift: Reduced involvement of team manger in triggering process; decisions are made more remote form the operation. (see also task unit process level). Team manager may lose some control over local planning. Opportunity: tbd	
	TATEM concepts: HM scheduling, mobile maintenance	
Review task requirements	Quantitative	Acknowledgement of task selection
	The step is shorter, i.e. it is automated in the PSS functionality (e.g. after log on task list appears and one is selected to start with) and it does only require input from a coordination activity that happens outside the process	
	Qualitative	
	Removed: removed at this stage (see next critical state) Change: workload reduced at this stage, so that task context can be better explored at next critical state Shift: Aspects of current responsibilities are removed from the local operation, e.g. a/c overview and zonal planning are being dealt with earlier on at another process level. Opportunity: activity definition happens at another organisational level, this reduces local workload and also reduces potential for reduplication of planning / scheduling work.	
	TATEM concepts: mobile maintenance; HM based scheduling, process orientation	
State 2: Task requirements identified – **future process: Task requirements in place**		
Review wider process context	Quantitative	Verify status of task requirements
	The time required for establishing an overview of the task context is reduced, because scheduling has been consolidated earlier.	
	Qualitative	

	Removed: Review is removed at this stage, has been consolidated earlier Change: Team manager can focus on monitoring / verifying accomplishment of requirements and has to be less involved in cross-level co-ordination activities. Shift: process context review has to happen at planning / scheduling levels, if planners / schedulers are better supported, i.e. By decision support tools and planning tools, they are in a better position than today to actually fulfil their role. Opportunity: better decision / planning / scheduling support not only makes process more efficient at these levels but also releases capacity at team manger level, i.e. the team manger can fulfil supervisory role more efficiently	
	TATEM concepts: Process orientation, mobile maintenance, proactive maintenance (?)	
Identify related tasks – "mushrooming"	Quantitative	Report operational exceptions
	There is a timesaving opportunity here, because operational constraints can be highlighted earlier	
	Qualitative	
	Removed: "mushrooming"-potential should have been explored at higher level so no need for it to be monitored here. Change: Instead of determining task requirements and requesting their fulfillment the team manger only has to manage exceptional cases and resulting adjustments (in co-ordination with other stakeholders). Shift: "mushrooming"-potential explored (and resolved) at higher level, leads to smoother process at this level. Opportunity: Given that planning and decision support tools are in place only exceptional operational problems / unexpected constraints should require co-ordination between team manger and higher management levels and lead to adjustments in the plan. If no exception occurs all requirements can be met by stakeholders as planned without further confirmation.	
	TATEM concepts: Process orientation, HM scheduling, mobile maintenance	
Define and validate resources	Quantitative	Identify own tasks
	The future process is closer to task kick-off and therefore time savings are imminent.	
	Qualitative	
	Removed: Removed at this stage, because all has been scheduled earlier at higher process level. Change: resource status has been verified earlier in this state. Shift: The responsibility for resource provision shifts to production planning level. Opportunity: Without need for further co-ordination the team manger can select (on the PSS) his own team's tasks. The team manager's role changes from resource manager to people manager and local process supervisor.	

	TATEM concepts: HM scheduling, mobile maintenance, process orientation	
Select crew	Quantitative	Initiate work of several LMEs or crews
	The actual task process can be kicked-off earlier	
	Qualitative	
	Removed: Change: crew could to some degree be pre-selected according to plan and task selection delivered into this process. The PSS will specify tasks for crew / LMEs so that shared task understanding can be achieved without explicit co-ordination. Shift: Opportunity: the local planning work load of the team manger is reduced and the actual task process kicks-off earlier. Earlier knowledge about crew selection could move this task further up in the process and crews – just as others resources – could be on stand-by according to selection.	
	TATEM concepts: HM scheduling, process orientation	
State 3 : System status established		
Allocate (sub)tasks	Quantitative	Monitor progress
	Task execution has already been kicked-off so there is a time saving to be expected. Furthermore, the team manager may have spare capacity.	
	Qualitative	
	Removed: task allocation has already happened, so it is removed here. Change: The team manager's role changes to more supervision and possibly less active involvement. The PSS should provide him with status information and thus reduce his need to personally check on progress / staff actions. Shift: n/a Opportunity: The team manager may have spare capacity that can be used for training purposes or quality / performance reporting to support e.g. intra-organisational quality management processes.	
	TATEM concepts: Process orientation, mobile maintenance	
Supervise activities	Quantitative	Supervise activities (if required, e.g. OJT)
	n/a - tbd	
	Qualitative	
	Removed: n/a Change: the supervisory role may become more important, but change in focus, e.g. from anticipating risks to training, e.g. by monitoring task progress on the PSS and identifying training needs according to information called up by the LME Shift: n/a Opportunity: Performance management aspects of data collection via PSS (e.g. time per step; interruptions etc) for HR strategy update and continuous improvement.	
	TATEM concepts: Process orientation, mobile maintenance	

Manage interferences	Quantitative	Provide expert support
	Avoid interferences through better planning at earlier stages and by providing support before problems occur.	
	Qualitative	
	Removed: Interferences may still happen but should be notably reduced so this activity may be removed to some degree. Change: The team manger should monitor task process (of individual LMEs) on the PSS and provide unsolicited expert support when the need arises. Thus he will avoid operational interruptions instead of managing / mitigating them. Shift: Local risk management instead of quality control at higher levels. Opportunity: reduction of operational interruptions and local risk management should reduce quality related occurrences.	
	TATEM concepts: Mobile maintenance, process orientation	
Report findings	Quantitative	Review reporting
	The reporting will be done by LMEs directly and thus there are time savings to be expected.	
	Qualitative	
	Removed: removed to a certain degree Change: The PSS allows reporting directly from the front line so the team manager will be less directly involved. Reviewing report will however be part of his supervisory role and will facilitate his "risk management" role. Also, he will have real time knowledge about any findings and not only after task completion. Shift: The LME will be more responsible for reporting than before, team manager will be monitoring. Opportunity: Some report may be dealt with faster, may be locally by team manager.	
	TATEM concepts: process orientation, mobile maintenance	
Sign-off	Quantitative	Sign-off (if required)
	Time savings because no physical sign-off and can be done remotely	
	Qualitative	
	Removed: Because task accomplishment can be monitored via the PSS the LME may be able to sign off more tasks on his own so in some cases the team leader will no longer be involved. Change: sign off will become more of a confirmation of the team manager's monitoring Shift: responsibility for sign off may move partially or totally to LME Opportunity: less paperwork, immediate integration of task execution results in company systems	
	TATEM concepts: Mobile maintenance, process orientation	
State 4: operational system delivered		
Adjust requirements	Quantitative	
	Time savings/ cost savings, because dealt with earlier in	

	process. Qualitative Removed: Removed because dealt with earlier. Change: n/a Shift: n/a Opportunity: TATEM concepts: Process orientation; Mobile maintenance	
Iterate process steps	Quantitative n/a – Activity to be largely the same. Qualitative Removed: n/a Change: n/a Shift: n/a Opportunity: PSS should facilitate some of the co-ordination activities here, in particular shift hand over. TATEM concepts: Process orientation; Mobile maintenance	Iterate previous 5 process steps
Schedule final testing	Quantitative Scheduling can be done earlier, e.g. when task context defined at planning level, so there is less work load here. Qualitative Removed: n/a Change: testing should not lead to new requirements, so the team manager need not take on his managing role but can focus on monitoring progress. Co-ordination with other team managers can happen remotely. Shift: n/a Opportunity: testing should no longer result in operational interruptions of parallel tasks. TATEM concepts: Process orientation; Mobile maintenance	Oversee final testing
Close item, e.g. log book entry	Quantitative Less time consuming, less paperwork Qualitative Removed: as a physical action, but not as regulatory requirement Change: The LME will be able to update the logbook electronically via the PSS. The team manager will only have to verify this. Shift: The LME will have more local responsibility. Opportunity: real-time monitoring of a/c availability at other organisational levels. TATEM concepts: Process orientation, mobile maintenance	Automatic update of logbook

8.1.5.2 Stakeholder diagram

The following tables summarise the changes.

8.1.5.2.1 Changes in the quality of the relation

Stakeholders	Element	Transformation	
		Type	Description
Team manager – LME	Task supervision	Changed	Today task supervision takes place as one activity of the many responsibilities of the team manager. In the future system this will be his main responsibility and the quality of this activity should change drastically. The team manager will have real time access to the task progress and will be able to monitor the LME's activities via the PSS. This will allow him to mitigate upcoming problems or to provide tailor made support or even OJT.
Team Manager – Other team	Management of process priorities	Removed	Process priorities should no longer be managed at Team Manager level. They should be coordinated at production management level or even higher up making use of new decision support and planning tools.
Team Manager – Production Manager	Definition of responsibilities	Shift	This activity will be shifted into the context of the LME tasks. The production manager will assign responsibilities through new planning functions and can set up tasks on an LME's PSS immediately.
Team manager – Production Manager	Alignment of process progress	Changed	This activity will change from more actively managing the progress to simply monitoring it in order to anticipate unplanned events and to mitigate them in co-ordination with the production manager.
LME – other team	Update on process priorities	Shift	The LME will in future use the PSS (exploiting its progress recording capability) to send updates on process priorities immediately to the production manager whose responsibility changes to a centralised monitoring and managing function.
Flight crew – LME	Update of a/c health status information	Removed	This will no longer be relevant because the HM functions will take over this role and provide more reliable and earlier information.
Flight crew – Production Manager	Provision of a/c health status information	Removed	This will be obsolete because the A/c itself will send updated information through HM capabilities.

8.1.5.2.2 Changes in the realisation of the relation

The relation between Team Manager and

- Production Manager

This relationship will require less face-to-face communication (and co-ordination) than today. Much of the co-ordination activities should be supported by the PSS (and/or other tools / planning support capabilities). It could be the case that the team leader will be a less important player in this co-ordination. Instead of being immediately involved in at least parts of the planning process he will receive the results of the process via e.g. the PSS and will only have to send information in case of emergent operational problems.

- LME

Given the PSS capabilities this relationship will rely less on personal communication in its management and supervision aspect and more on remote communication via the PSS. However, Identifying training opportunities while monitoring task progress puts the Team manager into a position that may require more personal interaction at this level. Therefore he should be able to manage personal relationships and might have to have enhanced training skills as compared to today.

- Other team

The other team comes into play much later than in today's process. Some face-to-face communication may be required to e.g. set up well co-ordinated function tests. However, the initial test set up and progress reporting should be facilitated by the PSS.

- Flight crew

The input requested from flight crew in personal communication today will be replaced by HM data send from the aircraft. Therefore this relationship will be obsolete.

- Stores

The team manager will only monitor the status of tools/parts/materials requested (by production planning). This should to a large degree be done using the PSS or other planning / scheduling capabilities.

- Outsourced support

The team manager will only monitor the status of support requested (by production planning). This should to a large degree be done using the PSS or other planning / scheduling capabilities.

- Airline representative

It is unclear how the airline representative will be included in the future co-ordination activities. Either the PSS or new planning/scheduling tools should allow him to monitor process progress and to request reports.

8.1.5.3 Dependencies at task sequence level

NOTE: Each dependency only features ones in this list although it may contribute to achieving subsequent states as well.

State	Dependency	Impact			Main contributing TATEM concepts
		Direct	In-direct	n/a	
State 1: Activity scheduled	Established communication channels	x			process orientation, HM scheduling (scheduling/planning/decision support tools), mobile maintenance (PSS)
	Adequate work order management	x			Process orientation, mobile maintenance
	Adequate timeline in overall scheduling	x			HM scheduling
	Shared understanding of a/c requirements	x			Process orientation, mobile maintenance
	Shared understanding of overnight process	x			HM scheduling, process orientation, mobile maintenance
	Anticipation of potential subsequent tasks	x			HM scheduling, process orientation, mobile maintenance
	Open communication	x			HM scheduling, process orientation, mobile maintenance
	Information on trigger (scheduled/unscheduled)		x		HM scheduling, process orientation, mobile maintenance
	Access to information sources (onboard/offboard)	x			Process orientation, mobile maintenance
State 2: Task requirements defined	IT system access	x			HM scheduling, mobile maintenance
	Adequate documentation (latest, complete)	x			HM scheduling
	Adequate work order quality (report, job card)	x			HM scheduling, process orientation, mobile maintenance
	Adequate manpower / trade ratio	x			HM scheduling, process orientation, mobile maintenance
	Scheduling agreement based on plan	x			HM scheduling
	Team definition		x		HM scheduling, process orientation
	Transparency of customer requirements		x		process orientation, HM scheduling
	Awareness of system interactions	x			process orientation, mobile maintenance
	Information on a/c status (current & history)	x			process orientation, mobile maintenance
	Part policy		x		HM scheduling, process orientation, mobile maintenance

State 3: System status established	Control of resource provision	x			HM scheduling, process orientation, mobile maintenance
	Reporting requirements fulfilled	x			process orientation, mobile maintenance
	Support availability	x			HM scheduling, process orientation, mobile maintenance
	Delivery on resource commitment		x		process orientation, mobile maintenance, HM scheduling
	Team work	x			Mobile maintenance
	Quality of relations with stakeholders in process	x			process orientation, mobile maintenance
	Understanding of origin of work order		x		HM scheduling, process orientation, mobile maintenance
	Communication of changing requirements	x			process orientation, mobile maintenance
	Knowledge of operational constraints	x			process orientation, mobile maintenance
	Information on a/c process progress	x			process orientation, mobile maintenance
State 4: Process requirements adjusted	Previous task achieved		x		process orientation, mobile maintenance, HM scheduling
	Availability of stakeholder (e.g. trade, OCC)		x		HM scheduling, mobile maintenance
	Reallocation of resources	x			HM scheduling, process orientation
	Consolidation of a/c process requirements	x			process orientation, mobile maintenance, HM scheduling

8.1.5.4 KSM Evaluation at task sequence level

This section discusses some of the implications for the dimensions that have been defined in the KSM modules as being critical in assessing and evaluating the wider transformation implications.

- Information integration

The TATEM HM approach improves the understanding of the aircraft status and thus increases the control over the maintenance production requirements. The main mechanisms to deliver the benefits into the maintenance operation (and also to other stakeholders) are (a) data management following the OSA CBM standard (from data generation to information presentation) and (b) the integration of information across onboard and off-board information systems (MIS). The benefits of the information integration are realised at each process level. Process orientation and mobile maintenance are concepts that further facilitate the improvement above and deliver the improved formation into the processes. However, both concepts also constitute an improvement in an operation without HM capabilities (current situation).

At the level of the maintenance task sequence the main benefits are

Increased transparency of current status (e.g. of process (via PSS functions), of aircraft (via HM functions) etc) through real time information management

Clear definition of set of tasks and their role in overall context provided upstream

Standardisation of information in information flows in and out of the process facilitated amongst others by PSS functionalities

Information may be pushed at Team manager which reduces the risk of oversight of critical developments; this also leads to less effort spent on information access, search and integration by team manager

Support of workflow in the process execution by adequate information: all in all the team manager will have to search less for information be it on appropriate team composition or material resources due to scheduling and planning capabilities.

As stated earlier, one major advantage of the new TATEM information capabilities will be that information is presented to the team manager – potentially through only one channel. This releases his capacity to better monitor and supervise the process. However, it has to be taken care that the information actually reaches the team manager because creating and packaging the information higher upstream without direct involvement of the team manager could imply that he will have no other way of accessing relevant information. It is an open question, too, how existing informal information flow patterns will be affected by new technologies and if their continuous existence will pose a threat to new information architectures.

- Operational system

Main process changes have been described along the dimensions outlined above (removed, change, shift, and opportunity).

The introduction of HM gives the opportunity for a formalisation of processes that can be traced into the operation and monitored in daily practices. The reduction of local management due to increased control over the aircraft status and thus its current and more importantly emerging maintenance requirements

enables a standardisation of inputs and outputs. This overcomes the current situation where formal systems do not necessarily reflect the daily practices which are driven by a requirement for flexibility within an operation characterised by constantly changing/updated requirements.

Today, local coordination activities add essential value to the current process because of the constraints of the existing operational system such as changing requirements or short lead times for decisions. Furthermore, downstream levels of the operation are today often left with the challenge to manage and monitor supply chain aspects of the operation that would formally belong to planning and scheduling processes. This process relies heavily on interpersonal relationships and informal ways of management. This operational deficit is due to a lack of – technological – support of the organisational units that would be responsible for these issues. A major problem here is that integrated monitoring and management (support) tools are currently missing. Future systems for decision support and scheduling/planning should step into this breach and thus this effort should be reduced or shifted to a central function and will then be remote from the local management due to increased control delivered by HM information.

The implication for the team manager is that he will still perform crucial interface functions between planning and production management on one side and task execution on the other. But his activities will no longer be a partial reduplication of planning and production management work. Instead he can supervise and support the execution of this planning work at task sequence level. Thus his actual role in ensuring process flow and stability will in future indeed be at the core of his activities.

On this basis clearer performance indicators for specific roles can be derived since the formal process is closer to the activities as they happen. Formalisation of interfaces also includes the identification of responsibilities, aspects of which are currently distributed or cascaded down, e.g. supply chain management: from a central planning effort to a local management to deal with changes. (Team, competence) For the team manager in particular this however leads to an open question: A key responsibility is sign off of work cards and thereby ensuring that maintenance work has been done according to specification and regulations. If now the LME has greater control over the sign off process, then the role of the team manager in this process has to be adapted accordingly. Further, it has been said that some of the team manager's capacity could be directed towards OJT for example. Again, this then needs to be formalised – probably even in terms of KPIs – and needs to become part of his official role and thereby skill profile.

Overall the transformation promises to reduce ambiguity which is part of the current system at different levels.

One concern: The HM approach provides the opportunity to transform the operational system. These potentials can only be maximised if adequately backed up in the organisation by wider process and system changes. An example is the opportunity for redesign of the supply chain around the new parameters introduced by the HM solutions (increased lead time; root cause knowledge etc).

- Competence

The information integration and subsequent change in the operational system have an impact on the human/social dimensions of the system such as competence, team and trust (in organisational relations).

The Team Manager is currently involved in coordination activities that are a response to the ambiguity in the operational system (in form of e.g. task mushrooming, changing scheduling priorities in response to events). Today this involves personal communication and negotiation (around e.g. access to equipment) that extend the technical skills that the person has been mainly trained in.

In the current situation the team manager has to draw from a very diverse skill set to cope with his complex tasks. However, as stated earlier a certain part of these tasks is not formally part of his responsibilities and only fell into his area of work because of system ambiguities and insufficiently supported information flow.

Roughly the following changes to his required KSAs can be anticipated: Perhaps the least changes are to be expected on the technical level. He should however be in a better position to play to them, because the operational changes affect the social and organisational profile of his position. Organisational he will need to be less skilled particularly in resource management and logistics. Currently he is taking these aspects on board, because of system instabilities that undermine higher level planning work. The most important change will then be on the social skills level. Instead of fire fighting unexpected situations on behalf to the LME who is too busy doing his assigned work to cope with the complexity of emerging additional tasks or support shortfalls, the team manager will be able to monitor his team's progress and that of each individual which gives him the responsibility to recognise potential problems early on and to provide specific support. This can be done personally or by triggering e.g. training sequences on the PSS. To do this appropriately the team manager has to have people management skills and training skills. For this he may need additional training and education amending his technical expertise. In this respect the new competence requirements put an onus on the organisation to prepare their personnel properly for the new challenges.

- Trust/Social relations

The transformations that are enabled through the introduction of HM address dimensions that contribute to an atmosphere of mistrust in organisational relations.

Formal versus normal

Example: Currently normal operation for the team manager implies that he does work that formally is not his responsibility. This has two effects. For the team manager it creates a feeling of being let down by the support functions upstream and thus creates mistrust and potentially dysfunctional relationships within the company. For the team managed by the team manager and probably also for the upstream functions the long habit of team managers taking on additional responsibilities has led to the impression that these are actually part of their work and they are at least partly to blame for unsatisfying outcomes.

Incompatible goals

Example: The situation described above (formal vs. normal) may lead the team manager to neglect some of his core responsibility or will put him in apposition to do so against his own work ethics. This can be counterproductive in terms of job satisfaction – feeling to underperfom constantly without a chance to change the situation – that is dangerous to the economic

objectives of the company. So there is a goal conflict internally for the team manager as well as at organisational level, i.e. having somebody taking on responsibility and at the same time having this person underperforming.

Performance requirement

Example: AS indicated above performance outcomes are hard to measure if the tasks to be performed contradict each other or are not formally defined.

No open communication

Example: Local knowledge from downstream may not be communicated upstream because of feeling let down and then assuming the others do not deserve to get this local knowledge. Further, upstream and downstream organisational units accuse each other of not doing their respective jobs properly and thus avoid communicating openly to produce a shared understanding of individual and shared objectives.

History of mistrust

Example: All the above mentioned issues lead in the long run to a history of mistrust that needs to be overcome if new technologies and procedures are to be implemented successfully.

At the same time the introduction of new technologies needs to address how it can contribute to the proactive creation of trust:

Belief in future

Examples: Implement service level agreements that make reference to new technologies and processes and that clearly state in how far these enable specific organisational units to deliver outputs that have not been delivered in the past. This should include an acknowledgement of each others goodwill even under the current less than optimal circumstances.

Genuine support

Examples: new technologies and process should enable the stakeholders to deliver towards any service level agreement and it needs to be made clear that not only on e party is gaining something from the new developments.

Personal relationships

Examples: Not everything needs to be done via indirect, automated information exchange (e.g. data links between system rather than people coordinating). Also personal means of communication can be used to control efficiency of processes and be monitored within the process context, e.g. call log book if communication function was to be included in the future on the mobile device.

Current well-functioning personal relationships need to be examined as to what they actually deliver but they need to be taken into account and should be further supported, because they may help to establish or maintain trust within the organisation.

These effects can be envisaged but are more difficult to trance and depend on the overall organisational management of introducing changes. This also relates to wider issues such as the coherence of business models, adequate key performance indicators for quality, safety and efficiency across all system levels.

8.1.6 Additional outcomes of KTWS#1: Operational unit level

8.1.6.1 Process activities

Current	Description of process transformation	Future
State 1: Fleet mx requirements identified		
Access information on current fleet status	Quantitative	Access integrated view on current fleet status
	Better presentation but at the same time more information. Time savings are more likely to be more explicit in other activities that feed into this step.	
	Qualitative	
	Removed: Manual integration of data from different systems which is still an issue in many organisations (e.g. between OCC and MCC). Change: Improved input into the step. Extended information basis and better decision support. Shift: Push information rather than pull. Opportunity: Merging distributed application into one IT system with common logic.	
	TATEM concepts: Health Management, MIS	
Identify aircraft overnight destinations	Quantitative	Identify aircraft overnight destinations
	Possible time savings in situations that see changes during the day. Those changes should no longer be due to the technical status in a fully health managed aircraft but would include issues like airport strike, bad weather etc.	
	Qualitative	
	Removed: n/a Change: Activity is integrated in application, information push rather than pull (manual search in information systems) Shift: n/a Opportunity: Integration across departments: Real time information from OCC and commercial on operational changes (e.g. due to bad weather) fed into MIS for optimising opportunistic maintenance.	
	TATEM concepts:	
Compile open tasks per A/C	Quantitative	Call up open item list
	n/a	
	Qualitative	
	Removed: The manual integration of information from distributed sources, e.g. deferred items, scheduled items, events is reduced. Change: Activity is integrated in application, information push rather than pull (manual search in information systems) Shift: tbd Opportunity: MIS is an opportunity to integrate data from different stakeholders, the TATEM innovations driven by the manufacturer	

	and OEMs relies on adequate links into organisational data.	
	TATEM concepts: HM scheduling/proactive planning, process orientation	
Discussion of real time fleet status	Quantitative	Automatic data integration across stakeholder
	Automatisation of information integration and supported evaluation of particular situations may see a reduction in time, depending on IT system complexity and number of new steps in interacting with it.	
	Qualitative	
	This activity pulls together the latest information from stakeholders involved in the fleet management, especially MCC and outstations, including their assessment of particular aircraft situations. In the future information will be integrated in the system automatically and assessments aided by the decision support application. Removed: Depending on the system capability in terms of info integration and coordination support between departments this step could become redundant. However, decision support leaves final decision to the human who in exceptional cases may want to coordinate with other people directly. Change: Information integration and decision support reduce the activity in this step significantly. Shift: Responsibility is more clearly allocated in a more formal standardised process of using the information. The individual plays his or her specific part rather than relying on group discussions. Opportunity: Advanced integration of outputs of information systems across the organisation as well as external sources (e.g. airport authority information on gate allocation ; weather update)	
	TATEM concepts:	
Update on operational changes	Quantitative	See above - Automatic data integration across stakeholder
	Maintenance related changes are fewer thanks to decision support (based on new information and integrated fleet picture are available). This activity will occur less. For all other influences on operational constraints (e.g. airport, weather, ATC etc) the information is to be made available in real time in the MIS for proactive maintenance planning.	
	Qualitative	
	Removed: Maintenance element in operational changes for HM items. Change: Less communication and personal information exchange but largely supported by OIT. Focused conversations and clearly driven search for defined pieces of information through human interaction such as meetings. Shift: Clearer responsibilities on a decision support framework, e.g. for feeding information into the system and for using the resulting integrated picture. Opportunity: tbd	

	TATEM concepts: HM scheduling/proactive planning, MIS	
State 2: Relative demand/resource match established		
Define task expiry dates	Quantitative	Review RUL/expected probability of failure
	Qualitative	
	Announcement of failure in advance rather than open task based on known failures. Removed: Documentation navigation to identify information for events that occurred. For HM items remaining useful life as an equivalent is given automatically by the system. Change: The remaining useful life is used for health managed items. In other cases, the MEL lifetime information should be provided with the alert of an impending event in the proactive application. Shift: Opportunity: Integration of HM and non HM items	
	TATEM concepts: HM scheduling/proactive planning, MIS, process orientated technical data (MEL)	
Include operational constraints	Quantitative	Include operational constraints
	Automatic integration in decision support application reduces time in manual information integration and mental workload.	
	Qualitative	
	For HM items the operational constraints cane be managed in advance and are part of the decision support. Sensitive issues such as the increased probability of APU assistance being required at airport if item fails can be flagged against route planning (outstation capabilities/ airport constraints). Removed: Manual information integration. Change: This step happens in advance for HM items. It is considered as a variable in the decision support. Shift: Decision support application can pull information relevant to operational constraints rather than person actively searching. Opportunity: Better (timely, effective, satisfying) collaboration between MCC/MRO and OCC/Airline as key drivers of airline business.	
	TATEM concepts: MIS, proactive planning	
Define resource requirements	Quantitative	Define resource requirements
	Automatic integration in decision support application reduces time in manual information integration and mental workload. Access to process orientated technical data reduces time spend on searching documentation and compiling information on resources for related tasks.	
	Qualitative	
	Per HM item status the related tasks and their characteristics need to be known to define and ensure adequate resourcing. This is currently embedded in the documentation (manufacturer/airline). There is a potential benefit if extracting it for proactive planning purposes (see link to process orientated technical data). Removed: Reduced information search in documentation if planning and management have access to improved technical data	

	(part of process orientation is to list required tools etc for each task). Decision support application to match tasks against the status of the HM items to enable easy access and reduce requirement for researching the tasks that are related to impending (or today's event) failure. Change: Stronger IT support of the activity as well as advanced lead-time for proactive planning decisions. Shift: Back office anticipates tasks to be done rather than troubleshooting at the aircraft. Defining the tasks and managing the resourcing is stronger in the planning and management area than today where LME and crew manager are actively involved in the case of events or items found at the aircraft. Opportunity: Optimisation of personnel deployment. Potential review of HR strategy, e.g. stronger focus of operational expertise and experience in the remote planning and management functions required	
	TATEM concepts: HM scheduling/proactive planning, process oriented technical data	
Include resource status	Quantitative	Include resource status
	Automatic check against resources by decision support application.	
	Qualitative	
	Removed: Manual information compilation, i.e. documenting outcomes of resourcing discussions. Change: Standardised use of IT systems to obtain integrated picture rather than customising several documents into planning aids. Shift: Real time information provided by al relevant stakeholders to the systems. Opportunity: expertise is located in the set up of the systems, including implicit assumptions (if developed and updated based on operational expert knowledge). This reduces the reliance on individual experience to a less critical role than today.	
	TATEM concepts: HM scheduling/proactive planning	
Negotiate exceptions	Quantitative	
	This step has the potential to become obsolete with an increasing number of health managed items and proactive planning decision support. Currently extensions for expiring items are managed in a joint effort, trying to keep their occurrence minimal.	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning	
Prioritise aircraft availability	Quantitative	Prioritise aircraft availability
	n/a	
	Qualitative	
	This step is driven by operational planning, with maintenance constraints as being one key influence factor. In the future, the step is better facilitated by the better advance planning and control of maintenance provided through health management. Removed: Change: Less iterative communication is required to establish the	

	optimal picture. Shift: Increase in control enables advance planning and less interference and thus a stringer focus on main tasks of departments such as providing maintenance or managing the operation. Opportunity:	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Discuss alternative resourcing	Quantitative	
	This step has the potential to become obsolete (for health managed items). Proactive planning (incl. decision support) gives the lead-time to match task to available resources before an actual event defines the constraints. The MIS provides access to information around the supply chain.	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning,	
Review resource supply chain status	Quantitative	Review resource supply chain status
	Reduction in time due to MIS access to relevant information. Today, part of this is still largely facilitated from human interaction.	
	Qualitative	
	This step is integrated in the individual's workflow based on the new information base. Removed: Change: Longer lead-times in setting up the resource inputs facilitate better control. Part of the current reactive resourcing can be shifted out of the daily operation management which can in future focus on providing the inputs at the right time and manage the work progress on the day, including external constraints such as airport resources, weather etc. Shift: Focus on managing the operation due to reduction in reactive planning. Proactive panning can be shifted to another function, given the new lead-times. Opportunity: Integration with supplier information bases., e.g. customer part inventory; lease agreements or manufacturer capacity. Optimise the deployment of resources, material as well as people (e.g. certification, trades)	
	TATEM concepts: HM scheduling/proactive planning,	
State 3: Mx work schedule defined per A/C		
Request rerouting	Quantitative	
	This step is obsolete in regard to health managed items.	
	Qualitative	
	n/a Proactive planning enables input into initial routing, rather than reactive request for changes due to maintenance occurrences. HM information and utilisation are key. MIS integrates data from all stakeholders so aircraft changes interfering with maintenance planning should be picked up by the system. In these cases maintenance department is in a position to react to new proposal.	
	TATEM concepts: HM scheduling/proactive planning,	

Select tasks per A/C	Quantitative	Select tasks per A/C
	This step may become more extensive, depending on the steps in using the IT system and its information as well as including of information assessment that was part of coordination tasks that went on in parallel before.	
	Qualitative	
	Proactive planning decision support strongly facilitates this step. Removed: Less research required into the task requirements that are associated with each unit/emerging failure. Change: Tasks are selected against overview of remaining time, MEL implications and resource availability with more lead-time than before. Shift: n/a Opportunity: Optimise the deployment of resources, material as well as people (e.g. certification, trades). Use maintenance expertise in the system to support less experienced decision makers.	
	TATEM concepts: HM scheduling/proactive planning, process orientated technical data	
Add latest occurrences	Quantitative	Verify and confirm selection
	This step will potentially become obsolete with full health management, enabling proactive planning.	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Iteration of resource/demand check	Quantitative	
	This step will potentially become obsolete with full health management, enabling proactive planning.	
	Qualitative	
	No events alerts should occur during the day. The lead-time for remaining useful life information against resourcing in the network is available days in advance.	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Confirm required resources	Quantitative	Confirm required resources
	This step is shorter. The MIS gives an update on status of resources planned for in advance.	
	Qualitative	
	Removed: Actively pursuing information on resources status. Change: Review of resourcing. External influences outside the control of the organisation can still affect the proactive planning outcome, e.g. no part delivery in bad weather conditions. Shift: Less requirement of negotiating best resource supply, more monitoring which is in line with core of production management role. Opportunity: Negotiate new contracts with suppliers, better deals based on longer lead-time for planning and sourcing.	
	TATEM concepts: HM scheduling/proactive planning, MIS	

Create task list	Quantitative	Create task list
	Possible reduction in time with application supporting populating the tasks list and supplementary information based on decisions.	
	Qualitative	
	Removed: n/a Change: Increase in automatisation reduces workload when tasks list can be created out of the proactive planning decision support application. Notes based on experience should be facilitated in a comment function. Shift: n/a Opportunity: tbd	
	TATEM concepts: HM scheduling/proactive planning, process orientated technical data	
Distribute list to production units	Quantitative	Distribute list to production units
	Time savings by availability of integrated reports and communication channels for them.	
	Qualitative	
	Removed: Manual compiling of task and resource status information. Change: Increase in automatisation reduces workload. Notes based on experience should be facilitated in a comment function. Shift: n/a/ Opportunity: Integrate IT systems across outstations, standardising documentation and communication channels.	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Negotiate operability priorities	Quantitative	Review operability priorities
	Increased automatisation of information integration in the MIS may save time compared to personal interaction and communication.	
	Qualitative	
	Removed: Iteration of information update and assessment due to accessibility of latest status of operation. Change: Support in evaluating the operational impact is provided by the system, using an integrated set of information from maintenance, operational, commercial and external stakeholders such as airport. The negotiation changes into a review that leads into consent against the integrated picture of the situation. Shift: n/a Opportunity: tbd	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Establish understanding of real time fleet status	Quantitative	Check system for fleet status changes (alert function)
	Qualitative	
	Removed: Information compilation and assessment. Change: The information on changes does not need to be actively be perused (or even left to informal channels) but can be provided as alert function over the system. Shift: Push of information rather than pull shifts responsibilities. Opportunity: Integrated view on the operation. In some airlines the	

	MCC and OCC are combined and well linked into the back offices but often system are not integrated well enough, leaving a lot to be managed in real time between people.	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Agree final resourcing	Quantitative	
	This step is obsolete due to increased control through proactive planning and consequently longer lead- times for and better definition of resources.	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Establish common understanding of requirements	Quantitative	Check common understanding of mx requirements
	Potential time savings due to increase in transparency of planning and resourcing.	
	Qualitative	
	Planning, resourcing and allocation of aircrafts and tasks is more transparent and automated in the future. Removed: n/a Change: There is less of a demand for iterative clarification and personal communication. The briefing on the plan of work is clearer and has all relevant information integrated. It is moves seamlessly from the proactive planning including the optimal resourcing into the task allocation, support and reporting on the PSS. Shift: n/a Opportunity: n/a	
	TATEM concepts: HM scheduling/proactive planning, MIS, PSS	
State 4: Complete picture of A/C technical status established & documented		
Assign A/C to team	Quantitative	Assign A/C to team
	tbd	
	Qualitative	
	The overview of the task characteristics determines which team is best qualified. The supervisor, team leader acts as intermediate. The proactive planning facilitates an optimisation of shifts based on personnel records. Removed: n/a Change: The task list derived from the proactive planning can directly trigger the tasks. Less human interaction required. The team leader may still brief the crew when handing out the PSS to ensure quality control but this briefing is now better supported. Shift: n/a Opportunity: optimisation of personnel training and shift planning	
	TATEM concepts: HM scheduling/proactive planning, MIS, PSS, process orientated technical data	
Monitor progress	Quantitative	Monitor progress
	IT support for this activity promises time savings.	

	Qualitative	
	Removed: tbd Change: In the future, the information exchange required to monitor the progress is less based on communication between people but between the systems, MIS and related applications and PSS and related applications. Shift: Clear responsibility for reporting elements. Real time feedback based on standardised PSS process rather than the potential need to inquiry reduces risk of misinterpretation or disruption of monitoring. Opportunity: Real time feedback can be channelled into the appropriate departments, e.g. engineering using data collected or HR using performance record.	
	TATEM concepts: HM scheduling/proactive planning, PSS, process orientated technical data	
Update task list per A/C	Quantitative	
	This step is potentially obsolete in the future. In fully health managed aircraft there are no additional findings when performing maintenance.	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning,	
Confirm additional resources	Quantitative	
	This step is potentially obsolete in the future. In fully health managed aircraft there are no additional findings when performing maintenance	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning,	
Integrate maintenance achievements for reporting	Quantitative	Integrate maintenance achievements for reporting (via MIS)
	tbd	
	Qualitative	
	Currently also reliant on manual effort and communication, in the future concurrent updating of status and automated reporting function providing input across organisation. Removed: tbd Change: Less active role in integrating information thanks to IT support of this activity, leaving more time for evaluating it if required and managing trends. Shift: Potential for remote support in managing reporting requirements, while production management resumes reviewer role and adds expert comments. Opportunity: Real time access to maintenance status from different departments or customers.	
	TATEM concepts: MIS, PSS	
Re-Negotiate priorities	Quantitative	
	This activity is potentially obsolete in the future. With no further	

	maintenance requirements detected initial priorities based on proactive planning predicted outcomes remain valid. Qualitative n/a TATEM concepts: HM scheduling/proactive planning, MIS	
Establish common understanding of task progress	Quantitative tbd Qualitative This can still be influenced by external factors, such as ground services at airport. This leaves a small opportunity for exercising flexibility within the given plan and requires a feedback loop. Removed: n/a Change: MIS and PSS support communication and information exchange on process progress. Flexibility in task performance as provided by PSS can be reviewed by central management if external constraints materialise (e.g. delay in fuelling availability) Shift: n/a Opportunity: tbd TATEM concepts: HM scheduling/proactive planning, PSS, process orientated technical data	Establish common understanding of task progress
State 5: Operational A/C delivered into operational schedule		
Reporting fleet status	Quantitative Possible time saving due to automatic integration of electronic inputs from PSS and reporting functions using MIS. Qualitative Removed: n/a Change: Defined reports, automatically populated with comment facility, are distributed in a standardised process. Today the concurrent and final reporting is strongly people mediated. Shift: tbd Opportunity: Increase the data utilisation. TATEM concepts: HM scheduling/proactive planning, MIS	Reporting fleet status
Integrate external requirements	Quantitative tbd Qualitative Today the emerging maintenance constraints emerging during maintenance activity needs to be counterbalanced with external requirements due to weather, ATC strike, flight crew constraints. In the future only the external events are contributing to changes and need to be considered as part of the otherwise sustainable maintenance outcomes. Removed: Adaptation of maintenance outcomes Change: Only external factors are possibly interfering with decision on aircraft assignment. Shift: n/a Opportunity: tbd TATEM concepts: HM scheduling/proactive planning, MIS	Integrate external requirements (if alerted)

A/C assignment to operational schedule	Quantitative	A/C assignment to operational schedule
	tbd	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Release to service	Quantitative	Release to service
	tbd	
	Qualitative	
	In the future, the MIS provides instant visibility of aircraft status changes and their documentation, e.g. link to electronic logbook. Increase in transparency of work performed. Removed: n/a Change: Reduction of possible ambiguity based on real time reporting on progress and A/C status via PZZ into MIS. Shift: n/a Opportunity: n/a	
	TATEM concepts: HM scheduling/proactive planning, MIS	
Negotiate constraint priority	Quantitative	Confirm constraint priority
	Possible time savings with change in quality of interaction.	
	Qualitative	
	Removed: tbd Change: This is to occur infrequently, due to external constraints as discussed above. In the future, due to proactive planning the maintenance operation has delivered the aircraft as planned and changes due to external constraints can be negotiated in parallel, reflecting the previously known Ac technical status. Shift: OCC can more easily take control and make a decision based on the visibility of the maintenance status. Opportunity: tbd	
	TATEM concepts: HM scheduling/proactive planning,	
Agree opportunities for residual tasks	Quantitative	
	This step is obsolete in the future since HM/ proactive planning drives a work plan that can be realised in the given situation	
	Qualitative	
	n/a	
	TATEM concepts: HM scheduling/proactive planning,	

8.1.6.2 Stakeholder diagram

The following tables summarise the changes in the stakeholder relations.

8.1.6.2.1 Changes in the quality of the relation

Stakeholders	Element	Transformation	
		Type	Description
MCC - OCC	Update on A/C status	Removed	MCC as broker of information and central coordination role between operation and maintenance and others today is going to change since some of this can be managed by direct interface in the wider IT system including MIS.
MCC - Routing	Update on A/C status	Removed	*See above*
Production – OCC	Update on A/C status	Shift	Direct access and re-directing of maintenance production information via MIS, supported by real time data capture and reporting from PSS.
Production – Routing	Update on A/C status	Shift	Direct access and re-directing of maintenance production information via MIS, supported by real time data capture and reporting from PSS.
Routing - Production	Design maintenance opportunities	Changed	Inputs taken by routing to accommodate maintenance requirements (amongst others) are based on proactive planning in the future. There are less changes, but maintenance planning and the delivery of expected technical outcomes becomes a given, known in advance. With this information the maintenance element can be optimised in routing plans.
MCC - Production	Maintenance request	Changed	MCC current role as real time managers and intermediate in ever changing situations will change. New functions could include remote support for production management, taking on the new control span that is the result of longer lead times, proactive planning etc. to leave production management focusing on the technical aspects of the maintenance operations. Current brokerage of maintenance requests can be substitutes by proactive item management and dealing with exceptional situation (e.g. triggered by external events such as weather)
MCC – support departments	Define real time mx support requirements per A/C	Changed	Rather than dealing with deferred defects based on event the MCC interact with the supply chain based on proactive items. The increase in control and lead time is facilitating better inputs for production.

8.1.6.2.2 Changes in the realisation of the relation

The relation between production management and

- MCC

Today's role of the MCC as broker of information and central coordination role between maintenance production and operations and others is going to change since some of this can be managed by direct interface in the wider IT system including MIS (i.e. integrating information across stakeholder that is relevant to maintenance and increasing transparency of technical fleet status within organisation – due to MIS and sustainable plans based on proactive planning)

Today's close collaboration between MCC and production management in adapting to changing operational/technical situations is to change as advance planning and technical control increases. This offers the opportunity to review the responsibilities. With less deferred defect management MCC can take on aspects of proactive planning (including resourcing) to enable production management to increase their focus on managing the technical aspects of maintenance.

Additionally, MCC can develop quality management trajectory and mitigate exceptions and external constraints put onto maintenance plan and operation, e.g. weather, strike etc

- OCC

Today the interaction with OCC is mainly mediated by the MCC functions. The direct access and re-directing of maintenance production information via MIS, supported by real time data capture and reporting from PSS, enables a direct feed from production management. Assumptions build into the decisions support capability and MIS interfaces with other systems can facilitate a better understanding in how the domains' respective processes impact on each other, increasing transparency and improve a shared understanding of the overall operation.

- Routing

A similar argument as above applies to the relationship with routing.

- Support departments

Today the production management is actively involved in managing the resourcing of tasks. This local, reactive management is due to the uncertainty and short lead-times of certain events in the operation. In the future the interaction is to be more standardised. Inputs are planned in advance and monitored, e.g. by a central MCC function. Less iterative negotiating and adapting is required which reduces the frequency of interactions. Also it is supported by the IT system/proactive planning application that increases visibility of the supply chain and supports automatic triggering of resourcing.

- Central planning

Proactive maintenance gives all items a control component that moves towards a similar logic as schedule items have today, with different time-lines and triggers. This needs to see collaboration between MCC, central panning and parts of production management to optimise the integration of different types of items. A way of structuring the planning organisation could be based around time lines rather than type of item (e.g. scheduled, HM, deferred).

- Commercial department

The commercial constraints are most remote from the production management and mostly mediated via OCC and routing. However, direct impact can result in short term adjustments. Thus, these commercial dimensions should be reflected as one dimension in the decision support capability.

8.1.6.3 Dependencies at operational level (overnight)

NOTE: As discussed before each dependency only features ones in this list although it may contribute to achieving subsequent states as well.

State	Dependency	Impact			Main contributing TATEM concepts
		Direct	In-direct	n/a	
State 1: Fleet mx requirements identified	Access to OCC data	x			Decision support application/ proactive planning; MIS
	Access to trend data	x			Decision support application/proactive planning, MIS
	Anticipation of consequential requirements	x	x		MIS; Decision support application/proactive planning; process orientated technical data
	Communication channels (real time)		x		MIS
	Legal obligations			x	
	MEL comparison			x	
	Availability of maintenance information (e.g. reports)	x			MIS, Decision support application/proactive planning, PSS
	Shared assessment of technical status		x		MIS
	Transparent customer requirements		x		MIS
State 2: Relative demand/ resource match established	Availability of required resources	x			MIS, Decision support application/proactive planning; process orientated technical data
	Common understanding of maintenance operation		x		MIS, Decision support application/proactive planning
	Effective resource network agreements			x	
	Knowledge of alternatives	x			MIS, Decision support application/ proactive planning; process orientated technical

					data
	Open communication		x		MIS
	Experiences with resource supply network			x	
	Supply network transparency	x	x		MIS; Decision support application/proactive planning
	Team system (internal/external)	x			MIS; Decision support application/proactive planning
	Update on changing parameters	x			MIS; Decision support application/proactive planning
State 3: Mx work schedule defined per A/C	Overview of task characteristics				Process orientated technical data
	MEL evaluation			x	
	Access to updated requirements	x			MIS; Decision support application/proactive planning
	A/C configuration information	x			MIS
	Access to route planning	x			MIS; Decision support application/proactive planning
	Capacity for iterative feedback		x		MIS; Decision support application/proactive planning
State 4: Complete picture of A/C technical status established & documented	Shared understanding of operational progress	x			MIS, PSS
	Visibility of resourcing	x			MIS, PSS
State 5: Operational A/C delivered into operational schedule	Completed documentation	x			MIS, PSS, process orientated technical data
	Integration of outcomes	x	x		MIS

8.1.6.4 KSM evaluation at operational level (overnight)

- Information integration

The TATEM HM approach improves the understanding of the aircraft status and thus increases the control over the maintenance production requirements. The main mechanisms to deliver the benefits into the maintenance operation (and also to other stakeholders) are (a) data management following the OSA CBM standard (from data generation to information presentation) and (b) the integration of information across onboard and off-board information systems (MIS).

The benefits of the information integration are realised at each process level. Critical to this level is the innovation in using the new HM capabilities (from data capture to condition derivation) for a advisory generation that is linked into the organisational systems that support maintenance production..

At the level of the overnight management the main benefits are

- Increased transparency of current status (e.g. of process (via PSS functions), of aircraft (via HM functions) etc) through real time information management
- Standardisation of information in information flows in and out the overnight planning and management activities – including internal as well as external interfaces
- Less effort spent on information access, compilation and integration
- Decision support reduces workload by providing "one stop" picture which facilitates human decision capability

The success of the envisaged proactive planning applications depends on the adequate integration into other processes and systems, e.g. operational schedule or supply chain management. There are information links required that are within control of maintenance (e.g. PSS and MIS), but also functions that can be managed in the wider organisation (e.g. integration with OCC systems such as operational scheduling) and, thirdly, functions that need external support, e.g. linking in with airport services such as gate allocation or service capability.

Furthermore, the information integration can only be as good as the information in and out of the different systems. This depends partly on how the customer organisations integrate the TATEM solutions in their wider systems and how well the applications and system are adapting assumptions based on existing good practices in the daily operation of the business.

- Operational system

Main process changes have been described along the dimensions outlined in the section on process activities (removed, change, shift, and opportunity).

- Time line changes give opportunity for reorganising processes
- Definition of responsibilities in processes is clearer
- Increased control over maintenance aspects of operation
- Standardisation, e.g. less meetings and negotiation or personal style
- New process interfaces for optimal use of new capabilities
- Increased transparency/visibility of overall operational system

The introduction of HM gives the opportunity for a formalisation of processes that support the management of the daily operation. The reduction of reactive short term management due to increased control over the aircraft status and thus its current and more importantly emerging maintenance requirements enables a standardisation of inputs and outputs. Today's daily practices are driven by a requirement for flexibility within an operation characterised by constantly changing/updated requirements for each department involved. Transparency of planning and progress is hard to maintain which makes coordination at the process interfaces a challenge. As discussed before the concepts enabled by HM facilitate increased control over the maintenance aspects and support the optimal integration with the overall operational performance of the airline.

Along the maintenance processes the formalisation of interfaces is enhanced by defining standardised inputs re information, also re other resources that can be accordingly delivered into the operation. This

supports the production management task through improved management of expectations for inputs from other processes (e.g. stores, operations etc).

Clearer performance indicators can be derived since the formal processes are closer to the activities as they happen. Formalisation of interfaces also includes the identification and reorganisation of responsibilities, aspects of which are currently distributed or cascaded down, e.g. MCC as key broker of real time information that is more or less formally structured.

Overall the transformation promises to reduce ambiguity which is part of the current maintenance system at all levels.

The described transformations in the operational system are facilitated by the opportunities of the new HM information approach. Important for the benefits to be realised is the lead time for information, the integration with processes and information systems outside maintenance and the quality of information in maintenance (e.g. confidence intervals in degradation model) as well as from other sources (e.g. supply chain inputs)

One concern: The HM approach provides the opportunity to transform the operational system as well as the while organisation and wider industry. The envisaged potentials of TATEM concepts can only be maximised if adequately backed up in the organisation by wider process and system changes as well as by increased integration with external stakeholders (e.g. manufacturer, airport authorities). An example is the opportunity for redesign of the supply chain around the new parameters introduced by the HM solutions (increased lead time; root cause knowledge etc) in the proactive planning decision support applications.

- Competence

The information integration and subsequent change in the operational system have an impact on the human/social dimensions of the system such as competence, team and trust (in organisational relations). Operating aircrafts is driven by a series of constraints form different sources (internal to organisation and external). Optimising the fleet operation in changing requirements is key to success. Today this involves personal communication and negotiation (e.g. regular meetings, iterative e-mail, phone calls etc) that move beyond technical skills.

The transformations of the operational system enable

- Clearer responsibilities in domain spanning team

  Better control over the planning of maintenance facilitates formulating clear expectations in better defined input/output relationships. With the relative stability provided by HM concepts the definition of key roles is sustainable in the daily processes.

- More autonomy in different roles

  An overview is given by the system, decision support by the application. The production manager is less reliant on collecting and compiling information himself but has the means to make informed decisions, with the assurance that all available information has been taken into account.

- Role of operational experience

Standardisation of processes and decision support decreases the need for operational expertise that is currently in many situations a key success factor. Human judgement and expertise will remain critical given the nature and complexity of the industry but the overall reliance on it is reduced.

- More technical expertise rather than negotiation

HM concepts increase the control over the operation and leave more time than today for managing the technical aspects rather than engaging in fire fighting and constant adaptation to changing requirements.

The new system will affect the KSA (knowledge skills abilities) required today: the technical ones will largely remain the same (new elements may be introduced in dealing with HM technologies), the social will be less frequently relevant due to reduction in coordination and the organisational ones are incorporated into the design of information technologies in more transparent processes.

At the same time it gives the opportunity to define clearer performance requirements. The formal process is closer to daily operations with information channels clearly established to facilitate as well as monitor its progress. The increased control of maintenance requirements due to HM technology results in fewer changes in operational requirements.

- Team

Sustaining a smooth operation of the fleet different departments are working together. Across departments there is a notion of an organisational team that delivers the business output. Today, the overall constructive collaboration is sometimes overshadowed by a lack of appreciation for each other constraints which stems from the nature of the business itself (e.g. changing requirements, non-optimal process integration, unavailability of information etc).

The TATEM concepts promise to enable

- Integrated view/shared understanding of interdependencies across domains
- Standardised processes, clearer expectations in processes that are remote in nature
- Integration of processes across different domains by introducing new interfaces
- Less mutual adjustment but centralised decision making; less opportunity for shifting blame but constructive collaboration based on transparent operational picture

Formalisation of process interfaces helps the definition of roles and mutual expectations for standard situations which should be higher in number in the future due to better information and subsequent control of technical status and its operational context. The problem solving capability of a team will be reserved for exceptions and difficult cases rather than being applied to daily fire-fighting (as experienced frequently today). With today's frequently changing or emerging requirements ambiguity is further increased because people in poorly defined teams have access to different information or different understandings of its meaning in a process.

Today there are opportunities for less than optimal coordination between different domains. The wider integration of information that is triggered by the introduction HM concepts promise to give an opportunity to improve the situation in organisations as well as across the industry.
Transparency of the processes and its status facilitates a shared understanding which improves the work between departments. This is important because in more remote teams there is less personal contact that can support the creation of trust, so the processes need to be transparent and reliable to mitigate the impact of this change.

- Trust/Social relations

The transformations that are enabled through the introduction of HM address dimensions that contribute to an atmosphere of mistrust in organisational relations.

- Formal versus normal

  Example: opportunity for congruence of daily practices and formal process via increased control and subsequent process transparency

- Incompatible goals

  Example: Clear responsibilities within process framework; defined performance outcomes for each team member across system levels

- Performance requirement

  Example: defined performance outcomes for each team member across system levels

- No open communication

  Example: Information integration; transparency of sources and use; decision support based on full picture

- History of mistrust

  Example: Criticality of implementation; positive experiences with HM technology benefits and how they are utilised to improve the overall operation; key to information sharing across departments and with external stakeholders

At the same time the introduction of new technologies needs to address how it can contribute to the proactive creation if trust:

- Belief in future

  Examples: Improvement of control in an ever more complex industry; Experience that increase in aircraft system complexity can result in less ambiguity in managing their maintenance; Visibility that technology introduction is channeling improvements across the organisation;

- Genuine support

  Examples: Transparency in regard to contributions from other departments via MIS and decision support applications; Decision support facilitating day job

- Personal relationships

  Examples: Not everything needs to be done via indirect, automated information exchange (e.g. data links between system rather than people coordinating). Personal exchange is in addition to the standard work tasks which are now IT supported and may thus be experienced more positively or satisfying when only addressing exceptions

These effects can be envisaged but are more difficult to trace and depend on the overall organisational management of introducing changes. This also relates to wider issues such as the coherence of business models, adequate key performance indicators for quality, safety and efficiency across all system levels.

8.2 Appendix 2: HILAS case study

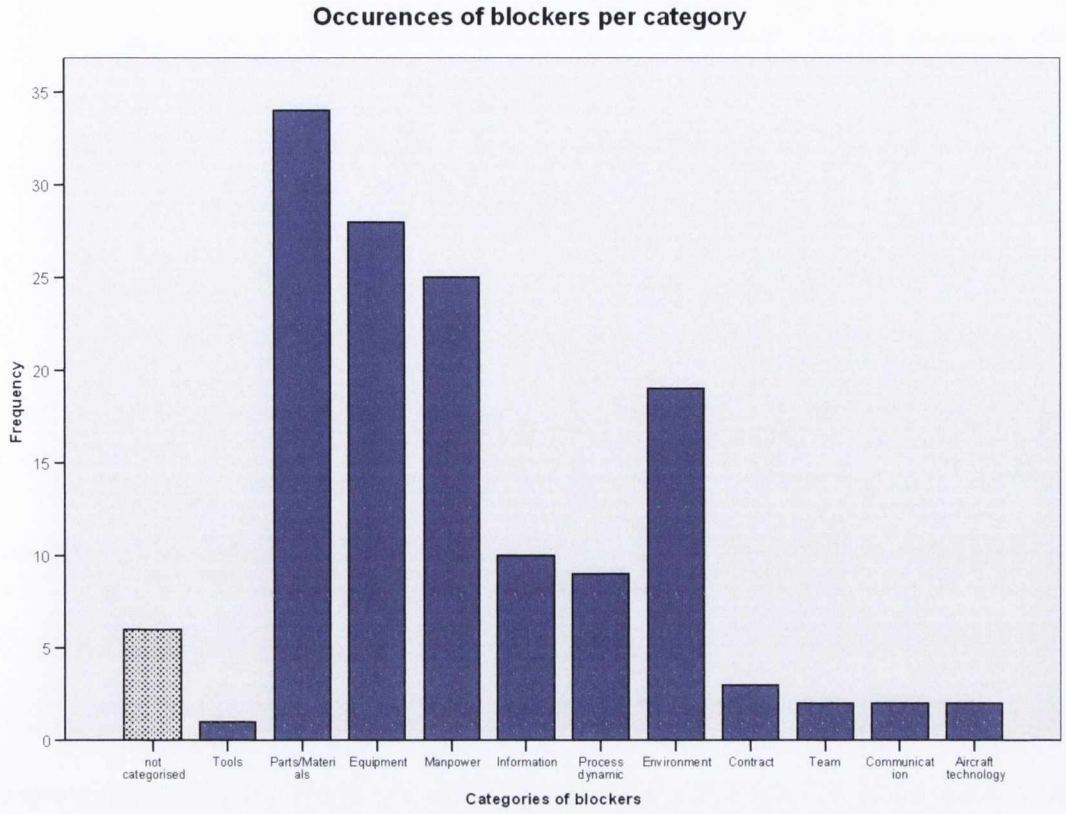
8.2.1 Overview of blocker report analysis outcomes

The results are a descriptive analysis of data patterns.

8.2.1.1 Frequencies in blocker categories

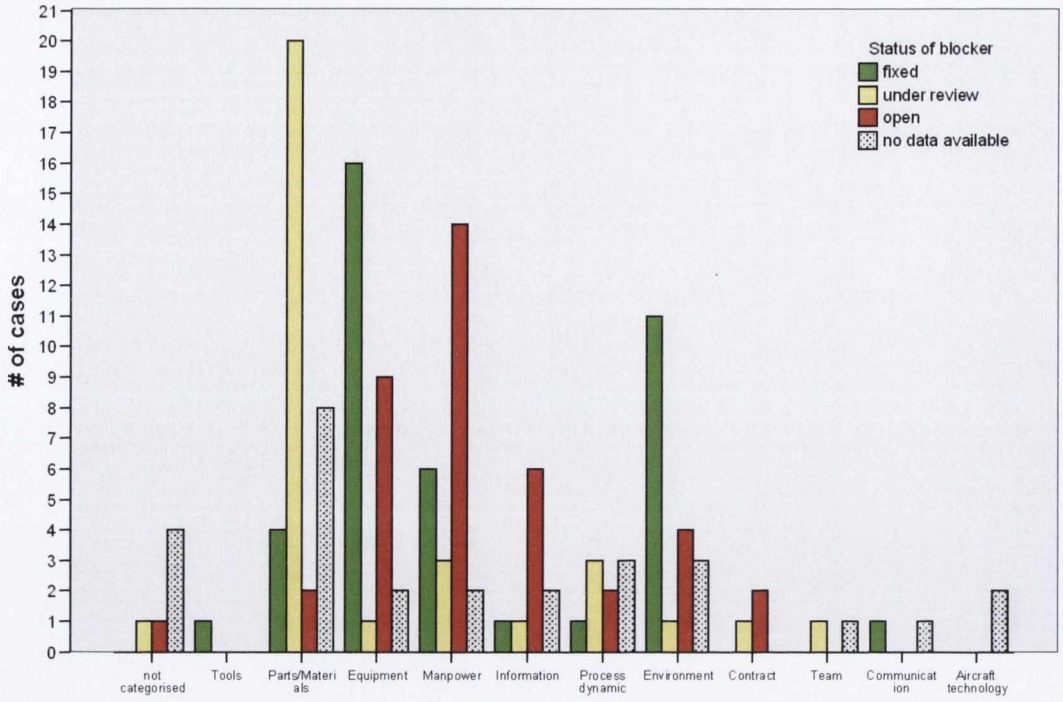
The total of n=141 blockers captured in the template were organised into the following categories:

Categories	*Frequency*	*Percent*
Material resources incl.	**63**	**44.7**
Tools	1	.7
Parts/Materials	34	24.1
Equipment	28	19.9
People resources	**25**	**17.7**
Information resources	**10**	**7.1**
Process dynamic	**9**	**6.4**
Environment	**19**	**13.5**
Base Mx System/Contract	**3**	**2.1**
People system incl.	**4**	**2.8**
Team definition	2	1.4
Communication	2	1.4
Aircraft technology	**2**	**1.4**
- Not categorised -	**6**	**4.3**
Total of blockers	***141***	***100.0***



8.2.1.2 Status of blockers

All blockers have been classified in regard to their status. The main difference between the blockers that are fixed or open is linked to the level of control that the operational staff has over them. If addressing blockers locally is able to provide a solution the blockers are more likely to have been resolved (e.g. purchasing equipment; reorganizing the process). The blockers that occur at process interfaces (across (sub)-departmental boundaries) have proven more challenging. Their solution requires the collaboration between departments.



Major improvements have been made in the environment, including hanger layout and provision of customised equipment such as stands and storage design (as delivered in collboration with environmental change strand of the improvement project).

8.2.1.3 Recurring blockers

The highest number of recurring blockers

- Manpower

The main recurring issue is in regard to the support staff, namely the cleaning support provided for the operation. Issues were reported across 6 out of 10 checks, in some of them different facets. Main dimensions were availability and standard of cleaning (which seems to be related to inadequate supervision).

- Information resources

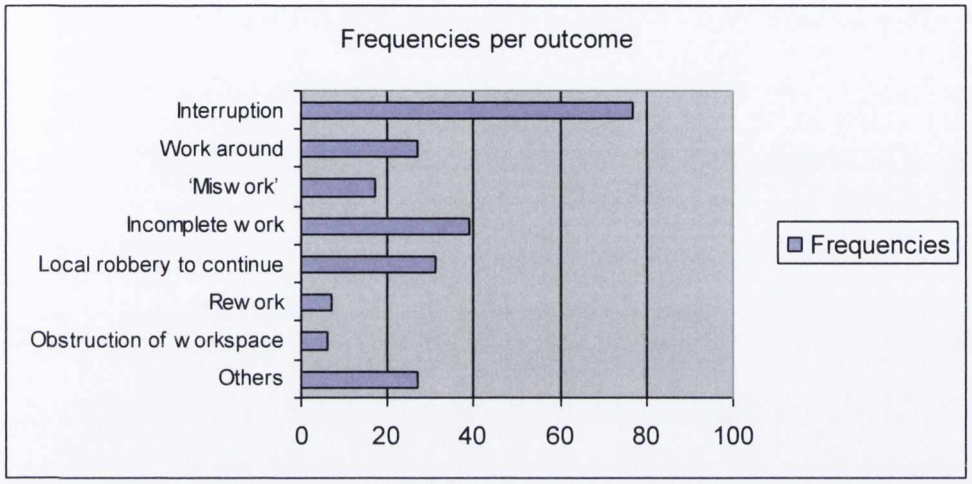
The design of panel charts is featuring as a recurring blocker for the smooth execution of the operation. Issues were reported across 4 out of 10 checks, emerging as an issue in second half of documented checks. (Note: Personal communication revealed that it had already presented itself as an issue in the early checks, but has been tried to be resolved locally.)

- Parts/Materials process interface

Issues were reported across each check. Their severity differs, but many remain unresolved. Key dimensions include the delivery of parts and consignment stocks.

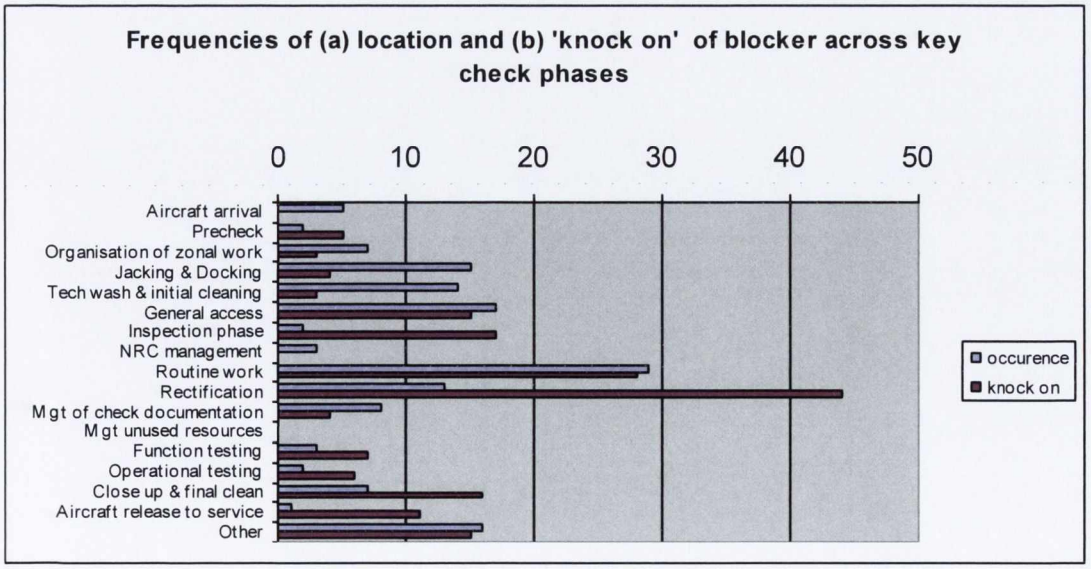
8.2.1.4 Outcomes for process blockers

The total number (n=231) for reported outcomes of a process blocker is higher than the number of blockers reported (n=141). This is due to the fact that in some cases it was felt appropriate to report more than one outcome. In most cases the occurrence of a process blocker resulted in an interruption of work. The impact of this is usually mitigated by local rescheduling (one of the frequently reported consequences). Other outcomes include work around (alternative way of progressing work) and leaving work in an incomplete state until it can be resumed.



8.2.1.5 Blocker occurrences and knock on across check phases

The high occurrence of blockers in the routine work phase can be linked to the issues in regard to parts/materials provision into the operation. In general the rectification phases (routine and non-routine) as well as the close up seem to suffer the most from knock on consequences of blockers occurring during the course of the check. This matches the perception of staff as those being vulnerable phases, including the increased workload experienced towards the end of checks.



8.2.1.6 Recurring blockers

The data suggests that at the moment there are three main areas that would benefit from the envisaged blocker resolution process. Those are include the recurring issues of

- Cleaning staff

- Panel charts

- Parts/Materials process interface

Their recurring nature and the impact that they have on the performance put them strongly on the agenda for a review of the overall risks involved and a dedicated approach to review related process to design a better organisational processes around them.