

Development of a performance framework to support the innovation process

A thesis submitted to the University of Dublin in partial
fulfilment of the requirements for the degree of Ph.D.

Vanessa Nappi

Department of Mechanical and Manufacturing Engineering

Parsons Building

Trinity College

Dublin 2

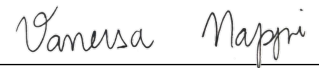
Ireland

2021

DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university, and it is entirely my own work.

I agree to deposit this thesis in the University's open access institutional repository or allow the Library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

A handwritten signature in cursive script, reading "Vanessa Nappi", positioned above a horizontal line.

Vanessa Nappi, September 2020

SUMMARY

Performance frameworks (PFs) are important to companies, industry, and practice communities as they are essential tools for process management. In innovation management, it is no different. Strategy implementation, performance evaluation, decision making, communication and process improvement can be achieved through a PF. Nevertheless, existing PFs fail to address recent changes in how innovation is being performed by companies. These changes in the current innovation landscape are driven by recent performance dimensions that need to be included in the PFs, e.g., knowledge management and innovation environment considering new trends like openness, servitisation and sustainability. Such dimensions also need to be populated with relevant PIs systematised to enable companies to generate a balanced selection. Thus, existing PFs make managers miss these changes or lack sound recommendations for how to address them in the context of performance measurement as well as making information available for the development of action plans.

This thesis introduces a new and updated PF to support manufacturing companies in the innovation process management and improvement. The PF was developed in the context of the hypothetic-deductive approach combining the conceptual and empirical developments. Initially, a theoretical approach is adopted in order to have in-depth knowledge and understanding about the issue, define the main elements of the framework and elaborate the content of the conceptual version. The research method adopted in this stage is the systematic literature review. Subsequently, the conceptual version of the framework is further developed following an empirical approach, with the application of the PF in action research in two medium-sized companies manufacturing. Lastly, to test the theory developed in this research, i.e., the PF can support manufacturing companies, particularly small and medium-sized enterprises (SMEs) in measuring innovation performance and the definition of improvement plans, a case study for theory-testing is carried out.

The results indicate that the PF can successfully support manufacturing companies, in particular medium-sized manufacturing companies with more emphasis on technology-push strategies, in measuring innovation performance and the definition of improvement plans to be applied within the scope of this research, based on the company's current innovation capability profile and its strategic goals and drivers. In this sense, the PF has demonstrated the potential to help manufacturing companies in the diagnosis of their innovation capability, with

the identification of improvement opportunities and the development of action plans to achieve the desired situation. This outcome is confirmed by the satisfactory results achieved in the evaluation questionnaire and further corroborated by the practitioner's testimonials expressing that the support received in identifying and addressing improvement opportunities was missing in the company before this study. In addition, the PF also supported continuous improvement towards better innovation performance in the participating companies. This support is validated through the positive results from the evaluation questionnaire and the fact that one of the companies have committed resources to implement the prioritised improvement projects. Finally, the developed PF enables establishing a common language and a shared vision across the company.

PUBLICATIONS

The following publications have been produced over the course of this PhD:

Nappi, V., & Kelly, K. (2017). Framework to support innovation performance measurement in product development for young companies. Doctoral Seminar on Research Methodology in Operations Management. Brussels, Belgium.

Nappi, V., & Kelly, K. (2018). Key performance indicators and dimensions for the innovation Process. 25th Innovation and Product Development Management Conference (IPDMC), 1–20. Porto.

Nappi, V., & Kelly, K. (In press). Measuring knowledge management in the innovation process: a systematic literature review. *International Journal of Knowledge Management Studies*.

Nappi, V., & Kelly, K. (In press). Proposing a performance framework for innovation measurement: an exploratory case-based research. *International Journal of Knowledge Management Studies*. *International Journal of Productivity and Performance Management*.

Nappi, V., & Kelly, K. (2020). Towards a better comprehension of sustainability performance indicators for the innovation process. 2020 IcRS International Conference on Resource Sustainability, Postponed 2021. Dublin.

Other productions:

Nappi, M. M. L., Nappi, V., & de Souza, J. C. (2019). Multi-criteria decision model for the selection and location of temporary shelters in disaster management. *Journal of International Humanitarian Action*, 4(16), 1–19. <https://doi.org/10.1186/s41018-019-0061-z>

ACKNOWLEDGEMENTS

First of all, I would like to express and gratitude to my supervisor Professor Kevin Kelly. Thank you for giving the opportunity to carry out this research and supporting me in this quest. You have provided me with the support and guidance I required during the research and trusted me to make key decisions about the project. It is not easy to find the words to express how thankful I am for having the opportunity to work (and learn) with you throughout these years.

During the time I have been in the Robotics and Innovation Lab, I have been lucky to meet and share experiences with amazing people. Life in Trinity would have been much more difficult and less fun, without the friends I made there. Adam Coyne, Michael Cullinan, Patrick Lynch, thank you for the great moments and fruitful PhD discussions we had together. Research engineers, Andrew Murtagh, Cian Donovan, Eamonn Bourke, Robbie Fryers and Talita Holzer, thank for your being a constant source of inspiration and companionship, and Alex Shackleton, Anna Rafferty, Cara O'Brien, and Iseult O'Donnel, thank you for your insightful work and dedication to students. In special, Mike, Paddy and Cara, it was an honour to teach 5E3 alongside you.

Within the Department of Mechanical and Manufacturing Engineering, where I completed my PhD research, I would like to give my sincere thanks to all academic staff. I would like to acknowledge Professor Conor McGinn for your energy as well as the encouragement you give students in the pursuit of their projects. In addition, I would also like to thank Professor Paul Coughlan from the Business School for the wise and thought-provoking discussions about the research methodology.

Furthermore, I extend my sincere thanks to the people, directly and indirectly, involved in the development and evaluation of the performance framework. In this regards, I am truly thankful to the three companies which kindly opened their doors to me.

Finally, I am also very grateful to my family and friends in Brazil. You have always encouraged me to follow my own path and reach my potential. Thanks for supporting me and making me feel beloved. Heartfelt thanks to my partner, Rapha, for always being there for me.

Muito obrigada!

CONTENTS

DECLARATION	iii
SUMMARY	v
PUBLICATIONS.....	vii
ACKNOWLEDGEMENTS.....	ix
LIST OF FIGURES	xvii
LIST OF TABLES	xxi
NOMENCLATURE	xxiii
1 INTRODUCTION	1
1.1 CONTEXT AND MOTIVATION	2
1.1.1 <i>Evidence from literature</i>	3
1.1.2 <i>Evidence from practice</i>	4
1.1.3 <i>Research gap</i>	5
1.2 RESEARCH OBJECTIVES AND SCOPE	7
1.3 RESEARCH CONTRIBUTION AND NOVELTY	8
1.4 DOCUMENT STRUCTURE	9
2 LITERATURE REVIEW	13
2.1 TECHNOLOGY AND INNOVATION MANAGEMENT	13
2.1.1 <i>Definition of innovation</i>	14
2.1.2 <i>The innovation process</i>	16
2.1.2.1 Main reference models for the innovation process	18
2.1.2.2 Analysis of innovation process reference models	26
2.1.3 <i>Definition of the innovation process phases</i>	28
2.1.3.1 Innovation front-end	30
2.1.3.2 Technology development.....	32
2.1.3.3 Product development	33
2.1.3.4 Market monitoring	35
2.1.3.5 End-of-life	36

2.1.4	<i>Characteristics of the innovation process</i>	37
2.2	MANAGERIAL ACCOUNTING.....	40
2.2.1	<i>Performance measurement</i>	40
2.2.2	<i>Performance measurement systems</i>	42
2.2.2.1	Individual performance indicators	43
2.2.2.2	Sets of performance indicators	47
2.2.2.3	Measurement environment	49
2.2.3	<i>Performance frameworks</i>	50
2.2.4	<i>Synthesis of the performance framework's elements</i>	54
2.3	EXISTING INNOVATION PERFORMANCE FRAMEWORKS	56
2.3.1	<i>Framework for selecting R&D productivity indicators</i>	56
2.3.2	<i>Technical innovation audit</i>	58
2.3.3	<i>Performance framework for integrated indicators</i>	59
2.3.4	<i>Performance framework for technology research</i>	60
2.3.5	<i>New product development best practice framework</i>	61
2.3.6	<i>Balanced innovation front-end measurement framework</i>	62
2.3.7	<i>Reference framework for R&D</i>	63
2.3.8	<i>Multidimensional framework of innovation</i>	64
2.3.9	<i>Framework to develop innovation key performance indicators</i>	65
2.3.10	<i>Analysis of existing performance frameworks</i>	67
2.3.11	<i>Development of performance frameworks</i>	72
2.4	REMARKS	74
3	METHODOLOGY	77
3.1	METHODOLOGICAL ASPECTS.....	78
3.2	RESEARCH DESIGN	79
3.3	RESEARCH METHOD	83
3.3.1	<i>Stage 1: Literature review of previous knowledge and existing theories</i>	83
3.3.2	<i>Stage 2: Conceptual development of the performance framework</i>	84
3.3.3	<i>Stage 3: Empirical development of the performance framework</i>	86
3.3.4	<i>Stage 4: Test of the performance framework</i>	89
3.4	SELECTION OF PARTICIPATING COMPANIES.....	90

3.5	QUALITY AND RIGOUR IN THE RESEARCH METHOD.....	92
3.5.1	<i>Rigour in qualitative research</i>	92
3.5.2	<i>Rigour in the assessment of the performance framework</i>	95
3.6	REMARKS.....	99
4	CONCEPTUAL DEVELOPMENT.....	101
4.1	PERFORMANCE FRAMEWORK OVERVIEW	102
4.2	DATABASE ELEMENTS	104
4.2.1	<i>Dimensions of performance</i>	106
4.2.2	<i>Performance indicators</i>	111
4.2.2.1	Top-cited performance indicators	113
4.2.2.2	Categorisation of performance indicators	116
4.3	SUPPORTING ELEMENTS	121
4.3.1	<i>Initial procedure</i>	121
4.3.2	<i>Facilitation</i>	123
4.3.3	<i>Visualisation of performance progression</i>	124
4.3.4	<i>Support for improvement actions</i>	131
4.4	REMARKS.....	134
5	EMPIRICAL DEVELOPMENT	135
5.1	COMPANY TRFR	136
5.1.1	<i>Diagnosis of the current situation</i>	137
5.1.1.1	Constructing	138
5.1.1.2	Planning action.....	142
5.1.1.3	Implementing action	144
5.1.1.4	Evaluating action	146
5.1.2	<i>Deployment of action plans</i>	147
5.1.2.1	Planning action.....	148
5.1.2.2	Implementing action	149
5.1.2.3	Evaluating action	151
5.2	COMPANY TRPT	155
5.2.1	<i>Diagnosis of the current situation</i>	156

5.2.1.1	Constructing.....	156
5.2.1.2	Planning action	160
5.2.1.3	Implementing action	161
5.2.1.4	Evaluating action	164
5.2.2	<i>Deployment of action plans</i>	165
5.2.2.1	Planning action	165
5.2.2.2	Implementing action	167
5.2.2.3	Evaluating action	169
5.3	KEY LEARNINGS.....	173
5.3.1	<i>Framework improvements during the action research</i>	173
5.3.2	<i>Consolidated version of the framework</i>	176
6	THEORY VALIDATION.....	183
6.1	CASE STUDY FOR THEORY TESTING	183
6.1.1	<i>Application</i>	184
6.1.2	<i>Evaluation</i>	191
6.2	OVERALL ASSESSMENT OF THE FRAMEWORK	194
6.3	ANALYSIS OF THEORETICAL CONTRIBUTION	198
7	CONCLUSIONS AND FINAL REMARKS	201
7.1	RESULTS AND RESEARCH OBJECTIVES	201
7.2	FUTURE RESEARCH	204
	REFERENCES.....	207
	APPENDIX I. SYSTEMATIC LITERATURE REVIEW PROTOCOL.....	231
	APPENDIX II. JOURNAL KEEPING FOR ACTION RESEARCH	235
	APPENDIX III. EVALUATION QUESTIONNAIRE.....	237
	APPENDIX IV. BIBLIOMETRIC ANALYSIS OF THE SYSTEMATIC REVIEW	241
	APPENDIX V. DATABASE OF PERFORMANCE INDICATORS	249
	APPENDIX VI. EVOLUTIONARY CHARACTERISATION OF PERFORMANCE LEVELS	311
	APPENDIX VII. IMPROVEMENT ACTIONS FROM THE LITERATURE	321

APPENDIX VIII. QUESTIONNAIRE S1 FOR CONTEXTUAL VARIABLES 327

APPENDIX IX. QUESTIONNAIRE S2 FOR PERFORMANCE ASSESSMENT 333

APPENDIX X. IMPROVEMENT PROJECT EXAMPLE 351

APPENDIX XI. SPREADSHEET FOR INNOVATION PROFILE CONSTRUCTION 355

APPENDIX XII. SPREADSHEET FOR PROJECT PRIORITISATION..... 357

APPENDIX XIII. EVALUATION QUESTIONNAIRE RESULTS 363

LIST OF FIGURES

Figure 1.1. Structure of the document.....	10
Figure 2.1. High-level structure of the literature review.	13
Figure 2.2. The innovation process according to Wheelwright & Clark (1992).	18
Figure 2.3. The innovation process according to Khurana & Rosenthal (1997).....	20
Figure 2.4. Innovation process according to Cooper (2001).	21
Figure 2.5. The innovation process according to Koen et al. (2001).....	22
Figure 2.6. The innovation process according to Pahl et al. (2007).	23
Figure 2.7. Innovation process, according to Crawford & Di Benedetto (2011).....	25
Figure 2.8. The innovation process defined in this work.	29
Figure 2.9. Characterisation of the innovation front-end (IFE) phase.	31
Figure 2.10. Characterisation of the technology development (TD) phase.	33
Figure 2.11. Characterisation of product development (PD) phases.....	34
Figure 2.12. Characterisation of the market monitoring (MAM) phase.	35
Figure 2.13. Characterisation of end-of-life (EoL) phase.....	36
Figure 2.14. Outline for performance measurement systems (PMSs) (Neely et al., 1995).	42
Figure 2.15. Representation of the elements of a PF.....	55
Figure 3.1. Methodological choices for the research design.	82
Figure 3.2. Summary of the research method with the four stages.	83
Figure 3.3. Outline of the research activities performed.....	85
Figure 3.4 Profile of evaluation respondents (n=18): a) areas; b) roles and, c) tenure.....	98
Figure 4.1. Location of the results for stage 2 of the research method.....	101
Figure 4.2. Foundations of the PF.....	103
Figure 4.3. Summary of the SLR steps (more details in Appendix IV).	105
Figure 4.4. Illustration of the dimensions and sub-dimensions of the innovation process....	110
Figure 4.5. Graph of the PIs accumulated citations.	113
Figure 4.6. Initial procedure of the PF to begin the AR.	122
Figure 4.7. Graphical representations of the progression of performance.	130
Figure 5.1. Location of the results for stage 3 of the research method.....	135
Figure 5.2. Constructing IFE in Company TRFR.....	139
Figure 5.3. Constructing the TD phase in Company TRFR.	140

Figure 5.4. Constructing the PD phases (with MAM and EoL activities) in Company TRFR. ...	141
Figure 5.5. Initial procedure of the PF: diagnosis.	142
Figure 5.6. Stakeholder map for the PF application in Company TRFR.	143
Figure 5.7. Company TRFR innovation capability profile.	145
Figure 5.8. Initial procedure of the PF: deployment of action plans.	148
Figure 5.9. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company TRFR.	153
Figure 5.10. Constructing IFE in Company TRPT.	157
Figure 5.11. Constructing the TD phase in Company TRPT.	158
Figure 5.12. Constructing the PD phases (with MAM activities) in Company TRPT.	159
Figure 5.13. 'Intermediary' procedure of the PF: diagnosis.	160
Figure 5.14. Stakeholder map for the PF application in Company TRPT.	161
Figure 5.15. Company TRPT innovation capability profile.	163
Figure 5.16. 'Intermediary' procedure of the PF: deployment of action plans.	166
Figure 5.17. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company TRPT.	171
Figure 5.18. Stage I: Diagnosis of the current situation.	176
Figure 5.19. Stage II: Deployment of action plans.	179
Figure 6.1. Location of the results for stage 4 of the research method.	183
Figure 6.2. Characterisation of the IFE in Company DFED.	185
Figure 6.3. Characterisation of the TD phase in Company DFED.	186
Figure 6.4. Characterisation of the PD and EoL phase in Company DFED.	187
Figure 6.5. Stakeholder map for the PF application in Company DFED.	188
Figure 6.6. Company DFED innovation capability profile.	189
Figure 6.7. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company DFED.	192
Figure 6.8. Comparison of the evaluation in companies TRFR, TRPT and DFED (n=18).	197
Figure I.1. Search string for the systematic review.	231
Figure II.1. Journal keeping used for Company TRFR.	235
Figure II.2. Journal keeping used for Company TRPT.	236
Figure IV.1. Systematic review paper selection summary.	241
Figure IV.2. Publication numbers per year (1983-2018).	242

Figure IV.3. Number of publications per journal (1983-2018).	242
Figure IV.4. Frequency of use research methods (1983-2018).	243
Figure IV.5. Co-citation network of publications visualisation by VOSView.	246
Figure XI.1. Initial screen of the spreadsheet for the profile construction.	355
Figure XI.2. Tabulating the data from the interviews.	356
Figure XI.3. Corroborating the measurements with evidence from the company.	356
Figure XII.1. Initial menu of the prioritisation spreadsheet.	357
Figure XII.2. Weighting of the criteria for prioritisation.	357
Figure XII.3. Registration of evaluators of the prioritisation spreadsheet.	358
Figure XII.4. Registration of the projects to be prioritised.	358
Figure XII.5. Evaluation of the projects according to the AHP method.	359
Figure XII.6. Results of the evaluation, showing a ranking of the projects.	359

LIST OF TABLES

Table 1.1. Synthesis of future research specified in the main outlets of research.....	6
Table 2.1. Clustering of common phases of the leading innovation process models.....	27
Table 2.2. Performance indicator (PIs) specification parameters.....	44
Table 2.3. Examples of visual representations of the progression of performance.	53
Table 2.4. Comparison of the procedures of the reviewed PFs.	68
Table 2.5. Main issues related to existing PFs.....	71
Table 2.6. Development of existing PFs.	73
Table 3.1. Methodological framework (adapted from Meredith et al., 1989).	80
Table 3.2. Summary of the participating companies.	92
Table 3.3. List of critical control points and the strategies taken in this research.	94
Table 4.1. Compilation of performance dimensions for the innovation process.	107
Table 4.2. Distribution of the indicators among the dimensions.....	112
Table 4.3. Top- cited indicators retrieved from the literature.....	114
Table 4.4. Overview of the distribution of the indicators' classifications.....	117
Table 4.5. List of rapid assessment PIs across the dimensions, and further classifications. ..	118
Table 4.6. Examples of the 'soft' characterisation of the performance levels.	127
Table 4.7. Examples of the 'hard' characterisation of the performance levels.	129
Table 4.8. Examples of improvement practices collected.....	132
Table 4.9. Description of improvement practice P01-IS-IO.....	133
Table 5.1. Company TRFR evaluation of the PF (n=7).	154
Table 5.2. List of practices suggested for Company TRPT.....	168
Table 5.3. Company TRPT evaluation of the PF (n=7).	172
Table 5.4. Improvements in the PF procedure.....	173
Table 5.5. Improvements in the PF facilitation.	174
Table 5.6. Improvements in the PF visualisation of performance progression.	175
Table 5.7. Improvements in the PF support for improvement actions.....	175
Table 6.1. List of practices suggested for Company DFED.	190
Table 6.2. Company DFED evaluation of the PF (n=4).....	193
Table 6.3. Comparison of existing PFs and the proposed PF.	199
Table V.1. Database of performance indicators.....	249

Table VI.1. ‘Soft’ characterisation of the performance levels for each dimension.....	311
Table VI.2. ‘Hard’ characterisation of the performance levels for each dimension.....	316
Table VII.1. Compilation of innovation practices for the literature.....	321
Table VII.2. Simplified domain mapping matrix relating levels with the practices.	326
Table XIII.1. Results of the PF evaluation in each participating company.....	363

NOMENCLATURE

LIST OF ACRONYMS

<i>AHP</i>	Analytical hierarchy process
<i>AR</i>	Action research
<i>EOL</i>	End-of-life phase of the innovation process
<i>IE</i>	Innovation environment dimension
<i>IFE</i>	Innovation front-end phase of the innovation process
<i>IP</i>	Intellectual property
<i>IS</i>	Innovation strategy dimension
<i>ISIC</i>	International Standard Industrial Classification of All Economic Activities
<i>KM</i>	Knowledge management dimension
<i>OC</i>	Organisation and culture dimension
<i>OECD</i>	Organisation for Economic Co-operation and Development
<i>OM</i>	Operations management research field
<i>MA</i>	Market dimension
<i>MAM</i>	Market monitoring phase of the innovation process
<i>NPD</i>	New product development phase of the innovation process
<i>PF</i>	Performance framework
<i>PFM</i>	Portfolio management dimension
<i>PI</i>	Performance indicator
<i>PM</i>	Project management dimension
<i>PMS</i>	Performance measurement system
<i>PSS</i>	Product service systems
<i>R&D</i>	Research and development
<i>SLR</i>	Systematic literature review
<i>SMEs</i>	Small, medium enterprises
<i>TD</i>	Technology development process
<i>TEAM</i>	Team management dimension
<i>TM</i>	Technology management dimension
<i>WoS</i>	Web of science electronic database

GLOSSARY

Action research (AR)	A research method in which a scientific approach is applied to study the resolution of key organisational problems within companies with the active participation of the people involved with these problems, applying an interventionist approach that allows the development of theory in action.
Case study	A research method that aims to understand if/how a certain theory developed works in practice within organisations, enabling to test the theory using empirical conditions, but without applying an interventionist approach.
Evolutionary levels	Levels used to describe the evolution of a process subdivided into separate stages, with an eventual stopping point of evolutionary 'superiority' or 'excellence'. It can also be called performance levels in the managerial accounting literature.
Improvement project	An action plan that is specified into a project charter with the definition of, for example, goals, description, main deliverables, requirements, risks, implementation time and necessary resources.
Innovation	New or significant improvements in characteristics or intended uses of products/services; this includes substantial improvements in technical specifications, components and materials, incorporated software, user-friendliness or other functional characteristics.
Innovation capability	The specific ability that must exist in an organisation in order to enable the execution of management activities within the innovation process.

Innovation practice	A specific type of professional or management activity that contributes to the execution of the innovation process, employing one or more techniques and tools.
Innovation process	A series of coordinated events and activities that may occur in sequence or concurrently performed by an organisation to transform knowledge into marketable solutions to be delivered to customers.
Performance dimensions	A meaningful category that organises indicators into typologies relevant to the domain in question to facilitate their operationalisation and ensure that no critical dimension is missing.
Performance framework (PF)	A managerial tool that supports companies in the execution performance measurement, evaluation, and the implementation of improvement action plans.
Performance indicator (PI)	The metric used to quantify the efficiency and/or the efficacy of an action or the result of an action within the context of a process or operation.
Performance measurement	The process that quantifies the effectiveness and efficiency of past actions within the context of business processes or operations in organisations.
Performance measurement systems (PMS)	A set of performance indicators organised into distinct and necessary dimensions used in the measurement of the performance of a process or operation.
Systematic literature review (SLR)	A reproducible and structure research method to review the literature aiming to obtain a meaningful collection of studies to map existing and preceding knowledge.

1 INTRODUCTION

It was the scientist Lord Kelvin who said:

When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. (Thompson, 1824–1907, cited in Niven, 2006, p. 1)

Kelvin, the creator of the absolute temperature scale, was a scientist, but his ideas also apply to organisations. The absence of measurement leaves us uncertain as to what is going on and incapable of acting accordingly. In other words, if you cannot measure it, you cannot manage it. If you cannot manage, you simply cannot improve it.

Measurement is as fundamental for managers as it is for scientists. Performance measurement has a central role in the management of processes and operations within organisations. However, measurement in our modern world goes beyond the assignment of numbers and includes using a series of tools to describe and evaluate performance, much more like a social activity. In this way, performance measurement helps companies make sense of the world around them, allowing managers to put things in perspective and make better-informed decisions.

In the management of the innovation process, it is no different. At the macro level, innovation is important to the advancement of society as it solves problems or enhances society's capacity to act upon them. Innovation also enables organisations to stay relevant in the competitive market, playing an essential role in economic growth. Strategy implementation, performance evaluation, decision-making, communication and process improvement can be achieved in the innovation process through performance measurement.

Within this theme, the Introduction Chapter initiates the discussion by addressing context and motivation of this research in terms of literature (1.1.1) and practice (1.1.2), respectively, and then focusing on the research gap (1.1.3). Following this, the research objectives and scope are presented (section 1.2), the contribution and originality of the research are highlighted (section 1.3) and the structure of this document is outlined (1.4).

1.1 CONTEXT AND MOTIVATION

The innovation process is critical for companies to achieve significant advantages over competitors, by satisfying new customer needs, increasing product performance, reducing time-to-market, creating new business arenas and changing the rules of competition (Bassani, Lazzarotti, Manzini, Pellegrini, & Santomauro, 2010; Cooper & Edgett, 2012; Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008).

Measuring the performance of the innovation process is considerably challenging (Adams, Bessant, & Phelps, 2006; Becheikh, Landry, & Amara, 2006; Cordero, 1990). There are some reasons for that. Firstly, not all innovation efforts are directly observable in quantitative terms (Crossan & Apaydin, 2010). Secondly, success is uncertain as the innovation process may be influenced by uncontrollable external variables from the market and further macro environment (Adams et al., 2006). Thirdly, outcomes of the innovation process can be only assessed after long delays as the process takes time to unfold (Pearson, Nixon, & Kerssens-van Drongelen, 2000; Tipping, Zeffren, & Fusfeld, 1995). Nonetheless, far from discouraging academics in the study of performance measurement of the innovation process, these difficulties make the topic more relevant for new research (Brattström, Frishammar, Richtnér, & Dane, 2018; Dziallas & Blind, 2018; Saunila, 2017).

The increasing number of publications examining innovation indicators reflects the demand for more studies enlightening the use of performance measurement for supporting the innovation process (cf. Dziallas & Blind, 2018; Saunila, 2017). Managers of the innovation process know very well that “you get what you measure” and that performance measurement can be an important tool for supporting innovation efforts in companies (Adams et al., 2006; Becheikh et al., 2006; Cordero, 1990). In contrast, there are a few opponents of this position, indicating that even terms such as ‘measurement’ are not widely accepted in the innovation context, where creativity, lateral thinking, freedom and collaboration are considered essential elements for the success of novel concepts (Bassani et al., 2010). Even so, the evidence gathered during through the last decades of research reinforces that performance measurement can clearly contribute to higher innovation effectiveness by providing opportunities to improve performance (Adams et al., 2006; Chiesa, Coughlan, & Voss, 1996; Chiesa, Frattini, Lazzarotti, & Manzini, 2009; Lakiza, Deschamps, & Cameron, 2018; Markham & Lee, 2013).

Therefore, the debate around innovation performance measurement is still open, and this work intends to contribute to this debate. The approaches to ensure effective and efficient management of the innovation process are not well consolidated either in the scientific literature or in the company practice, as detailed next.

1.1.1 EVIDENCE FROM LITERATURE

Performance measurement can be defined as the process that quantifies the efficiency and effectiveness of business processes or operations of organisations (Neely, 2005). In this context, performance frameworks (PFs) are, in essence, managerial tools that organise indicators into relevant dimensions and prescribe steps to be followed to evaluate and improve performance (Neely, 2005; Niven, 2006).¹ Scholars argue that the systematic approach for performance measurement provided by a PF can help managers evaluate antecedents, activities and outcomes, thus ensuring that innovation is sufficiently supported and efficiently performed (Adams et al., 2006; Crossan & Apaydin, 2010; Dziallas & Blind, 2018).

PFs are relevant to the advancement of research in many fields. They provide comparability of studies between distinct entities, companies, industries, time-periods, cultures, and even geographic regions (Kerssens-van Drongelen & Cook, 1997; Lee & Markham, 2016). They also provide a basis for empirical validation of performance indicators (PIs) and the establishment of relationships between concepts and definitions (Franco-Santos et al., 2007). Furthermore, PFs that are reliable and valid enable accumulation of research in a scientific field and free subsequent researchers from the need to redevelop these measurement instruments (Boudreau, Gefen, & Straub, 2001; Kankanhalli & Tan, 2005).

Preceding research on PF for innovation management inform valuable learnings for researchers, such as suggestions of relevant PIs (Chiesa et al., 1996; Cooper & Kleinschmidt, 1995), the need to balance quantitative and qualitative PIs (Pawar & Driva, 1999; Werner & Souder, 1997), the use of relevant performance dimensions (Adams et al., 2006; Crossan & Apaydin, 2010), and the application of a continuous process (Chiesa et al., 2009; Crawford, 1985). Nevertheless, existing literature does not indicate a suitable PF for the innovation process (Dziallas & Blind, 2018). Moreover, whether PIs from academic findings are applicable in companies remains underexplored in the literature (Saunila, 2017).

¹A detailed discussion about PFs definitions is given in section 2.2.3

Despite the many contributions of past work, recent studies have been calling for more research. Authors like Dziallas and Blind (2018); Henttonen et al., (2016); and Lee and Markham, (2016) emphasise that new PFs are needed to provide an overview of relevant performance dimensions and to accommodate sets of 'best practice' PIs and further steps to support their use (Brattström et al., 2018; Lee & Markham, 2016). New studies proposing PFs should also consider small and medium-sized companies (Boly, Morel, Assielou, & Camargo, 2014; Dziallas & Blind, 2018). Moreover, the use of PFs needs to shift from only measuring performance to evaluating where there are opportunities to improve and making information available for the development of action plans (Boly et al., 2014; Brattström et al., 2018; Dziallas & Blind, 2018; Henttonen et al., 2016; Lee & Markham, 2016).

1.1.2 EVIDENCE FROM PRACTICE

In practice, a PF is a managerial tool for supporting innovation managers to measure and track performance in order to determine the degree to which innovation and new product development strategic goals are being met (Adams et al., 2006; Crossan & Apaydin, 2010). PFs can help managers in many aspects, such as setting targets, assessing and feedback of implementing actions, and developing benchmarks for future comparison (Kankanhalli & Tan, 2005). Moreover, PFs can also assist in providing a foundation to understand performance and even capture lessons learned (Ardito, Messeni Petruzzelli, & Albino, 2015; Bose, 2004; Gonzalez & Martins, 2017).

The importance of measuring the innovation process is also increasingly gaining the attention of manufacturing companies and consultancies (Dziallas & Blind, 2018; Junko Kaji, Hurley, Gangopadhyay, Bhat, & Khan, 2019). Existing surveys emphasise that applying PFs has become indispensable for companies to measure and update their indicators (Erkens, Wosch, Piller, & Lüttgens, 2014; Ringel, Zablit, Grassl, Manly, & M, 2018). Furthermore, according to a recent Boston Consulting Group's survey, 73% of managers from top-performing companies believe that measurement of the innovation performance should be considered a core business process for any company (Ringel et al., 2018). However, in practice, measuring innovation performance is also difficult, as 59% of the managers consulted in another survey have felt that they needed further help and support to measure and improve their innovation performance (Dewangan & Godse, 2014).

Anecdotal evidence also substantiates that PFs provide clarity in performance measurement, helping management detect problems and encourage behaviours that align with the company's goals (Bourne, Mills, Wilcox, Neely, & Platts, 2000; Neely, 2005), and identifying actions for improvement (Nilsson & Ritzén, 2014). Therefore, the continuous use of PFs can strengthen the company's existing capability through the evaluation of current performance, analysis of strengths and weaknesses, definition of the desired performance and identification of action plans to improve performance (Kaplan & Norton, 2007; Niven, 2006).

Further evidence demonstrating the increasing importance of the PFs for practice is the publication of the International Standard Organisation (ISO) newest standard for measurement and improving the innovation process, in late 2019. The ISO 52006 aims to provide guidance for the establishment, implementation, maintenance, and continual improvement of a system to manage the innovation process for use in all established organisations. The publication of such a standard provides additional weight to the topic of performance measurement and improvement of the innovation process. However, with a limited number of pages (ISO 52006 has 26 pages), it will be up to researchers to answer how to support companies with a PF in the performance measurement of the innovation process and evaluation of the opportunities to improve.

1.1.3 RESEARCH GAP

It can be said that evidence from both literature and practice indicate room for more research in the area of performance measurement for the innovation process, in particular, PFs. Despite the many contributions of the PFs, they present some shortcomings that need to be addressed in new research.

Table 1.1 illustrates a synthesis of the future research directions outlined in the main outlets² of innovation research. One of the underlying issues of the existing PFs leads to underestimating the potential of innovation measurement (Boly et al., 2014; Brattström et al., 2018). It refers to measuring only the parts as opposed to the whole, as PFs either use too few dimensions or overlook relevant ones to the current innovation landscape. Indeed, many PFs overlook performance dimensions already proven to be indispensable in the measurement of the innovation process, e.g., knowledge management (Dzallias & Blind, 2018). Others more

²These cited outlets are positioned within top 10 specialty journals in the technology and innovation management literature (Linton & Thongpapanl, 2004).

INTRODUCTION

recent ignore new trends addressed in the current landscape mostly related to the innovation environment, such as openness and servitisation (Lee & Markham, 2016). In contrast, a new updated PF needs to provide a comprehensive compilation of performance dimensions relevant to the innovation process demonstrated to be significant in past research.

Table 1.1. Synthesis of future research specified in the main outlets of research.

Researchers, Journal	Development	Application
Boly et al. (2014), Research Policy	Relevant dimensions for current companies' practices are overlooked in existing PFs.	Empirical research is needed to support PF application in companies, including small-medium-sized enterprises (SMEs).
Lee and Markham (2016), Journal of Product and Innovation Management	PFs need to address performance dimensions and PIs for, e.g., innovation environment.	PFs need to be applied in real-world companies after the development.
Henttonen et al. (2016), R&D Management	Current PFs need to update their performance dimensions.	Existing PFs lack support the definition of action plans to improve performance.
Dzallias and Blind (2018), Technovation	PFs need to include new dimensions like knowledge management and PIs qualitative and quantitative and leading and lagging characteristics.	Research lacks the application of dimensions and PIs in a case study, especially in SMEs.
Brattström et al. (2018), Journal of Engineering and Technology Management	PFs must include new and update dimensions to companies' current needs.	New PFs need to address performance issues from practice and support the definition of actions to resolve those issues in case-oriented research.

An additional underlying issue is that many PFs apply quantitative PIs but neglected qualitative ones. Others overemphasised output-oriented PIs that are also known as lagging, (e.g., new products sales) over leading input-oriented PIs (e.g., level of awareness and clarity of innovation goals). This overreliance on quantitative and lagging PIs confines the performance evaluation to past results, which are hard to influence and act upon and can hinder a more balanced set of PIs (Dzallias & Blind, 2018; Lee & Markham, 2016). Authors such as Costa *et al.* (2014) argue that managers see greater value in the systematisation of leading PIs to create a balanced set of PIs since they enable management to proactively act on the course of ongoing projects. Hence, studies will have a higher value for practice if they also focus on leading PIs (Dzallias & Blind, 2018). In this sense, research needs to promote a systematisation that congregates several PIs in a database, considering qualitative and quantitative and leading and lagging characteristics.

A further issue relates to missing the potential benefits of providing a step-by-step procedure to measure innovation and define action plans to improve performance in a systematic way. In this sense, researchers emphasise the need to extend the PF beyond just measurement to encompass performance evaluation to produce essential performance information to be used in the definition of actions plans (Brattström et al., 2018; Dziallas & Blind, 2018; Henttonen et al., 2016). Action must always follow measurement; otherwise, there is no point in wasting efforts.

Finally, a relevant PF for the current innovation landscape needs to follow company-oriented research (e.g., Brattström et al., 2018) especially in SMEs, often overlooked (Boly et al., 2014; Dziallas & Blind, 2018). Such an approach would enable a deeper understanding of performance measurement of the innovation process in real-world settings, which the researcher is a participant.³ Because of this, the thesis turns to action-oriented research to achieve the research objectives outlined next.

1.2 RESEARCH OBJECTIVES AND SCOPE

In light of the context and motivations previously introduced, the overall objective of this research was to develop a PF that can support manufacturing companies in the measurement of innovation performance and definition of action plans to improve performance, according to companies' strategic objectives and drivers.

The proposition presented in this research is that the measurement and management of the innovation process of a manufacturing company can be supported by the use of a PF, which indicates the most suitable action plans to be implemented into the innovation process according to the manufacturing company current innovation capability profile, strategic goals and drivers.

The following specific objectives are derived from the overall objective:

- Study of the literature on the innovation process, focusing on its fundamental phases and typical characteristics;
- Identify in the relevant literature what are the critical elements that form a PF;
- Systematically map the existing elements from the theoretical domains, with particular attention to performance indicators;

³A deeper discussion around the philosophical position of the researcher is given in the Methodology Chapter, section 3.2

- Structure a step-by-step procedure and further elements of the PF, including their construction, validation and respective evaluation by the users in the participating companies.

Innovation has been a major driver of success in the manufacturing sector for quite some time. Researchers like Tidd et al. (2005) argue that technology-intensive manufacturing firms, with the accumulation of technological knowledge produced by the design, creation and operation of complex production systems, have similar posture toward the innovation process. This is the reason why companies classified under section C, manufacturing, according to the International Standard Industrial Classification of All Economic Activities (ISIC)⁴ are the ones considered suitable participants of this research. Section C includes companies involved in the physical or chemical transformation of materials, substances, or components into new products and technologies.

Three prerequisites are proposed for delimiting the scope of application in companies: a minimum formalisation level of the innovation process and commitment to innovation (in terms of strategic alignment and/or resources to projects). In addition, previous research has focused on specific types of organisations, mostly large companies, therefore, overlooking small and medium-sized companies (Biberoglu & Haddad, 2002). In this way, SMEs⁵ following a formalised innovation process and aiming to improve their innovation process are, therefore, the target group for whom the research is being conducted.⁶

1.3 RESEARCH CONTRIBUTION AND NOVELTY

The work contained in this thesis addresses several important issues relating to innovation performance measurement in the corporate environment. Through the consideration of a theoretical approach combined with empirical application in manufacturing companies, it was possible to develop a novel PF that allows managers to not only measure but also identify gaps while supporting the definition of action plans to improve performance.

In doing so, the following contributions were made:

- 1) The identification and systematisation of existing PIs and performance dimensions based on an extensive systematic literature review.

⁴The International Standard Industrial Classification of All Economic Activities (ISIC) is an international classification of economic activities of industries based on a set of well-established definitions, concepts and principles (United Nations, 2008).

⁵According to OECD, SMEs employ fewer than 250 people (OECD, 2017).

⁶The discussion about the participating companies is presented in Chapter 3 ("Methodology").

- 2) The definition of a novel innovation capability profile for manufacturing companies to provide a diagnosis of the current performance.
- 3) Proposition of a new step-by-step procedure to apply the PF in the company, supporting the deployment of action plans based on continuous improvement approach and action-oriented results from the application in a real-setting in the manufacturing industry.
- 4) Establishment of a broader understanding of the aspects involved in innovation measurement and management, in terms of the necessary elements for a PF and their real-life application into manufacturing companies participating in this research.

Furthermore, the use of the PF in practice has the potential to help companies not only in the diagnosis of the innovation capability and identification of improvement opportunities but also in the development of a roadmap to achieve the desired situation and the establishment of a common language and a shared vision across the organisation.

1.4 DOCUMENT STRUCTURE

This thesis is structured into seven chapters and thirteen appendices, according to the scheme presented in Figure 1.1.

- Chapter 1 introduces the context and motivation of this work with initial evidence from the literature and practice culminating in the research gap. Then, the research objectives and scope are presented, followed by contribution and novelty.
- Chapter 2 presents a detailed review of two bodies of literature central to this research. The first body of literature, technology and innovation management, discusses the definitions for innovation, its process, phases and characteristics, while the second body, managerial accounting, presents concepts from a performance measurement perspective. These streams are then reviewed for existing PFs and their limitations.
- Chapter 3 presents the methodology, beginning with the presentation of the methodological aspects in which this research is positioned. Then the discussion moves on to the research design and the outline of the activities of the research method. This is followed by a discussion on the selection of the participating companies. This chapter concludes with a discussion on the validity and rigour of the research methods employed.

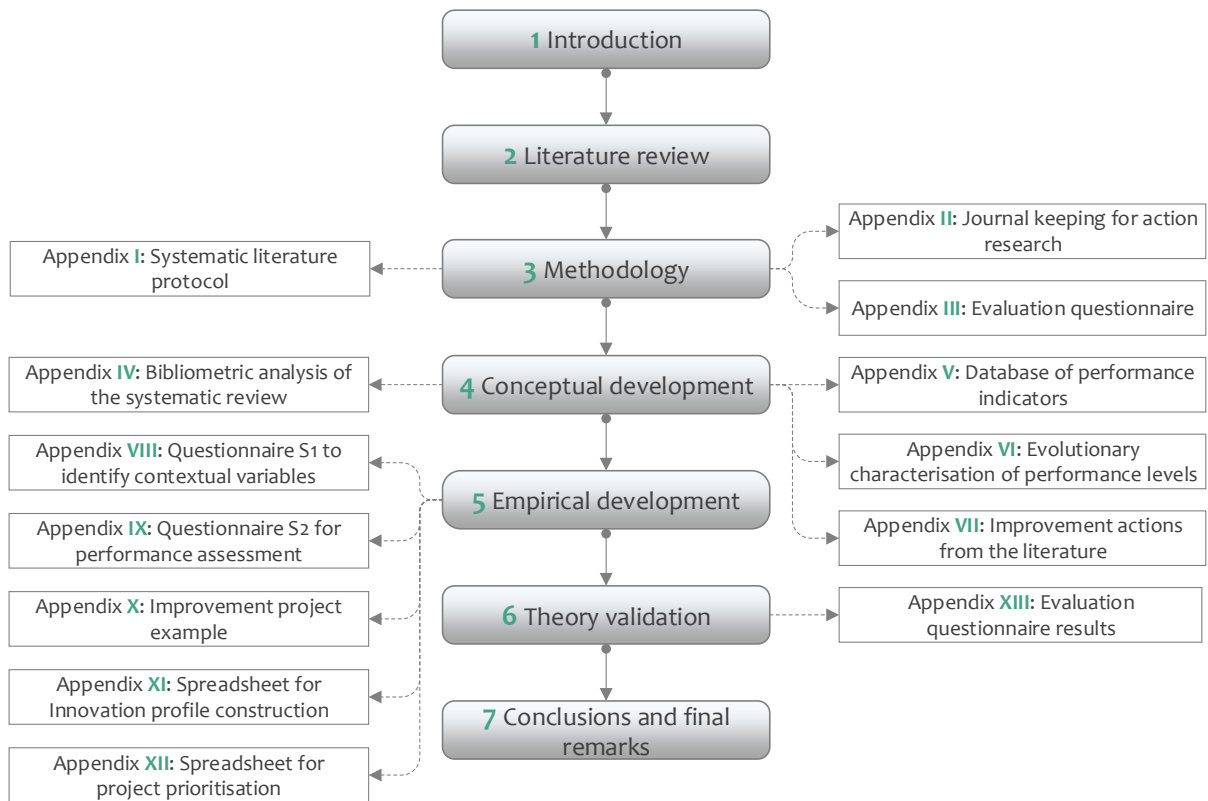


Figure 1.1. Structure of the document.

- Chapter 4 describes the conceptual development of the PF, based on a systematic literature review to define the database and supporting elements. This review indicated the existence of a number of dimensions, PIs and further definitions that are used as the building blocks of the conceptual proposition of the PF.
- Chapter 5 demonstrates the empirical development of the PF, beginning with the conceptual PF being applied and tested via action research (AR) in two manufacturing companies. The findings from practice gathered during the AR enabled the improvement of the PF in action, especially the supporting elements, and the proposition of the final and consolidated version of the PF.
- Chapter 6 presents a further case study for theory-testing of the final version of the PF carried out at a third manufacturing company. The PF is assessed in terms of applicability, usability, and usefulness applied to this research context. Usefulness is analysed, in particular, through an evaluation survey for all practitioners of the three participating companies. Finally, the PF theoretical contribution is compared against existing ones.

- Chapter 7 presents the conclusions and implication of the research for companies and researchers followed by suggestions for future work.
- The remainder of the thesis is comprised of both references and attached appendices (see Figure 1.1).

2 LITERATURE REVIEW

Innovation is a multifaceted research field composed of several schools of thought (Blessing & Chakrabarti, 2009). The meaning and definition of the terminology related to innovation presented in the literature may vary between subdomains, and therefore, their use in this work demands further clarification.

There are two main streams of literature relevant to the innovation research reviewed in this chapter: technology and innovation management, and managerial accounting. As illustrated in Figure 2.1, section 2.1 presents the literature on technology and innovation management, focusing on the definition of innovation as an outcome and as a process, the different stages of the process and its main characteristics. Section 2.2, in turn, discusses the literature on managerial accounting addressing the definition of performance measurement, indicators, measurement system, PFs and its elements. Then, the review turns to the existing PFs from the two streams of literature, comparing and analysing their limitations, and lastly, discussing their development (section 2.3).

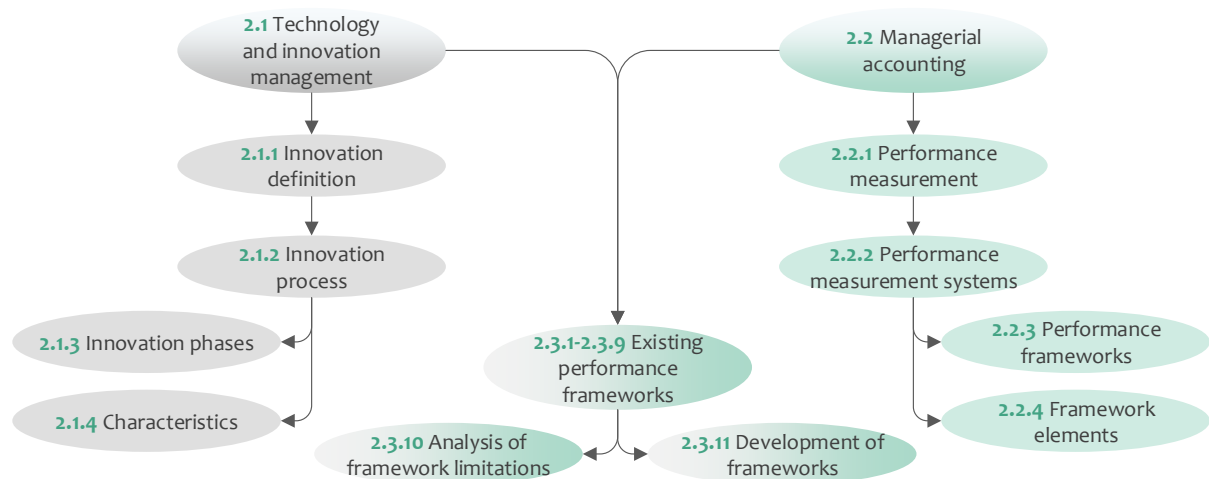


Figure 2.1. High-level structure of the literature review.

2.1 TECHNOLOGY AND INNOVATION MANAGEMENT

This first body of literature originated in technical disciplines, mostly engineering, and advanced to a broader scope encompassing management sciences (Crawford & Di Benedetto, 2011; Pahl, Beitz, Feldhusen, & Grote, 2007; Tidd et al., 2005; Ulrich & Eppinger, 2008). Research within this stream underlines that in a global competitive environment, the capability

to innovate has become essential to companies' survival. Companies that develop innovative products and services gain competitive leverage over others. More importantly, this collective body of work acknowledges that a systematic approach can help companies manage the 'fuzziness' of the innovation process and support performance improvement (Crawford & Di Benedetto, 2011).

The studies found in this stream have a pivotal role in the literature and establish a solid foundation for research so far. For instance, organisations such as the OECD – Organisation for Economic Co-operation and Development – established definitions widely used in research and practice. Garcia and Calantone (2002) conducted seminal works on the definition of distinct degrees of innovation. Cooper (2001), in turn, introduced a widely known reference model for the innovation process for both research and practice, the stage-gate. Moreover, authors such as Khurana and Rosenthal (1997) and Koen et al. (2001) focused on the definition of the activities of the early phases of the innovation process while others like Pahl et al. (2007) and Ulrich and Eppinger (2008) focused on later development stages. Further authors concentrated on studying the characteristics of the innovation process in practice (Brem & Voigt, 2009; Tidd et al., 2005). All of these and more are discussed in the next sections.

2.1.1 DEFINITION OF INNOVATION

Extensive research and increasing popularisation of day-to-day use of the term 'innovation' led to a plethora of definitions. This also resulted in a broad range of disciplines dealing with innovation research besides engineering and management science, including, but not limited to, economics, sociology, psychology and geography (Tidd et al., 2005). These distinct disciplines have adopted a variety of definitions that led to a degree of ambiguity in the way the term innovation is used in the scientific literature.

Within the scope of the technology and innovation management literature, innovation can be defined as an outcome and as a process. Innovation as an outcome is always preceded by innovation as a process. For this, Henttonen et al. (2016); Lopez-Valeiras, Gonzalez-Sanchez, & Gomez-Conde, (2016) argue that the Oslo Manual created by the OECD for collecting and interpreting innovation data captures the definitions that are most commonly used for innovation as an outcome. According to the Oslo Manual (OECD, 2005), innovation can be defined as:

- Product innovation refers to the introduction of new goods or/and services or significant improvements over its characteristics or intended uses, including substantial improvements in technical specifications, components and materials, incorporated software, user-friendliness or other functional characteristics.
- Process innovation corresponds to the significant changes in the methods of production or delivery methods of the goods or services.
- Organisational innovation involves the use of new organisational methods, which can lead to changes in business practices, workplace organisation, or the company's external relations.
- Marketing innovation involves the implementation of new marketing methods, which may involve significant changes in product design or packaging, product placement, product promotion or pricing.

Innovation in products and processes has been a familiar topic in past research, as those types of innovation are recognised as significant contributors to companies' competitive advantage and capability to innovate, especially to manufacturing companies (Tidd et al., 2005). In particular, product innovation can assume not only the form of a physical product but also a product-service system (PSS), where the material component is inseparable from the service, which enables new streams of revenue and a lower environmental impact than the products and services offered separately (T. S. Baines et al., 2007; Manzini & Vezzoli, 2003).

Recent studies also embrace innovation in the company's business model. In general, a business model refers to the rationale of how a company creates, captures and delivers value to customers (Osterwalder & Pigneur, 2005). In this sense, innovations can be developed in the strategy, marketing, supply chains, value creation, pricing or cost structures (Stindt et al., 2017). Business model innovation, in the end, inevitably results in one of the four types of innovation, product, process, organisational or marketing⁷ (Barquet, 2015).

Another line of research defining innovation revolves around the degree of novelty of an innovation, designated as innovativeness. Innovativeness is defined as the degree of 'newness' of an innovation. According to Garcia and Calantone (2002), this concept builds upon the idea of a continuum that begins with a highly innovative product at one extreme and ends up with a barely innovative product at the opposite extreme. To identify this degree of

⁷Marketing innovation is beyond the scope of this thesis, as it falls out of the domain adopted in this research.

newness, most studies adopt the perspective of the originating organisation, looking at the innovation to understand whether it is new to the world, new to the industry, new to the market in which the company acts (Verganti, 2008).

Several authors follow the Garcia and Calantone (2002) typology to classify innovation according to their degree of innovation or innovativeness (e.g., Kahn, Barczak, Nicholas, Ledwith, & Perks, 2012; Oliveira, Phaal, Probert, Cunha, & Rozenfeld, 2011; Verganti, 2008):

- Radical: reflects changes in both the structure of the market and the existing technology. It refers to changes that cause a discontinuity in a world, industry or market level that will automatically result in discontinuity on the company and the customer experience. It is also called 'breakthrough' innovation.
- Really new: includes either introducing new technologies into existing markets, i.e., new product lines or additions to existing ones, or using existing technologies into new markets.
- Incremental: incorporates new features, benefits, or improvements to existing technology in the existing market, not resulting in discontinuities in either the market or the technology, but rather only within the company.

The definition of innovation as an outcome should answer the questions 'what' or 'what kind' (Crossan & Apaydin, 2010). Although the distinction between innovation as a process and as an outcome is sometimes blurred, definitions on innovation as a process should answer the question 'how', as discussed next (Cooper, 2006; Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008).

2.1.2 THE INNOVATION PROCESS

Innovation as a process refers to the development and implementation of a successfully commercialised new idea. It consists of an iterative chain of activities and events, some of which are sequential, while others are concurrent (Cooper, 2006; Crawford & Di Benedetto, 2011). Innovation processes may differ to some degree across organisations, and within organisations on a project-to-project basis (Adams et al., 2006; Hart, Hultink, Tzokas, & Commandeur, 2003), as unpredictable events and external triggers may occur and influence the process (Loch & Tapper, 2002).

One approach to reducing uncertainties and guiding the flow of information in the development consists of following a process which indicates what needs to be done and

suggests the best way to conduct these activities (Amaral & Rozenfeld, 2007; Cooper, 2001; Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008; Wheelwright & Clark, 1992). Boeddrich (2004) voices the concerns of several researchers by arguing that the lack of a methodology, systematic or structured procedures for performing the innovation process can cause a series of negative effects for a company. To name a few:

- Absence of a common language among employees, from distinct areas/departments, business units, suppliers, to address the innovation activities and deliverables,
- Deficiency in the planning for innovation with *ad hoc* or late definitions, leading to missed opportunities;
- Waste of time and resources as ideas that offer no prospect of success continue to be discussed for a long time;
- Lack of transparency in the new projects' decisions, e.g., in the selection of new ideas for the portfolio, or continuity of ongoing projects ('go/kill' decisions), and
- Absence of a learning process seeking to accumulate knowledge and lessons learned to implement improvements.

Hence, to increase the chances of a company succeed in the innovation process, several authors started studying benchmarks (Cooper, 2006; Crawford & Di Benedetto, 2011). Building on these studies, reference models for the innovation process synthesising activities to be performed and tools and techniques to support those activities become a common research practice (Cooper, 2001; Crawford & Di Benedetto, 2011; Khurana & Rosenthal, 1997; Koen et al., 2001; Pahl et al., 2007; Wheelwright & Clark, 1992).

Cooper, one of the most-cited authors in innovation research, highlights the importance of following a formal process to sustain good innovation performance and overcome the adverse effects emerging from the innovation process (Dubiel, Durmusoglu, & Gloeckner, 2016; Tidd et al., 2005). Accordingly, in the next sections, the main reference models are presented and compared to define a 'meta' description of the innovation process phases. In addition, the characteristics of the innovation are also studied so that when the development of the PF starts, these characteristics can be compiled and ensure a methodological fit between the participating companies and the application of the PF.

2.1.2.1 MAIN REFERENCE MODELS FOR THE INNOVATION PROCESS

The literature review on technology and innovation management reveals a variety of reference models for the innovation process. Due to a large number of models; for instance, 19 models were found for manufacturing companies by Amigo (2013), this review selected the leading models in terms of relevance and impact.

The relevance can be indicated by the level of details provided by the authors whereas the impact can be based on the number of citations, as adopted in previous reviews. For consistency, the same approach has been used here. In this way, the level of details refers to the existence of a representation of the process and a description of main activities, and the level of impact is informed by the number of citations.⁸ However, it can be noted that newer publications which have not had as much time to accumulate citations may temporarily be at a disadvantage. The models are synthesised chronologically, as follows.

Wheelwright & Clark (1992)

These authors were the first to propose the innovation funnel in the literature. The model illustrates many ideas conforming to a large entry and a funnelling process that progressively selects projects instead of merely tunnelling them through phases (Figure 2.2). Note that from the moment the funnel model was introduced, graphical representations of the innovation process become tools to convey key information in a visually simple way.

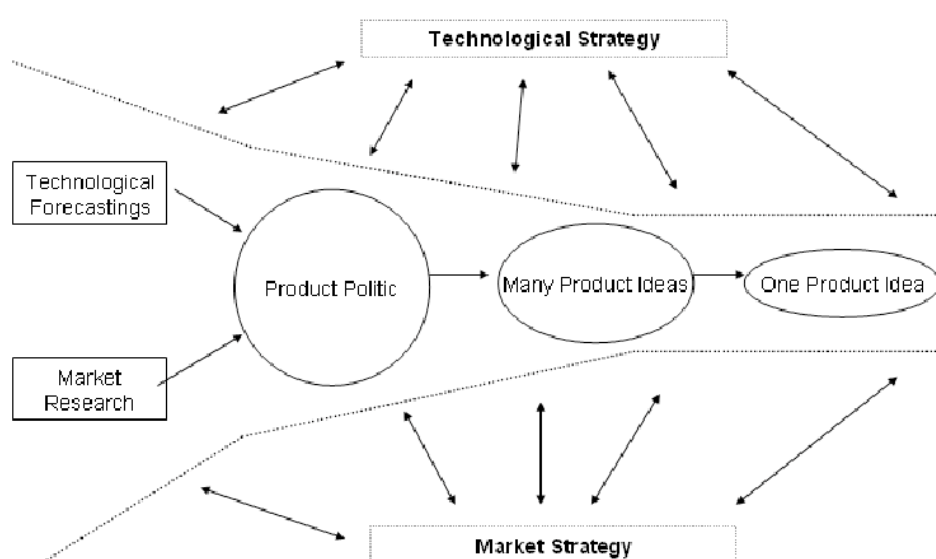


Figure 2.2. The innovation process according to Wheelwright & Clark (1992).

⁸Criteria adopted in other literature reviews (Amigo, 2013; Pigosso, 2012) with high impact models constantly cited by other authors (above 200 citations), medium/low impact (cited less), considering the Web of Science database.

Wheelwright and Clark (1992) focused on the auto industry to develop this model. First, technological forecasting and market research inform the generation of ideas. Then, technological and market strategies align business objectives and define the new product objectives that must be achieved in development (product 'politic'). These strategic definitions provide the integration between the aggregated planning of projects (the portfolio of projects) and the projects individually. Usually, objectives and goals would arise from the assessment of the market, competitor analysis, financial analysis and the timing of the application of new technologies in the product platforms.

In the activities of the innovation funnel, the aim is to ensure that characteristics of the project portfolio will cover the product objectives defined previously and guarantee the organisational competencies necessary to obtain success in the development of the projects. By determining the scope of the project and planning the changes required to develop the organisational competencies to meet the project requirements, the product 'leaves' the funnel and enters the design and production phases, following the standard procedures in place to guarantee product quality.

Khurana & Rosenthal (1997)

Khurana and Rosenthal (1997) were pioneers in directly addressing the initial activities of the innovation process, known now as the innovation front-end (IFE). The authors established a clear separation between these early phases and the rest of the innovation process, indicating its importance for the success of the process.

The model, illustrated in Figure 2.3, divides the early activities into two types. The first encompasses the 'foundation' elements that support the proper functioning of the process in the early activities. These elements are characterised by both the strategy (for portfolio and product) and the organisation foundation in place for supporting the innovation process (structure, roles, incentives and norms). The second type involves the project-specific activities: identification of opportunities, definition of the product concept, definition of project scope and project planning.

According to the authors, companies normally begin work when they first recognise, in a 'semiformal' way, an opportunity (pre-phase zero). If this newly defined opportunity is worth exploring, the company assigns a small team to work together on the product concept and definition (phase zero).

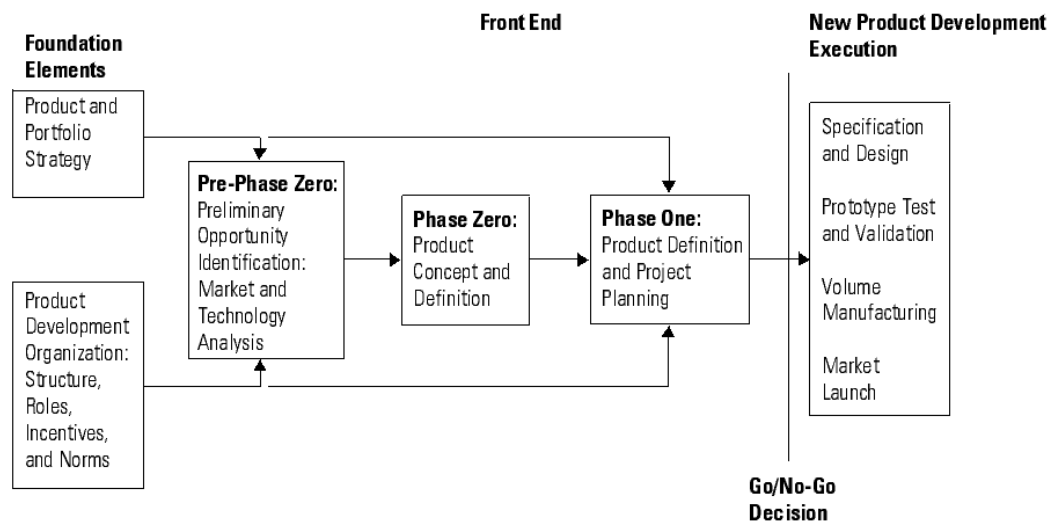


Figure 2.3. The innovation process according to Khurana & Rosenthal (1997).

Then, in phase one, the company assesses the business case and technical feasibility of the new product, confirms the project scope, and plans out the project. Thus, the development team identifies the business rationale for its development to proceed. The front-end is complete at this phase when the team is able to present the business case, and the decision-makers either commit to funding, staffing, to go ahead or kill the project. The subsequent phases of the new product development execution are not fully explored in this reference model, so this review turns to the next model.

Cooper (2001)

The stage-gate model for the innovation process proposed by Cooper (2001) has not only a large number of citations in the literature but also a broad application in the manufacturing industry (Amigo, 2013).⁹ This model is mainly characterised by clearly defined phases composed of a set of best practices necessary for the project's progress to the next decision point, known as gates, where the decisions of go or kill the projects are taken. Decision gates became highly popular in other models after the stage-gate because of its widespread adoption of this model in the industry (Tingström, Swanström, & Karlsson, 2006).

Figure 2.4 illustrates the Cooper model with five phases, followed by the decision gates. The early phases of the front-end are formed by discovery, stage 1 and stage 2. Discovery aims to search for opportunities and generate ideas. Then, these ideas are selected in a first screen

⁹Although the model reference cited here is from 2001, the model was proposed in the mid-80s. (Cooper, 2001) is cited because it is the best-known version of the model.

in gate 1. The selected ideas are then further complemented with information available at this time. Again, these ideas are screened, and the ones selected to move on to the next stage. In stage 2, the business case is created based on credible assumptions and the main financial indicators are calculated. Then, with the third gate (go to development), the company commits to funding and staffing to develop these ideas.

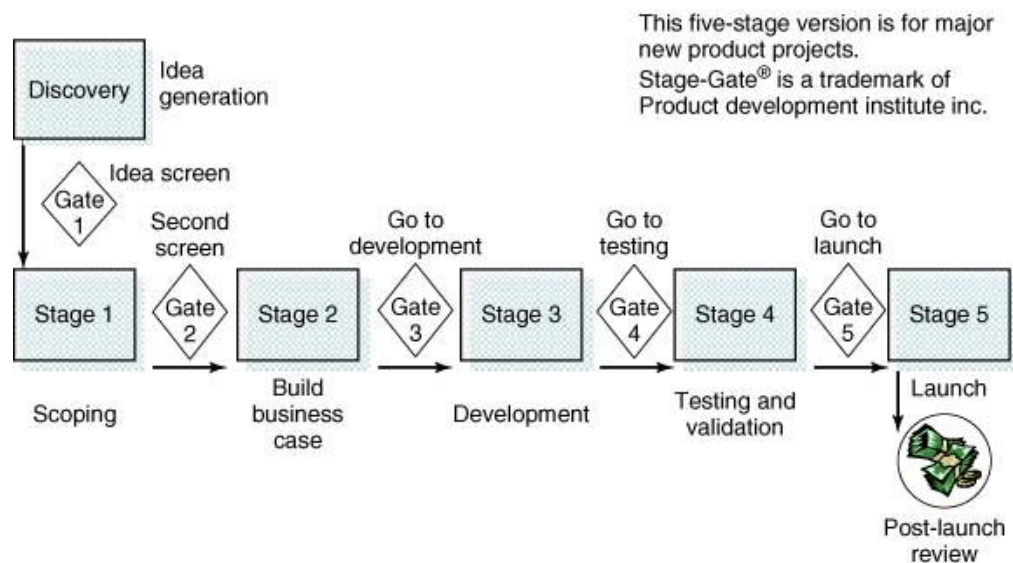


Figure 2.4. Innovation process according to Cooper (2001).

Stage 3, development, seeks to define the requirements of the product and develop them until the point where prototypes can be produced. Production processes are then assessed to verify if they have the capability to deliver and meet the product requirements. Modification in the production lines may begin at this point. At the same time, the marketing plan begins to be designed. Following this, stage 4 involves testing not only in the production lines but also in the marketplace. Based on the testing, the company should be able to decide to go ahead or kill the project. Finally, stage 5 is the stage in which the product is launched, when the production and marketing plans are implemented.

This model represents one of the first times that the literature explicitly addresses testing with the user in a reference model for the innovation process (Amigo, 2013). The process continues with post-launch reviews to verify if the product is meeting the expected results. At this point, it is important to note that the adoption of this model in practice entails its customisation to the company setting, meaning that, typically, the company can expand or suppress phases according to their own context.

Koen et al. (2001)

The reference model by Koen et al. (2001) is the result of a study carried out jointly by a research institute and industry, aiming to consolidate a compilation of best practices that should guide each phase of the innovation process.

The resulting model is presented in Figure 2.5. It is not a typical representation of the innovation process. The model is composed of two main parts, the engine formed by the internal area and the five elements, and the influencing factors. First, the core of the engine comprises the organisation's leadership, culture and business strategy, which are responsible for driving the five internal elements that are controllable by the company. These five elements of the engine correspond to opportunity identification, opportunity analysis, idea genesis (generation and enrichment), idea selection and concept definition, which are usually designated as phases of the innovation process in other models.

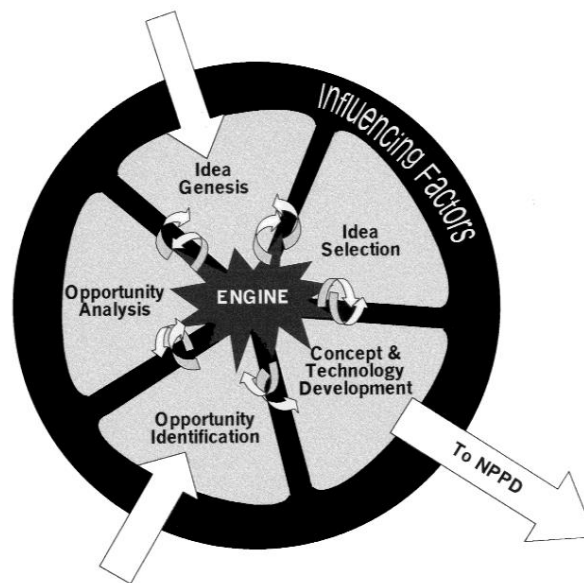


Figure 2.5. The innovation process according to Koen et al. (2001).

This reference model seeks to provide a common language and perspectives for innovation activities carried out by different companies. Their focus is specifically in the front-end as it appears to represent the greatest area of weakness in the innovation process at the time it was proposed. Bringing more clarity and rationality to the front-end means helps companies better articulate concepts and manage front-end activities. This model distinction from others is the way it is presented, that is, in a circular format, suggesting that ideas should flow, circulate and interact between and along the five elements (the phases – opportunity identification, opportunity analysis and so on) controllable by the company.

Pahl and Beitz

The innovation process proposed by Pahl et al. (2007) is represented in Figure 2.6. This model is deeply rooted in the engineering disciplines. It is viewed as one of the standard references for engineering design in general (Adams 2015), as it has been part of many technical universities' engineering curricula. It describes the innovation process as a sequence of four phases: task clarification, conceptual design, embodiment design, and detail design.

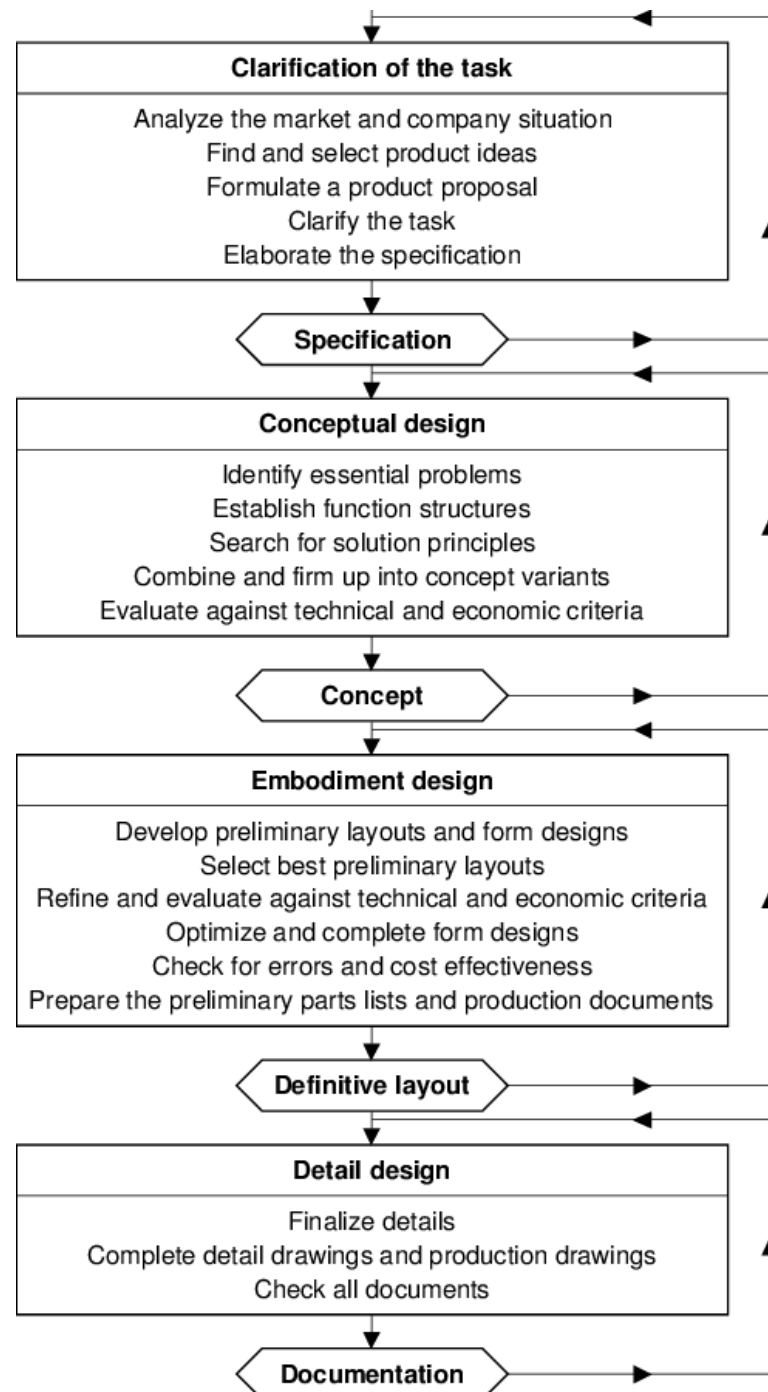


Figure 2.6. The innovation process according to Pahl et al. (2007).

This model is one of the most technically detailed ones for the innovation process. It is also widely referenced in the literature alongside Cooper's stage-gate. The authors built this model based on their experience and observations of engineers and designers' professional practice. It was first published in German in 1977 and enriched throughout the years of studies and revisions. The model has had a significant influence on the development of other models as well as guidelines and further models, including the design guideline VDI-2221 (Amaral & Rozenfeld, 2007).

The first phase, clarification, is concerned with collecting and documenting the requirements of the product to be designed. Having specified the initial requirements, the conceptual design begins, aiming to identify the basic principles of the concept must perform. Then, embodiment design focuses on orchestrating the design of the concept based on the basic principles defined, following the specified technical and financial criteria. This design is further detailed into systems, subsystems and components until all specifications and preparations are ready for production. Each of these four phases comprises a sequence of activities that may be executed iteratively and result in an extensive documentation. After every phase, a design revision is performed to assess the results and to decide whether some subsequent activities can be started or more work needs to be done.

Interestingly, Pahl et al. (2007) introduced activities to cover the monitoring of the product performance in the market in their latest version of the model, aiming to identify opportunities for improvement and ensure that the product disposal processes have the least possible impact on the society and the environment (these activities are not represented in Figure 2.6, only in their discussion).

Crawford & Di Benedetto (2011)

Crawford & Di Benedetto (2011) built upon learnings from previous models' and their own research to propose the phased process model shown in Figure 2.7. Despite not being portrayed in the figure, this model instructs, besides the phases composed of a set of best practices, periodic evaluations all the way through the process to hold go/kill decisions.

This model recognises that a company may have access to several ideas in phase 1, aiming to identify opportunities and then preliminarily select ideas. Weaker ideas are almost immediately eliminated based on a specified range of evaluation criteria, and the better ones are refined into concepts in phase 2 with more information. With the concepts refined with

more information from concept testing and customer feedback in phase 3, only the best are approved via business cases and impact analysis and moved forward to development.

During phase 4, the product design is continuously detailed and refined with prototyping and testing. Organisational competencies, necessary to obtain success in the development of projects, are also further developed. Nevertheless, projects could still be halted before the launch phase if testing results demand more exploration or there are significant changes in the external environment. With the 'go' decision, marketing tasks that target post-launch promotion are triggered. So, by the time the product is launched (phase 5), it has a much higher likelihood of succeeding.

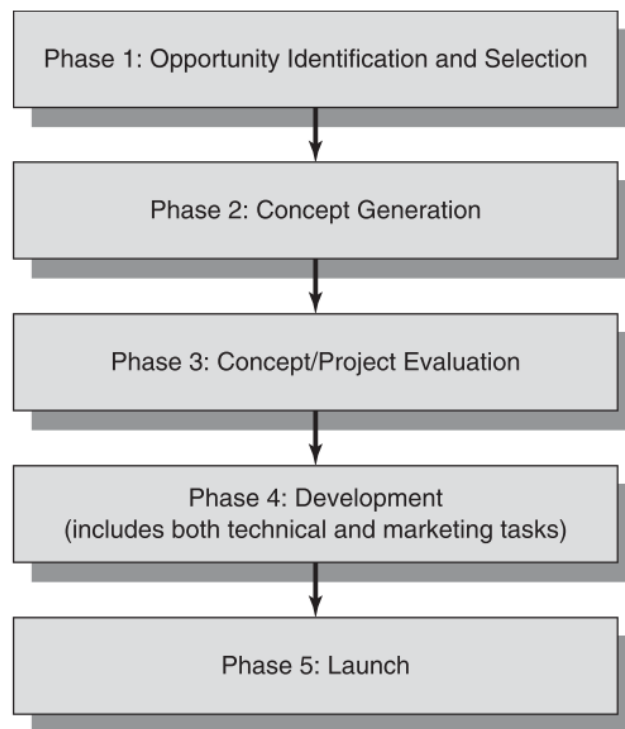


Figure 2.7. Innovation process, according to Crawford & Di Benedetto (2011).

A noteworthy observation in this model that should be emphasised here is that these authors explicitly call out that the neat, linear sequencing of phases shown in Figure 2.7 is not the real case (Crawford & Di Benedetto, 2011, p.20). The authors highlight that, in reality, the activities are not sequential but overlapping, with multiple iterations. This observation is sometimes overlooked by readers and researchers when discussing this and other models. Therefore, like this one, most current models do not prescribe that one phase must be completed before work can begin on the next one, like a 'pass-the-baton relay race'.

2.1.2.2 ANALYSIS OF INNOVATION PROCESS REFERENCE MODELS

The review of reference models demonstrates that the process of innovation has been portrayed as a linear sequence of activities divided into phases, where efforts and resources are channelled at one end from which a new product emerges (see models from Cooper, 2001; Khurana & Rosenthal, 1997; Pahl et al., 2007; Wheelwright & Clark, 1992).

From a managerial perspective, it is no longer sufficient to treat innovation as a linear process. In this sense, some authors acknowledge this limitation and already proposed distinct approaches with concurrent activities and multiple iterations, as exemplified in the previous section (see models from Crawford & Di Benedetto, 2011; Koen et al., 2001). Therefore, the process is not seen as only a 'waterfall' sequence of phases anymore, where there is breakdown into linear sequential phases, that relies on the work of a previous phase being complete before proceeding to the next one, but an integrated and cyclical process composed of activities within stages/phases and decision gates (Kress & Schar, 2012; Schuh, Rozenfeld, Assmus, & Zancul, 2008).

One of the main contributions of these influential work on reference models is establishing a process-based approach to managing the innovation process. This process-based view is built on commonalities that suggest five clusters of phases shared among the models, as shown in Table 2.1. These phases can be defined as 1) planning of innovation, 2) development of technology to be applied in the new product or processes, 3) detailed development of new products, 4) market monitoring and launch and 5) end-of-life processes (more recently). Other authors have reached similar conclusions about these common phases (e.g., Guelere Filho, Pigosso, & Rozenfeld, 2009; Schuh et al., 2008).

On a closer look, other contributions can be highlighted within those typical phases to deal with the innovation process. For instance, Wheelwright & Clark (1992) started the innovation funnel to address the progression of the process as decisions and commitments are made, particularly used to address the planning of innovation, with considerations about the technological forecasting and market research. Khurana & Rosenthal (1997) also contributed to the technology and innovation management literature by introducing the discussion of innovation planning in the front-end and what that implied in terms of activities for the innovation process.

LITERATURE REVIEW

Table 2.1. Clustering of common phases of the leading innovation process models.

Reference models	Planning innovation	Technology development	Product Development	Market and launch	End-of-life
(Wheelwright & Clark, 1992)	- Technology forecasting and market assessment - Development goals and targets - Aggregate project plan		- Project management and execution	- Post-project reviews	
(Khurana & Rosenthal, 1997)	- Preliminary opportunity identification - Product and concept definition - Product definition and project planning		- New product development execution - (Specification and design) - (Prototype test and validation) - (Volume manufacturing)	- Market launch	
(Cooper, 2001)	- Discovery - Idea screen - Preliminary investigation - Second screen - Build the business case - Go to development	- Scope definition - Technical - Evaluation - Detailed investigation	- Development - Test and validation	- Launch - Implementation of marketing plans - Post-launch project review	
(Koen et al., 2001)	- Opportunity identification - Opportunity analysis - Idea generation - Idea selection - Concept definition (product and technology)	- Technology development	- Product development		
(Pahl et al., 2007)	-Product planning	- Task definition - Conceptual design	- Task definition - Conceptual design - Preliminary design - Detailed design (Production/test)	- (Marketing/sales) - (Use/consumption /maintenance)	- (Recover energy - Recycling) - (Disposal/ Environment)
(Crawford & Di Benedetto, 2011)	- Identification and selection of product opportunities - Concept generation - Concept evaluation	- Concept generation - Concept evaluation	- Development - Preparation for production	- Launch -Implementation of marketing plans	- Life cycle concerns

Another contribution worth mentioning is the cyclical representation of the innovation process by Koen et al. (2001) that focuses on the front-end activities. Cooper (2001), on the other hand, contributed to the dissemination of best practices for the phases across the innovation and decision gates for continuous evaluation of projects. Furthermore, Pahl et al. (2007) focused on disseminating best practices on the later phases of the innovation process based on an engineering tradition of manufacturing products. They also introduced environmental concerns, mainly referring to recovering energy and recycling and final disposal of the products.

As previously mentioned, the purpose of following an innovation process approach is to manage down the amount of risk and uncertainty as one goes from idea generation to launch. A company may have access to hundreds of ideas. Thus, the reasoning behind establishing the innovation process is that weaker ones are eliminated, and the better ones are refined into concepts. Later in the process, only the best concepts are approved and moved forward to the development phase. Then the product or PSS is continuously refined during the development phase. By the time the product is launched, it has a much higher chance of succeeding in the market (Crawford & Di Benedetto, 2011).

2.1.3 DEFINITION OF THE INNOVATION PROCESS PHASES

Based on the review of the innovation process, this work adopts the definition of the innovation process as represented in Figure 2.8. The phases are illustrated in a cyclical representation in order to emphasise the multiple rounds of iteration that may occur during the innovation process, as activities may be performed concurrently or sequentially. Additionally, decision gates should take place in-between the phases to evaluate the deliverables and assess the projects' continuity as new information emerges from the market research and technological forecasting.

The first phase of the process is the innovation front-end (IFE) that typically involves identifying opportunities, generating ideas, creating and screening concepts, and, ultimately, defining the scope of potential projects. Once resources and funding are initially committed to the project, depending on the project's scope, the process can progress to either technology development or product development, if the required technologies or processes are mature enough to do so (Cooper, 2001; Crawford & Di Benedetto, 2011; Khurana & Rosenthal, 1997; Koen et al., 2001; Pahl et al., 2007; Wheelwright & Clark, 1992).

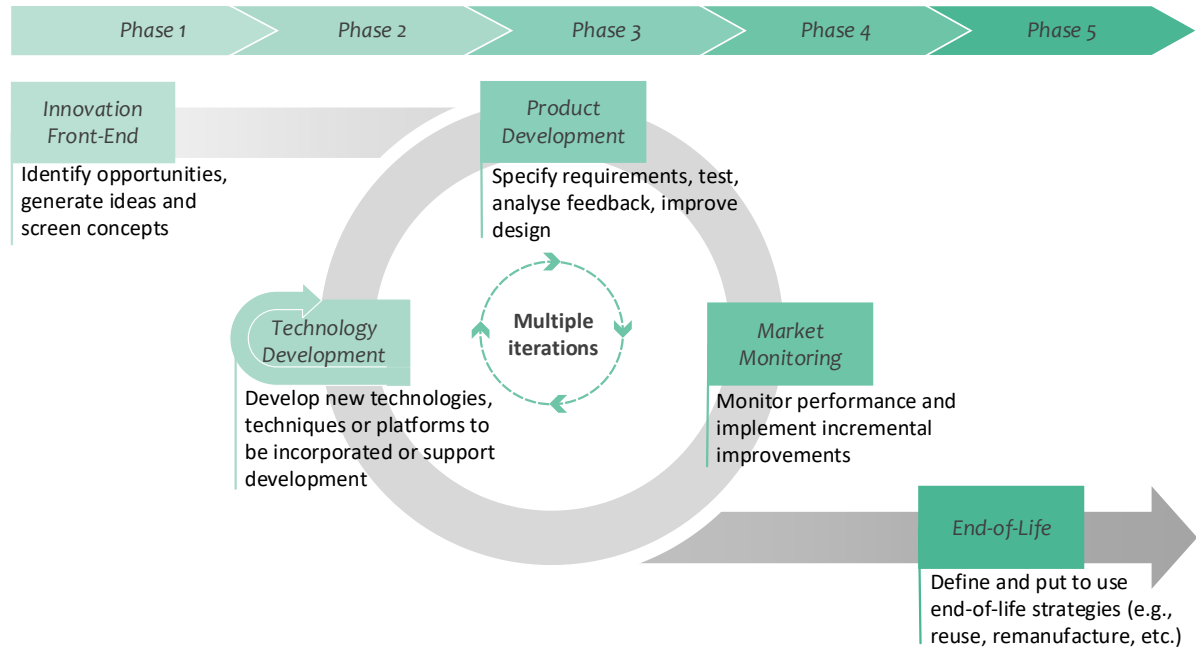


Figure 2.8. The innovation process defined in this work.

The technology development takes place when research is needed to develop a new technology prior to its commercial development, to be incorporated into the product/PSS or processes (Cooper, 2001; Crawford & Di Benedetto, 2011; Koen et al., 2001; Pahl et al., 2007). It is almost as another innovation funnel with cycles on its own that feeds the innovation process. Following this, the development phase starts by cycles of defining and refining the requirements, designing the solution, testing and analysing the data which can result on new design cycles or the preparation of production (Cooper, 2001; Crawford & Di Benedetto, 2011; Khurana & Rosenthal, 1997; Koen et al., 2001; Pahl et al., 2007; Wheelwright & Clark, 1992).

With the launch of the product/PSS, the monitoring phase begins. In this phase, the market is monitored in order to not only to provide the necessary maintenance, repairing services but also to identify opportunities for improvement. Finally, depending on the company's strategy and the regulations in force, the end-of-life phase can begin in order to manage the handling of the final disposal or other alternatives to deal with the environmental burden of the products/PSSs (Crawford & Di Benedetto, 2011; Pahl et al., 2007).

In the following sections, each of these five phases are described with more detail, aiming to clarify the activities carried out and the typical decisions made during the phases. It is important to note that the phases may be illustrated linearly in representation just for clarity purposes; however, their descriptions acknowledge the cyclical and iterative nature of the innovation process.

2.1.3.1 INNOVATION FRONT-END

The IFE refers to the phase of innovation planning and is also called by other names, such as pre-development, or the commonly used fuzzy front-end. This work follows Koen et al. (2001) suggestion to use 'innovation' instead of 'fuzzy' to characterise the front-end. They argue that fuzzy implies that this phase is unknowable, and this may result in a lack of accountability and a notion that the front-end can never be managed, which is not what the evidence suggests (Crawford & Di Benedetto, 2011; Khurana & Rosenthal, 1997; Koen et al., 2001).

This phase encompasses any activity or decision made before a more structured phase of development begins. In other words, the moment that defines the transition between the IFE and further development phases is the definition of the project scope and the commitment to allocate resources to implement the project. In practice, some activities of IFE can overlap with the beginning of the development phases, since the moment for scope definition can vary depending on the types of project and the company's policies (Khurana & Rosenthal, 1997; Koen et al., 2001; Nobelius & Trygg, 2002; Oliveira et al., 2011).

Studies indicate that the IFE activities are most troublesome in the innovation process due to its inherent uncertain and ambiguous nature (Khurana & Rosenthal, 1997; Koen et al., 2001; Nobelius & Trygg, 2002; Oliveira et al., 2011). At the same time, the IFE is considered one of the most significant opportunities to improve the degree of innovativeness of the future product/PSS. Customarily, the overall concept the main characteristics of the future product/PSS is defined in the front-end, which will strongly influence the subsequent development activities and the necessary investments (Cooper & Edgett, 2008; Markham, Ward, Aiman-Smith, & Kingon, 2010; Verganti, 1997; Zhang & Doll, 2001).

Much progress has been achieved through research to provide a better understanding of the IFE terminology, activities, and characteristics (Oliveira et al., 2011). According to the literature review performed so far, Figure 2.9 illustrates IFE inputs, core activities and outputs for this work. First, the inputs are represented by the company's innovation goals and any initial ideas that they might have captured. The innovation goals could be more high-level, offering guidance in terms of the target market/product arenas, or more assertive by defining the goals for new products/PSS. Ideas, in turn, represent any type of thought of action from people within or outside the organisation which may bring innovations (Crawford & Di Benedetto, 2011; Oliveira et al., 2011; Pahl et al., 2007; Wheelwright & Clark, 1992).

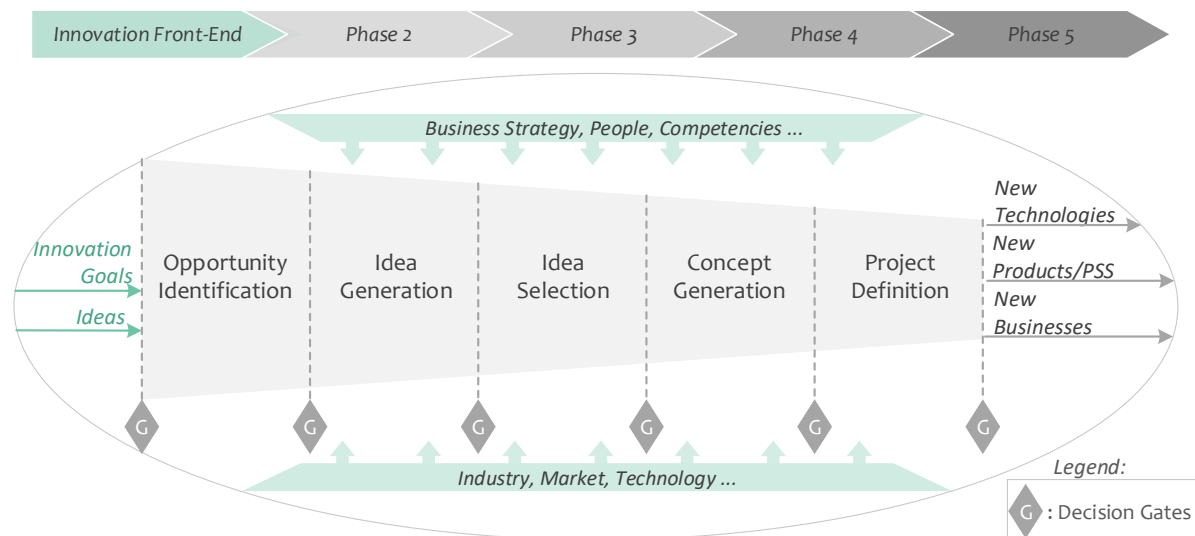


Figure 2.9. Characterisation of the innovation front-end (IFE) phase.

The IFE begins with opportunity identification. The opportunity can be defined as a market or technology gap capable of conferring competitiveness and improving business performance. With the opportunity identified, the company starts generating ideas to address the market or technology gap with the support of creativity methods and tools. Ideas generated are then screened based on criteria deployed from the company's strategy. With the most interesting ideas selected, the concept development can begin. The concept definition refers to a written or visual description of a product/PSS idea in terms of its primary technical features, customer benefits and required technology. Following this, an initial business case is typically defined with market and financial analyses to support the decision of continuing the project (Cagan & Vogel, 2008; Cooper, 2006; Khurana & Rosenthal, 1997; Koen et al., 2001; Nobelius & Trygg, 2002).

It is essential to highlight that the IFE activities must be aligned with the business strategy, people, and internal competencies to ensure an uninterrupted and smooth flowing pipeline of new products/PSS ideas into the organisation. Coherent strategic plans not only facilitate the planning activities but also help in maintaining corporate identity and consistency across the product portfolio. Sometimes, however, strategic planning can also impose unnecessary constraints in the IFE, especially related to financial targets. In this way, it is essential to find a balance between overall strategic direction and responsiveness to changing the surrounding environment (e.g. industry, market, technology) (Cooper, 2006; Khurana & Rosenthal, 1997).

The outputs of the IFE include the proposition of concepts for new technologies, products/PSS or even new businesses. The differences between them reside on the need to integrate technology or business development to enable the design of innovations (Cooper, 2001; Khurana & Rosenthal, 1997; Koen et al., 2001). These outputs, often in the form of project scope or charter (associated with a business plan), can enter either the technology development phase and then following development phases, or directly the development phases. Alternatively, the outputs can be further studied to gather more information or create alliances/partnerships (for new businesses) (Oliveira et al., 2011).

2.1.3.2 TECHNOLOGY DEVELOPMENT

The purpose of the technology development (TD) phase is to provide technological solutions when new technology or techniques need to be properly researched, developed, and assessed in order to be incorporated into new product/PSS or related processes. The need for these technological solutions can emerge from many distinct sources. Most of the time, the trigger originates from the IFE strategic planning, technology forecasting or roadmapping or competitor analysis. Less frequently, the trigger may come as product development requirements, which is highly associated with improvements in the production process (Cooper, 2006; Eldred & McGrath, 1997; Sheasley, 1999). However, it was recently demonstrated that this trigger could also originate from outside the company via partnerships with research institutions and other third parties (Zobel, 2017).

There are three macro activities involved in TD: project scoping, technical assessment and detailed investigation. Thus, based on the learnings from the literature review, Figure 2.10 illustrates the activities identified for the TD phase for this work, applying the concept of innovation funnel in the same manner as the IFE. The first main activity is the project scoping, in which the foundation for the research project is established with the definition of the scope and planning of the project. The activities may include technical literature search, patent and intellectual property (IP) search, competitive alternatives assessment, and analysis of current competencies within the company and gap identification (Cooper, 2006; Eldred & McGrath, 1997; Sheasley, 1999).

The next macro activity consists of the initial analysis to demonstrate the project's technical or laboratory feasibility under defined circumstances. A more detailed view reveals the activities of: conceptually analysing the technology, conducting initial feasibility

experiments, developing partnership networks for the needed competencies, identifying resources, and assessing the potential impact of the technology/technique on the company performance (Cooper, 2006; Eldred & Mcgrath, 1997; Sheasley, 1999).

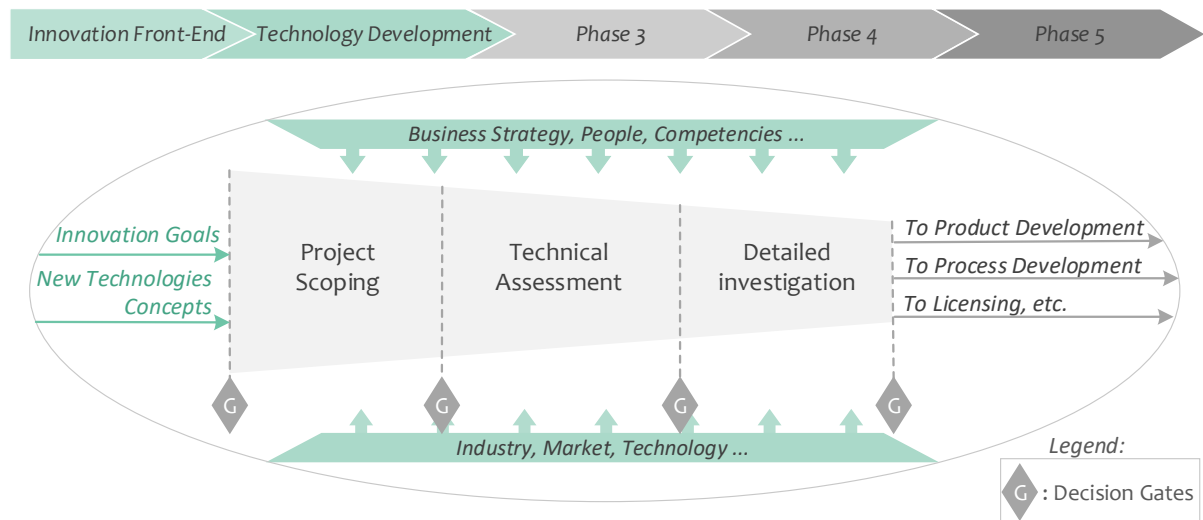


Figure 2.10. Characterisation of the technology development (TD) phase.

Finally, the detailed investigation of the technology begins with the implementation of the full experimental plan to prove technological feasibility. This detailed investigation could entail significant expenditure and years of work. It involves extensive technical work, defining commercial product/PSS or process possibilities, and performing all kinds of analysis. At this point, project management techniques and tools are critical (Cooper, 2006; Eldred & Mcgrath, 1997; Sheasley, 1999). The results of this investigation inform the decision to 'go/kill' the project. Depending on the technology value for the company and the established innovation goals, the decision can proceed to development or other options (joint-venture, licensing – outside the scope of this research). A final decision gate for this phase would be typically combined with an early gate in the development phase, which is discussed next.

2.1.3.3 PRODUCT DEVELOPMENT

Product development (PD) phases can be defined as a systematic set of activities involved in generating the design specifications of a product/PSS concept and its manufacturing processes in order to provide the organisation with the capability required to produce it. This set of activities unfolds based on the company's innovation strategies, market research, technological forecasting and definitions made in the previous phases (from the IFE and/or TD phase) and constraints in place (Cooper, 2001).

PD is when the product acquires form, that being a tangible good or a specific sequence of resources and activities that will perform an intangible service, or even a combination of both, to originate a PSS, increasingly more common these days (Barquet, 2015). The macro activities of the development can be visualised in Figure 2.11. Note that even though each company may employ an arrangement for the PD, there are everyday activities for manufacturing companies that signpost a 'roadmap' to successful products/PSS (Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008). This roadmap can also present different variations of the same activity depending on the type of product/PSS being developed (new to the world, new to the company, or incremental) (Hanson, Melnyk, & Calantone, 2011).

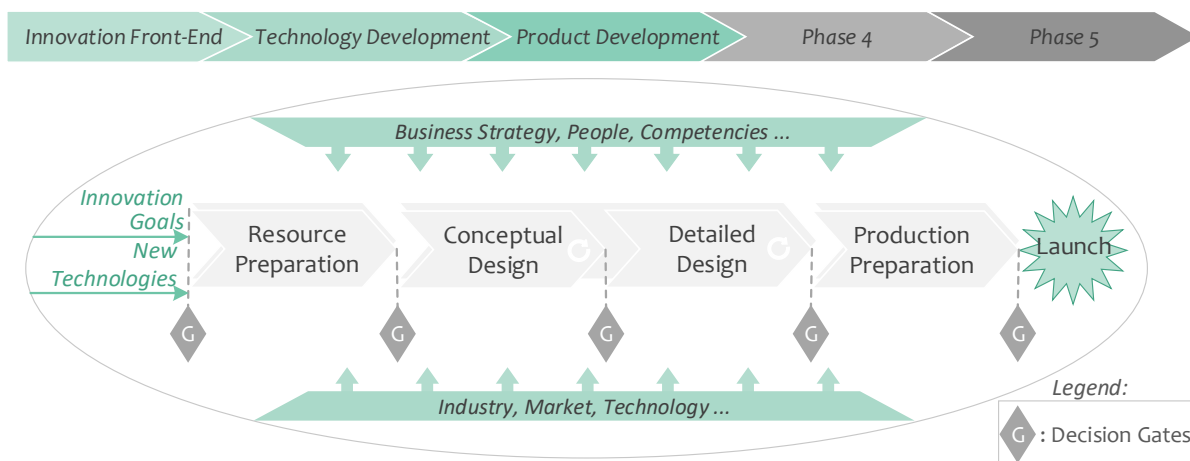


Figure 2.11. Characterisation of product development (PD) phases.

The development phase initially involves resource preparation, especially if the company desires to develop new-to-the-world products/PSSs. Thus, the development team may need specialised training, new design tools, updates in the company's review system, and special permissions make any changes. Then, cycles of technical work start with the definition of the conceptual design,¹⁰ if necessary, and then further design detailing to define, systems, subsystems, and components, which leads to production preparation (Cooper, 2001; Crawford & Di Benedetto, 2011; Pahl et al., 2007).

Along this process, several design evaluations and reviews take place. Prototypes are built and tested to verify technical assumptions and refine user requirements. By the time the development phase winds down, the company need to increase the testing and user feedback

¹⁰Most reference models would have a conceptual design and detail design phases, but other authors advise that sometimes companies would have the design phase, especially after the advent CAD/CAM systems (Pahl et al., 2007).

so that the new product/PSS actually does solve a relevant problem, to begin with. The development completes all the required definitions to produce and launch the new product/PSS (Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008).

The launch can be described as that time when the company decides to market a product/PSS. In the past, this would be the point where most authors would define as the ending of the innovation process (Pahl et al., 2007). Nevertheless, it is not the case anymore. There are further activities that are considered vital and part of the innovation process, aiming to cover the whole the product's life cycle (Guelere Filho et al., 2009), as discussed next.

2.1.3.4 MARKET MONITORING

The market monitoring (MAM) phase aims to ensure a proper follow-up on the performance during the product's use. The purpose is to identify needs or opportunities for improvement in a continuous manner. Thus, this phase aims to track product-related data during its use phase with protocols and reactive or active activities in place in the production, distribution (supply-chain), customer service, technical assistance and more (Funk, Rozinat, & Alves De Medeiros, 2009; Hegde & Konakanchi, 2011; Lau, Hui, Chan, & Wong, 2002).

In the past, most reference models did not include this phase (see Table 2.1 in section 2.1.2.2); however, its importance is growing in light of new sustainability concerns and new regulations (Guelere Filho et al., 2009; Pahl et al., 2007). In order to monitor the product/PSS performance during use, and provide the necessary services this phase presents a long-term horizon, and its activities may originate in adjacent areas to the typical ones responsible for the innovation process (Crawford & Di Benedetto, 2011; Ulrich & Eppinger, 2008). As the scope of this phase may be vast, the representation is simplified in Figure 2.12.

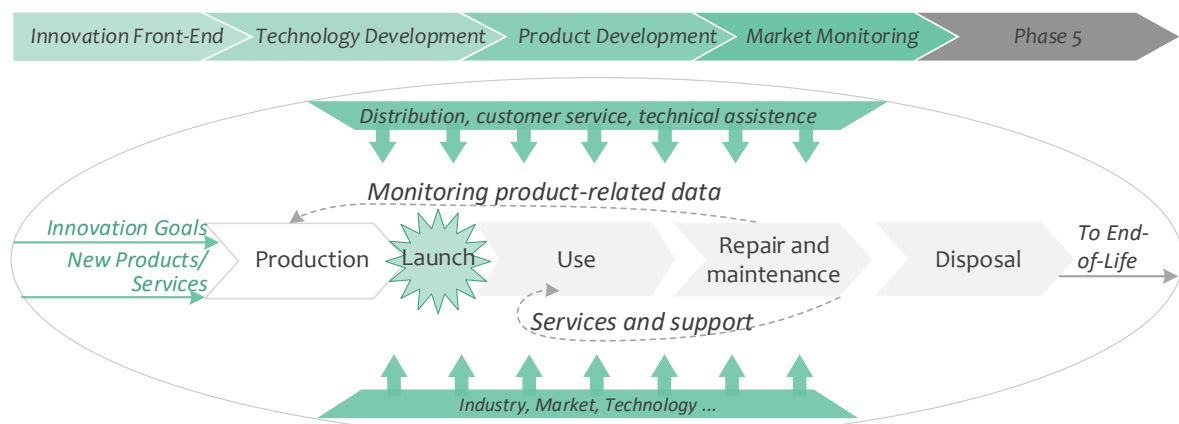


Figure 2.12. Characterisation of the market monitoring (MAM) phase.

2.1.3.5 END-OF-LIFE

The last phase of the innovation process, end-of-life (EoL), deals with closing the loop of the materials and ending the services that may produce environmental impacts during their delivery. Similar to the previous phase, most innovation reference models do not include this phase, as not all companies carry out EoL activities (see Table 2.1 in section 2.1.2.2). Nevertheless, it is increasingly being acknowledged in research and practice to deploy strategies to reduce the environmental burden (Guelere Filho et al., 2009).

This phase involves a set of activities that lead to the selection and execution of the end-of-sale strategies for the company's products/PSS, as illustrated in Figure 2.13. In short, this phase can cover three macro activities: the collection of the physical product or materials (that may include residual waste) by the company or designated carriers, the discontinuity of production and similar affairs, and the completion of the service support for product/PSS (Crawford & Di Benedetto, 2011; Guelere Filho et al., 2009; Pahl et al., 2007).

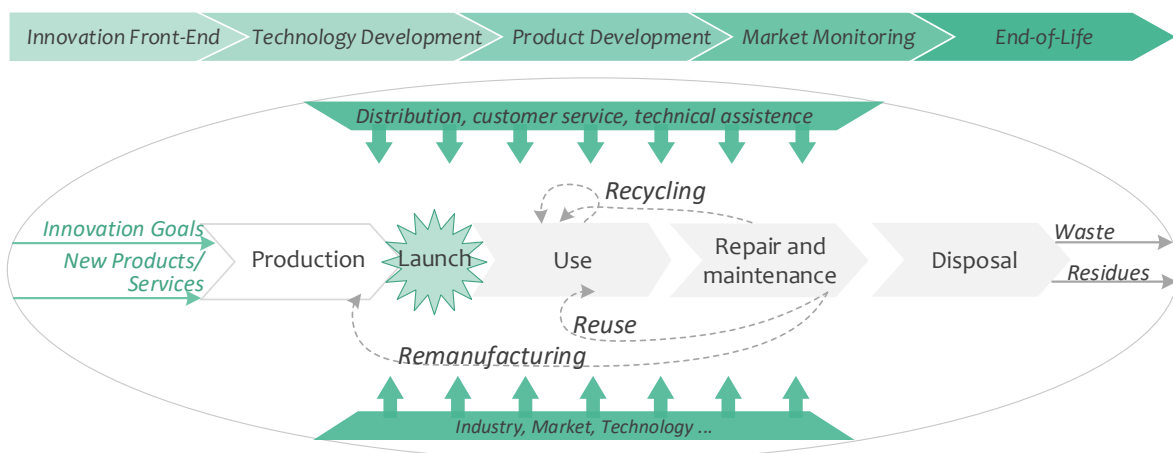


Figure 2.13. Characterisation of end-of-life (EoL) phase.

This final phase can be initiated during the product/PSS use phase, as typical analysis carried out in the MAM phase may trigger end-of-life strategies to start the product disposal, and thereby, some companies perform activities of the MAM and EoL together. For this, prior phases, especially PD, must consider reuse, remanufacturing and recycling as strategies for the products' end-of-life so that this phase can be carried out. The choice of which strategy is best for a company will depend on many factors, such as organisational drivers, internal constraints, regulations and legislation and the product/PSS characteristics (Crawford & Di Benedetto, 2011; Pahl et al., 2007).

2.1.4 CHARACTERISTICS OF THE INNOVATION PROCESS

Innovation as a process refers to the development and implementation of an iterative chain of activities and events, some of which are sequential while others are concurrent, aiming at delivering a successfully commercialised new idea, as discussed previously (Cooper, 2006; Crawford & Di Benedetto, 2011; Koen et al., 2001; Pahl et al., 2007).

Innovation processes may differ to some degree across organisations, and within organisations on a project-to-project basis (Adams et al., 2006; Hart et al., 2003). Because of this, researchers defined common activities in reference models that can be followed to help manage down the amount of risk and uncertainty as one goes from idea generation to launch, as discussed in the previous sections. On a closer look, there is a further discussion on the common elements and what they tell us in terms of major characteristics of the innovation process (Cooper, 2006; Crawford & Di Benedetto, 2011). The main characteristics discussed in the literature are: the level of formalisation, the drivers of the innovation process, the closed and open innovation paradigm, and the surrounding environment (Cunha, 2011).

The formalisation of the innovation process activities can vary from highly formalised processes to the absence of any type of formal structure. For instance, in the first extreme, ideas are generated through specific methods, tools, and techniques supporting the IFE activities. On the opposite side, new ideas can also arise through informal processes, with, for example, a supplier offering new material, or customer placing a special order (Cooper, 2001; Crawford & Di Benedetto, 2011; Koen et al., 2001; Ulrich & Eppinger, 2008). Manufacturing companies, in particular, known to be a vastly regulated sector, would typically follow a variation of the innovation stage-gate by Cooper (2001) or the design model by Pahl et al. (2007), with moderate to high level of formalisation (Tidd et al., 2005).

An important issue raised in the technology and innovation management literature is the link between the level of formalisation and the creative potential of those involved in the innovation process. Most authors would agree that a greater formalisation of activities contributes to the effectiveness of the management of ideas, providing greater guidance and focus (Koen et al., 2001; Oliveira et al., 2011; Ulrich & Eppinger, 2008), while a few others argue that formalisation can result in a negative impact, as the emergence of new ideas must occur spontaneously outside the limits of any formal process (Nishikawa, Schreier, & Ogawa, 2013). All things considered, both previous and recent studies provide enough evidence that the

benefits of a formalised process surpass the ones from an informal one, as researchers like Eling et al., (2016) clearly show that a formal idea generation process leads to higher project success rates.

An additional characteristic considered important in this review involves the trigger that drives innovation. It refers to two main kinds of stimulus: 'market pull' or 'technology push' (Brem & Voigt, 2009). In the market pull, the stimulus that drives innovation is a response to customers and users' needs and satisfaction, resulting in new demands for the resolution of those needs. In technology push, on the other hand, the stimulus for new products comes from internal or external R&D, with the goal is to make commercial use of new technical knowledge developed or acquired available to the company (Caetano & Amaral, 2011; Tidd et al., 2005).

It is essential to emphasise that both drivers, market pull and technology push, can be found in the same company. In the past, authors like Brem & Voigt (2009) have described technology push as the sole driver responsible for the generation of radical ideas, with a higher degree of innovation, whereas ideas originated in market pull were characterised as less innovative, with replacements or incremental improvements to current products. However, as customer involvement became more popular in the innovation process research and practice (e.g., with user-centred design and more, Brown & Rowe, 2008), research has demonstrated that market pull can also generate breakthrough ideas (Geissdoerfer, Bocken, & Hultink, 2016; Seidel & Fixson, 2013).

A further characteristic to be discussed about the innovation process, introduced by Chesbrough (2006), is the new paradigm that advocates that not all good ideas should arise exclusively from within the company ('closed innovation') and that not all good ideas created within the organisation can be developed only with internal skills and competencies. This new paradigm is called 'open innovation', which considers ideas from the external environment with the same level of importance as internal ideas generated inside the company (Chesbrough, 2006; Hung & Chou, 2013). Therefore, the innovation process followed by companies aiming at this new paradigm should have in place appropriate mechanisms and procedures to facilitate its application (Dubiel et al., 2016)

Besides the paradigm in which the ideas are originated, a fundamental characteristic to be reviewed for the success of the innovation process revolves around the company 'posture' in encouraging the creativity of its employees and the efforts for the emergence of new ideas. Thus, an innovative organisation can also be defined by the posture adopted

towards the encouragement of generation activities through the combination of strategic orientation to use of resources and create an environment for innovation (Berg et al., 2008).

In this sense, Miles & Snow (2003) suggest four distinct profiles of companies based on their strategic behaviours: prospector, defender, analyser, and reactor. First, a prospector company is typically growth-oriented, proactively searching for new markets and new growth opportunities and encouraging risk-taking with new ideas. A defender, on the other hand, aims to protect its current markets, maintain stable growth, and serve existing customers. An analyser company is a combination of both prospector and defender behaviours, as the company seeks to maintain current markets and current customer satisfaction with a moderate emphasis on innovation. Finally, a reactive company has no clear innovation strategy but reacts to changes in the environment and sees drifts in the strategic direction according to internal and external events (Miles & Snow, 2003).

On the whole, these innovation characteristics (also called here as ‘contextual variables’) – formalisation of activities, innovation drivers, closed and open innovation paradigm, and surrounding environment – can influence the company’s ability to, ultimately, develop innovations. According to Saunila & Ukko (2012), this ability is known in the literature of technology and innovation management as ‘innovation capability’. Therefore, innovation capability consists of the company’s potential to develop innovations due to the interaction of a set of mechanisms that sustain, through management processes and practices, the transformation of knowledge into innovative product/PSS, process, organisational or marketing.¹¹

Furthermore, this concept of innovation capability can be considered the link between the literature on technology and innovation management and managerial accounting (the topic of the next review section), as it appears in both bodies of literature (Saunila & Ukko, 2012). Thus, research focused on developing PFs to improve the innovation process is, in essence, addressing the company’s innovation capability (Becheikh et al., 2006; Dziallas & Blind, 2018). Nevertheless, before this review of the literature moves on the existing PFs; it is necessary to contemplate the definition and concepts from managerial accounting used to define the performance measurement landscape.

¹¹As mentioned earlier, marketing innovations are beyond the scope of this thesis, as it falls out of the domain and research position adopted in this research.

2.2 MANAGERIAL ACCOUNTING

Managerial accounting literature originated in business-related disciplines (Brattström et al., 2018). Its emphasis is on the implementation of strategies rather than systematic approaches to deal with the innovation process. Even though this stream does not focus directly on the innovation process, its collective body provides central definitions that any study on measurement and management of processes or operations should consider.

This section first introduces the concept of performance measurement and its main roles in the management of companies' business processes and operations (section 2.2.1). Then, the building blocks that support the execution of the performance measurement process are defined (2.2.2), with particular attention dedicated to the definition of the indicators and their parameters (2.2.2.1), followed by considerations of their use in measurement systems (2.2.2.2), and the application environment (2.2.2.3). Finally, the concepts for PFs are discussed (2.2.3), and the main elements synthesised (2.2.4).

2.2.1 PERFORMANCE MEASUREMENT

Performance measurement is defined as the process that quantifies the effectiveness and efficiency of processes or operations and tracks their progression over time (Bourne, Neely, Platts, & Mills, 2002; Neely, Gregory, & Platts, 1995). On the one hand, effectiveness refers to the degree to which an entity successfully produces the desired result. This translates as assessing whether the customer's requirements are being met (considering both internal customers of the processes/operations and final users). On the other hand, efficiency refers to the state or quality of being efficient, i.e., how well the resources available in the organisation are used to achieve the established targets.

Performance measurement emerged as an approach to control and improve the productivity of the shop floor at the beginning of the 20th century (Neely, 2005). By the time managerial accounting reached the innovation process, only financial performance was being applied, focused on profit/loss and cash flow analysis (Kaplan & Norton, 2007). As the field of managerial accounting accumulated knowledge, this type of performance measurement, purely financial, was found to have limitations (Kaplan & Norton, 1992; Neely et al., 1995). Since then, it has been widely argued that performance measurement cannot merely rely only on financial information as they do not properly address all the factors that a company must

fulfil in today's competitive business environment (Neely, 2007). As a result, much effort has been made in the last two decades on research that can cope with a broader scope of innovation performance (Dziallas & Blind, 2018).

According to Brattström et al., (2018), innovation performance can manifest itself as the realisation of outcomes generated from the innovation process, considering a range of performance implications within and across companies, from effects on customer satisfaction, market share, turnover, productivity and efficiency. Therefore, although performance measurement can be defined as the quantification of performance, its effects should go beyond the boundaries of quantification. In order to help researchers in the process of developing new research, Franco-Santos et al. (2007) identified five primary roles of the performance measurement process:

- 1) "Measure performance" encompasses the long-established main role of tracking the progress of processes/operations and quantifying the performance achieved;
- 2) "Strategy management" refers to the supporting role of enabling the alignment between the strategy formulated and what is being executed in terms of actions;
- 3) "Communication" comprises the roles of internal communication via the establishment of a common language among distinct levels and areas, and external communication enabling benchmarking¹² and compliance with regulations;
- 4) "Influence behaviour" involves the roles of rewarding and compensating behaviour according to the performance achieved; and
- 5) "Learning and improvement" refer to the role of supporting the loops of feedback, reflection on the results achieved and learning what did work and what did not in terms of improvement actions pursued.

Scholars argue that a systematic approach can help managers ensure that the performance measurement process is sufficiently supported within the company to execute its five main roles (Adams et al., 2006; Crossan and Apaydin, 2010; Dziallas and Blind, 2018; Saunila, 2017). This systematic approach is known in the literature as a PF. To define this concept, it is vital to identify the necessary and sufficient conditions for its existence, initiating by the definition of performance measurement and then passing to its main constructs. That is the reason why the next topic is performance measurement systems.

¹²Benchmarking is used here to refer to the organisational activity of comparing one's performance versus the average of top performers among competitors (Cooper & Edgett, 2014a)

2.2.2 PERFORMANCE MEASUREMENT SYSTEMS

A performance measurement system (PMS) can be defined as a collection of PIs that are jointly considered when making sense of process/operation's performance, in terms of efficiency and efficacy (Neely et al., 1995). PMSs are, in essence, information systems that transform data into relevant information, which are then used to evaluate performance and provide feedback to the company (Braz, Scavarda, & Martins, 2011; Nudurupati, Bititci, Kumar, & Chan, 2011a). In this way, measurement systems are vital instruments that support information supply (Adams et al., 2006).

Because of their wide application in so many distinct fields, such as manufacturing (Azzone & Noci, 1998), supply chain (Björklund, Martinsen, & Abrahamsson, 2012), sustainability (Kühnen & Hahn, 2017), humanitarian logistics (Nappi, Nappi, & Souza, 2019), among others, researchers confer to PMS a 'universal' application in practice and academia (Hald & Mouritsen, 2018). According to Hald & Mouritsen (2018), a measurement system states what is relevant and what is not; what is congruent with the company strategy and not; and what is to be reviewed and not. Therefore, a PMS provides signals for where management must intervene (Kennerley & Neely, 2002).

Figure 2.14 shows the representation of a PMS that can be analysed from at three different levels, beginning from the centre: 1) individual measures (the PIs); 2) sets of PIs (the performance measurement system as an entity and its dimensions), and 3) the relationship between the PMS and the environment within which it operates.

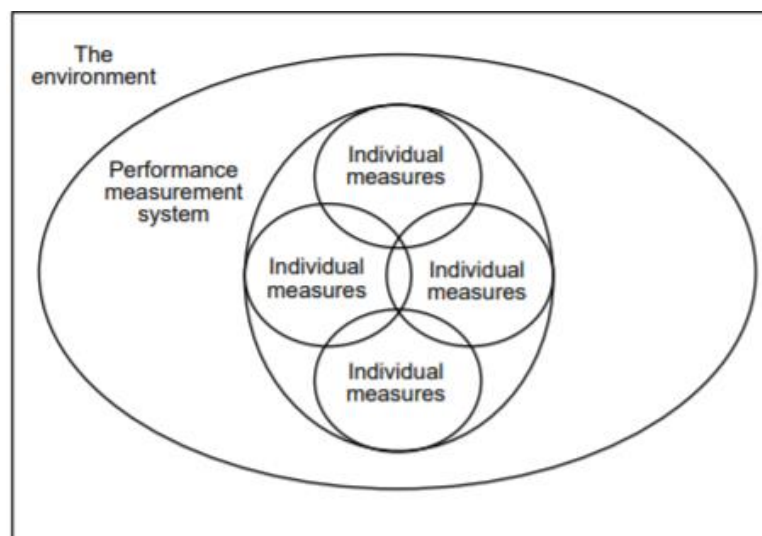


Figure 2.14. Outline for performance measurement systems (PMSs) (Neely et al., 1995).

As Figure 2.14 shows, measurement systems are an assembly of several individual PIs designed to be used together in a system to support the analysis of performance in a specific environment. The rationale underscored in the managerial accounting literature is that these sets of indicators need to be clearly positioned within the company's strategic context, as they influence what people do. As Neely et al. (1995) have pointed out, the measurement may be the process of quantification, but its effect is to stimulate action, and it is only through the implementation of actions that the targets are achieved.

Following Figure 2.14, the next topics covered are, respectively, the individual indicators (section 2.2.2.1); the sets of PIs that form a measurement system (section 2.2.2.2) and the environment in which the PMS operates (section 2.2.2.3).

2.2.2.1 INDIVIDUAL PERFORMANCE INDICATORS

Indicators are the central building blocks in the performance measurement process. Following the definition of performance measurement by Neely et al. (1995), PIs can be understood as the metrics used to quantify the efficiency and/or effectiveness of an action within the context of a process or operation. The lack of well-defined PIs may not only hinder the management of these processes/operations and but also affect the employees' motivation (Globerson, 1985). Within this context, an indicator becomes a key performance indicator (KPI) when the object of measurement lies in the critical path of the company for the achievement of the high-level strategic goals established (Niven, 2006).

A PI is characterised by more than just a formula. An indicator must also fulfil certain functional requirements so that its user is able to perform the measurement as well as understand and analyse the results (Kennerley & Neely, 2002; Neely, Richards, Mills, & Platts, 1997). In other words, it is essential that the PI is presented with the necessary specifications in order to avoid confusion. Without specifications, there is a significant risk that the indicator will not be measured correctly. In this way, an indicator should have a clear purpose and be defined in an unambiguous manner (Neely, Bourne, Mills, Platts, & Richards, 2002; Tangen, 2004a). Moreover, it is also necessary that measurement instructions are given with the PIs addressing the how to analyse the achieved results so that the user is able to identify when and where there are needs to be attended in the process/operation being measured (Neely, 2005; Tangen, 2004b).

According to Tangen (2005), there are several required specification parameters for the establishment of indicators related to:

- General information about the PI, such as title, purpose, and unit of measurement;
- Instructions of how the indicator should be measured and by whom; and,
- Instructions of how the results from the measurements should be analysed, and how to identify courses of action to improve performance.

Table 2.2 summarises the specification parameters that a PI should present in terms of general information. The must-have parameters are: title, purpose, formula and/scales and unit of measurement. These parameters should always be provided in the research in which they are presented in order to enable comparability of studies between distinct entities, companies, industries, time-periods, cultures, and even geographic regions, and to build a basis for empirical validation or in practical guidance (Boudreau et al., 2001; Kankanhalli & Tan, 2005). Further parameters that are nice-to-have are: ‘related to’ (other PIs associated with this indicator), benchmark values, and type of indicator (that, in turn, refer to distinct classifications to facilitate their use). Both must-have and nice-to-have parameters are indispensable for creating a compilation of PIs, in a database, for example (Tangen, 2004a).

Table 2.2. Performance indicator (PIs) specification parameters.

Parameter	Description
Title	A PI should have a clear title, which indicates what it is and why it is important. A title facilitates communication among users and reduces the risk of different indicators being mixed up.
Purpose	A PI must have an explicit purpose, and the people who use it must be fully aware of what that is. Without a relevant purpose, the existence of a PI will only consume resources and time in the company.
Formula and/scales	It is one of the essential parameters but also the most challenging to specify. The issue is defining a formula that gives both relevant and accurate information and has a positive influence on people’s behaviour. Attention must also be paid to specify the formula to a proper grade of detail. PI’s information should not be too rough (for qualitative PIs), but not too precise to a detail that it is not needed (for quantitative indicators). One must also keep in mind that some things cannot be measured and that it may be necessary to make compromises when forming the formula.
Unit of measurement	The unit of measurement depends on the formula and scales defined. Nevertheless, they need to be defined and explicit in the definition of the PI.
Related to	If the PI in question, in some way, has associations or connections to other PIs, this must be specified.
Benchmark values	Benchmark values should be established to drive performance. They can enable the definition of a target value for the PI and facilitate comparisons.
Type of indicator (categorisation)	While some PIs may have a direct effect on vital decisions, others have a more informative nature and are used on a casual basis. Classifications of different types help in the design and selection of PIs.

Special attention must be given to the specification of the parameter “type of indicator (categorisations)”. Most studies apply quantitative versus qualitative categorisation (Dziallas & Blind, 2018) since both types are equally important to address the innovation process (OECD, 2005). Indicators can also be classified according to how directly they address a process/operation (Kaplan & Norton, 1992). Leading indicators are indirect determinants of process outcomes (e.g., clear innovation roles). In contrast, lagging indicators refer directly to results of the process, output-oriented (e.g., new product launched, sales, revenue and customer satisfaction). Indicators may be classified as both, for example, rate of product ideas approved. A company would need a few lagging indicators whereas leading indicators should make up to the more considerable part of the measurement system, as they enable managers to act on the course of ongoing activities (Costa et al., 2014; Dziallas & Blind, 2018).

Relevant studies employ rapid assessment and in-depth differentiation, as well. Rapid assessment indicators provide a quick overview of a dimension used in diagnosis or audits in previous studies (Chiesa et al., 1996; Czuchry & Yasin, 2001), and are easy to capture (e.g. organisational climate for innovation, Lee & Markham, 2016). Their application would typically encompass both small and large firms (Czuchry & Yasin, 2001). Conversely, in-depth indicators are resource-consuming to capture (e.g., technology synergy, a survey-based PI, Atuahene-Gima, 1995) and most commonly applied after a first diagnosis/audit, whenever a more profound analysis may be necessary (Chiesa et al., 1996). Thus, they are more accessible to large companies, and as a result, more common in this setting (Czuchry & Yasin, 2001).

Besides the general information, further parameters should be specified, for example, “related to” measurement instructions. Unlike the previous parameters found in the literature and state-of-the-art collection of practices, these parameters are company-specific. Hence, they need to be defined during the planning or implementation of a PF. According to Tangen (2005), they are as follows:

- Who measures? In order to ensure that the indicator is measured in the company (if not done automatically), someone has to take responsibility for the collection and report of measurement data.
- Source of data: the input data for the indicator must always be collected according to a procedure defined before the measurement and, if measured in a timely basis, the input data must be from the same source.

- Frequency of measurement: deciding the correct frequency of the measurement is another challenging task, which is highly dependent on the volume of available data and the importance of the indicator. Some PIs should be measured daily (mostly for production processes), while others only need to be reported once or twice a year (this is the case for the innovation process).
- How is the measure displayed? There are many ways to display the result from a PI. For instance, De Benedetto and Klemeš (2009) state that graphs should be the primary vehicle for reporting performance data. This is true if one wants to create visibility of the PI, such in a diagnosis situation, but different PIs have different purposes, and the best way to display them will strongly depend on each case.

Finally, additional PIs parameters can also be used to inform analysis instructions. In the same manner as the measurement instructions, these parameters are company-specific, and as a result, they need to be defined during the planning or implementation of a PF. The instructions parameters for analysis should cover the following (Tangen, 2005):

- Who acts on the data? The measurement of the PI itself will not improve performance. Action must always follow the measurement. Therefore, the person(s)/team/area responsible for this work of implementing action plans should be identified.
- Target: in order to support the improvement work, it is necessary to specify a target for the PI and a timeframe for reaching the target.
- What to do? Instructions should be given regarding the definition of appropriate actions to take after the results; a parameter often overlooked in research discussing indicators. In the case of a PF for the innovation process, a viable shortcut in the definition of action plans can be found in the form of innovation practices applied to improve performance related to that PI in previous studies (Lakiza et al., 2018).
- Known limitations: if the indicator contains any limitations that must be considered when analysed, it should be noted here.

This review on individual PIs enables the user to ensure that the necessary specification parameters are defined when an indicator is designed or selected. These parameters can work as the necessary conditions to create a meaningful collection of PIs to support the application of a PF. Now that PIs are defined, it is time to the review sets of indicators.

2.2.2.2 SETS OF PERFORMANCE INDICATORS

In the context of performance measurement, dimensions are typologies used to classify PIs relevant to the domain in question, which facilitate their operationalisation and ensure that no critical dimension is missing (Becheikh et al., 2006; Dziallas & Blind, 2018). Dimensions might also be called organisational factors or categories of best practices required for better performance (Markham & Lee, 2013). Moreover, dimensions can be further characterised as company-specific referring to those that are particular to a company that affect the organisational innovation behaviour, or as contextual in which it relates to a company and its surrounding environment (Becheikh et al., 2006; Dziallas & Blind, 2018).

In this sense, this section adopts a slightly different angle from the previous one to review sets of individual PIs together as a system. A measurement system should then display performance information on dimensions that are relevant to the process/operation under analysis (Chiesa et al., 2009). For this, it is essential to discuss the concept of the performance dimensions that form PMS previously in the literature.

Historically, the initial research describing performance dimensions started with the measurement of production processes to increase productivity (Hanson et al., 2011). At that time, dimensions were defined in terms of quality, time, and cost (Cedergren, Wall, & Norström, 2010). Several examples of their application can be cited, such as Azzone & Noci (1998) and Rouse & Putterill (2003). Although these dimensions are relevant to the context in which they emerged, production productivity, they are not sufficiently detailed to deal the new process-based approach for innovation process aiming to provide essential performance information to managers (Adams et al., 2006; Crossan & Apaydin, 2010).

Further authors take a slightly deeper stance than quality, time, and cost, as performance measurement began to cover the analysis of more processes and operations and services (Striteska & Spickova, 2012). Two types of dimensions are proposed following the lagging and leading rationale, those related to results (competitiveness, financial performance), and those focused on the determinants of the results (quality, flexibility, resource utilisation and innovation). The work of Fitzgerald, Johnston, Brignall, & Silvestro (1991) and Striteska & Spickova (2012) reflects these dimensions. Once more, the dimensions may be relevant to the context in which they emerged; however, they overlook important

dimensions of the innovation process, such as knowledge management (Becheikh et al., 2006; Dziallas & Blind, 2018).

Probably the best-known dimensions originated from the balanced scorecard (Kaplan & Norton, 1992). The system (scorecard) should provide managers with sufficient information to address the financial perspective “how do we look to our shareholders”, internal business perspective “what we excel at”, customer perspective “how do our customers see us” and learning and growth perspective “how can we continue to improve and create value”. Its main advantage is the overview of the four dimensions, allowing the strategy to be deployed into relevant and aligned PIs. In turn, this scorecard structure is more directed to reporting top management rather than supporting middle management to act on relevant information (Martins, 1999). Moreover, researchers argue that the definition of non-financial dimensions and their integration are particularly challenging (Attadia, Canevarolo, & Martins, 2003).

The scorecard, in the same way as the literature on managerial accounting, typically treats innovation as a determinant of the results, in the similar fashion to quality, flexibility and resource utilisation, and not as a systematic process (Bourne, Neely, Mills, & Platts, 2003; Neely, 2005). Nevertheless, several studies applied balanced scorecard into the innovation process context. For instance, Tuomela (2005) and Ivanov & Avasilcăi (2014) applied the same four dimensions of the traditional scorecard. In contrast, other authors like Bassani et al. (2010) and Lazzarotti, Manzini, & Mari (2011a) introduced a new dimension of alliances and networks and applied scorecard within the R&D department. Nonetheless, the use of these four dimensions or even five, with the addition of alliances and network, is not sufficient to deal the innovation process performance, as highlighted by Adams et al. (2006), which may hinder the recognition of opportunities to improve performance in other dimensions (Crossan & Apaydin, 2010).

It is important to note that the performance dimensions mentioned in one specific past study may not be enough to characterise all relevant performance dimensions to build a snapshot of reality for a current study. An alternative route taken by researchers in the PF domain nowadays is to build on existing research by identifying several dimensions in the previous literature that are expected to be significant for a better understanding of the innovation process (cf. Becheikh et al., 2006; Crossan & Apaydin, 2010; Dziallas & Blind, 2018). Before this route is taken in this research, this review moves to the discussion of the measurement environment.

2.2.2.3 MEASUREMENT ENVIRONMENT

Once the need to determine the relevant performance dimensions has been established, the PMS must be designed. Among other things, this means that the measurement system will have to interact with the company's environment. According to Neely et al. (1995), there are two fundamental perspectives to address in the measurement environment. The first is the internal environment – that is the company. The second is the external one –the market within which the company competes.

In the internal environment, the system relates to the main characteristics of the innovation process (Bourne et al., 2000; Rogers, Ghauri, & Pawar, 2005), discussed in section 2.1.4, particularly the formalisation of activities and the innovation drivers. The formalisation of process activities in companies can vary from highly formalised processes to the absence of any formalisation. Prior studies indicate that a more formalised process tends to present an architecture to support the performance measurement process, especially a measurement system (Cooper, 2001; Crawford & Di Benedetto, 2011). Therefore, it is vital to consider the level of formalisation of the innovation process when contemplating the application of the PF in a company.

The second characteristic of the innovation process previously reviewed is the driver of innovation that can be either market pull or technology push (Brem & Voigt, 2009; Caetano & Amaral, 2011). Because the performance measurement first emerged in the manufacturing context, there is still a technological bias in the proposition of performance measurement tools (Tidd et al., 2005). Consequently, most measurement systems reported in the literature for the innovation process focus on the technology dimension (Adams et al., 2006; Dziallas & Blind, 2018). However, these two types of trigger, market pull and technology push, can be found at the same time in the company, and therefore, both should be covered within in the company's measurement systems (Barczak & Kahn, 2012).

The external environment of the PMS relates to the posture assumed by the company in the market. In this sense, the PMS is impacted by two further characteristics of the innovation process: closed and open innovation paradigm, and the surrounding environment (both discussed in section 2.1.4). First, the new approach of open innovation by Chesbrough (2006) considers ideas from the external environment as important as internal ideas developed inside the company. Thus, this new approach has two main consequences for a measurement

system. One is that the performance dimensions need to acknowledge this new approach and capture it somehow, a need already identified as Adams et al. (2006) and Crossan & Apaydin (2010) work. The other is the possibility of shared use of a PF for more than one company within an innovation ecosystems context. It implies a relatively higher level of complexity for even traditional inter-firm performance measurement. Thus, the PMS application should address issues to better cope with this new paradigm, whenever this situation arises.

Finally, the company posture to deal with market changes is a characteristic of the innovation process that should be addressed (already discussed in section 2.1.4). The four distinct profiles of companies based on their strategic behaviours, prospector, defender, analyser, and reactor (Miles & Snow, 2003), may suggest the position adopted in the performance measurement process. For example, one would expect that either a prospector or an analyser would be more likely to implement improvement actions than a company posing a reactor posture. In addition, a defender, on the other hand, may be more eager to tackle improvement actions aiming to protect their current markets, maintain stable growth, and serve existing customers (Sarac, Ertan, & Yucel, 2014).

2.2.3 PERFORMANCE FRAMEWORKS

Once PMS concepts have been defined, the tool that enables its design and development should be addressed. A PF is a managerial tool that supports companies in executing the performance measurement process and developing and implementing measurement systems, enabling the measurement and evaluation of organisational capabilities (Folan & Browne, 2005; Franco-Santos et al., 2007).

There are two types of PF defined in the managerial accounting literature. Structural frameworks aim to organise the PIs into dimensions of performance, that, in turn, are typologies used to classify PIs relevant to the domain in question, to facilitate their operationalisation and ensure that no critical dimension is missing (Folan & Browne, 2005; Franco-Santos et al., 2007). Procedural frameworks, on the other hand, prescribe a sequence of steps to be followed in order to put the framework into use (Folan & Browne, 2005; Franco-Santos et al., 2007). PFs can also be specified as the two types together, facilitating their application (Folan & Browne, 2005).

In essence, PFs help define, either structurally or procedurally, measurement systems that are composed of sets of PIs jointly analysed to support informed decisions (Bourne et al.,

2003; Neely, 2005). In this way, PFs provide performance-related information when management has to intervene and identify actions to realign performance with the firm's goals (Bourne et al., 2003; Neely, 2005). Hence, PFs enable the definition of what is relevant to the company in terms of indicators and dimensions to measure performance (structural), and how this relevant performance information should be reviewed in order to identify where there are needs to be attended and to define appropriate action plans to improve performance (procedural).

A PF enables management to identify gaps in the performance of the company process/operation under analysis and, consequently, to identify where there are improvement opportunities. In this context, one big question appears among researchers and practitioners in this stream of literature (e.g., Brattström et al., 2018; Neely et al., 1995): how can one ensure that the management loop is closed – that appropriate actions follow measurement? Hence, a major concern for new PFs should be support for improvement actions. For this, several authors apply the concept of improvement projects to act as the action plans, which could include innovations practices¹³ implemented in past studies to improve performance after the measurement (Costa, 2010; Pigosso, 2012).

To make sure that action follows measurement, the company needs to engage in performance evaluation. It means that the PF should enable the tracking and analysis of companies' performance progression of a process/operation on a specific domain of interest (Costa, 2010; Pigosso, 2012). The outcomes from applying the PF not only inform possible courses of action that the company can implement but also work as a motivational driver for management to change the performance level on dimensions, projects, or organisational capability (Maier, Moultrie, & Clarkson, 2012). In this way, evaluating the company's current situation can guide and shape improvement initiatives addressing opportunities to act upon to achieve the desired performance (Roglinger, Poppelbuß, & Becker, 2012).

For instance, a common principle is to represent the progression of performance over time as a number of cumulative levels or stages of increasing sophistication, where higher levels build on the requirements of lower levels (Pigosso, 2012). Indeed, the representation of

¹³Practice is defined as a specific type of professional or management activity that contributes to the execution of a process and it may employ one or more techniques and tools. Technique is a defined systematic procedure employed by a human resource to perform an activity to produce a product or result or deliver a service, and that may employ one or more tools. Tool, in turn, is defined as something tangible, such as template, procedure, software, using in performing activities to produce a desired result (PMI, 2008).

the progression of performance measurement applying evolutionary levels/stages appears to have full practical acceptance (Kohlegger, Maier, & Thalmann, 2009; Maier et al., 2012). In essence, the main point of representing the progression of performance is that it should be easy to understand and communicate across the company (Klimkó, 2001).

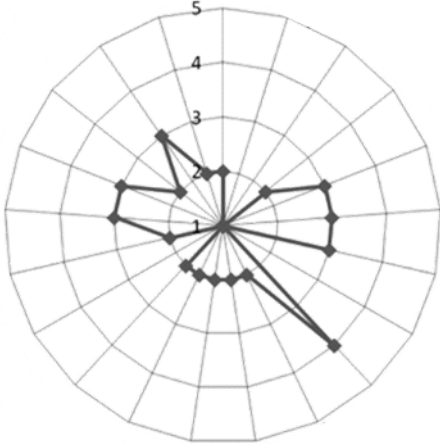
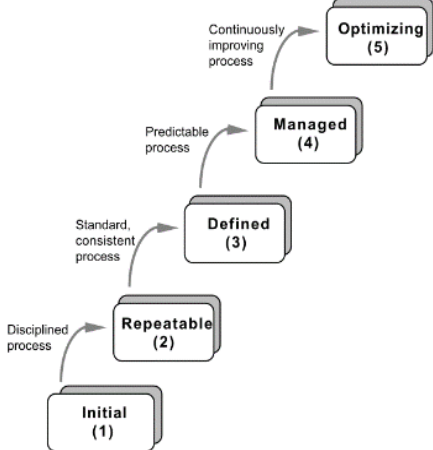
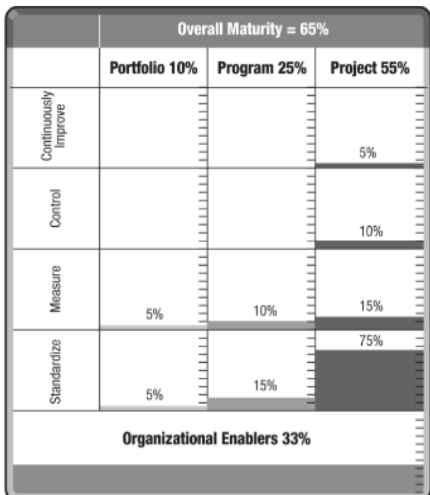
An important consideration of the progression of performance analysis concerns its visualisation (Pigosso, 2012). A visual representation is not only a powerful communication aid amongst the company's employees but also a useful resource for increasing the management's motivation (Maier et al., 2012). The most common visual representations of evolutionary levels found in PFs can be seen in Table 2.3 with a description of their characteristics: a radar graph, which is also known as a spider-web, a ladder, and a 'progress report' representation.

The first example, the radar graph, represents multiple dimensions radiating outward on spokes from a central hub (Enkel, Bell, & Hogenkamp, 2011). The second diagram illustrates the variables in a ladder representation, which can address each selected dimension separately or provide an overall overview (Chrissis, Konrad, & Shrum, 2003). Thirdly, the 'progress report' representation displays percentages achieved or progression bars typically achieved on each level (PMI, 2008).

The critical aspect of having a visual representation is the clear definition of the performance levels and what that means for the performance dimensions considered in the PF (Maier et al., 2012). Several authors, such as Barczak & Kahn (2012) and Gullledge & Chavusholu (2008), argue that the visual representation of the performance progression is a useful mean to perform gap analysis, which entails understanding what is the current performance of the company in regard to the process/operation under analysis and what is the desired level of performance, enabling the identification of the company's strengths and weaknesses.

In sum, PF is a management tool intended to help an actor, individual or a collective, to conduct the performance measurement and evaluation, followed by the identification of course of actions to improve performance. Nevertheless, in the end, a PF is only useful if improvement action follows measurement.

Table 2.3. Examples of visual representations of the progression of performance.

Visual representation	Characteristics
Radar representation by (Enkel et al., 2011) 	- The radar is a graphical representation which displays multiple dimensions in the same view. - The scores achieved for each displayed dimension radiate outward on spokes from a central hub. - All axes are arranged radially, with equal distances between each other. - The relative angle of the axes is typically uninformative.
Ladder representation by (Chrissis et al., 2003) 	- The ladder is a representation of one dimension at a time. - Sometimes, the ladder can represent an overall overview of a company's profile considering all dimensions. - The scores achieved for the dimension is displayed as one of the steps of the ladder. - The ladder is mostly a qualitative representation.
'Progress report' representation by (PMI, 2008) 	- The progress report represents a few selected dimensions in the same view at a time. - It typically presents the selected dimensions on stacked rows with the scores achieved. - It is also very common to represent an overall overview of a company's profile considering all dimensions.

2.2.4 SYNTHESIS OF THE PERFORMANCE FRAMEWORK'S ELEMENTS

At this point in the review, it is indispensable to provide an overview of the core elements that form a PF. Franco-Santos et al. (2007) argue that, more often than not, researchers utilise the term framework without specifying which elements they are focusing on, nor what conditions are (or have to be) present in the empirical contexts they study, jeopardising the potential comparability and generality of the resulting PF.

A review of PF definitions informs two basic types of composing components: 'database'¹⁴ elements and 'supporting infrastructure' elements (Franco-Santos et al., 2007). Database elements refer to both PIs and dimensions of performance. That indicators and dimensions are necessary elements for a framework is clear and established, but sometimes surprisingly neglected in developing a PF¹⁵ (Dzallas & Blind, 2018). In addition, although the existence of indicators is taken as a given, there is no consensus on the second database element, the dimensions. There has long been a discussion about which ones should be considered in a PF as new research seems to overlook past research on relevant performance dimensions (Dzallas & Blind, 2018).

The supporting infrastructure elements, on the other hand, can vary from very simplistic manual procedures for the acquisition, analysis, interpretation and dissemination of performance information to sophisticated software (Drongelen, Nixon, & Pearson, 2000; Neely et al., 1997). The supporting elements, regardless of their degree of sophistication, must include a procedure to apply the PF (Franco-Santos et al., 2007; Medori & Steeple, 2000), facilitation to conduct the application (Chiesa et al., 1996; Mettänen, 2005), means to evaluate performance progress (Kohlegger et al., 2009; Maier et al., 2012) and support for defining improvement actions (Chiesa et al., 1996; Tangen, 2004b).

Figure 2.15 illustrates the composing elements of the PF, considering both database and supporting elements. Indicators are the building blocks of any PF. Without them, the first and primary function of measuring performance cannot be fulfilled. The second database element, performance dimensions, represent the configuration of the PIs. The definition of dimensions included the PF is particularly necessary to delineate what is considered important

¹⁴The original term used by Franco-Santos et al. (2007) was 'metrics' to refer to both dimensions and PIs. To avoid confusion, this research opts to use the concept 'database' instead of 'metrics'.

¹⁵The discussion about the neglect of PIs in existing frameworks is given in section 2.3, when existing PF from both streams of literature are reviewed.

to the company and what is not. It must be a conscious and deliberate definition of the people involved in the development or implementation of the PF in the company. Their definition will depend on the type and nature of the process or operation that is being measured.

The supporting elements, in turn, work as the infrastructure that needs to be in place in order to put to use the PIs and the dimensions. First, a procedure needs to outline the activities to be carried out to support the application of the PF. Second, the visualisation of performance progression should be provided to enable the evaluation and comparison of performance over time. Third, the facilitation should also be defined, so it is clear the role of facilitators needs to play to conduct the procedure or the mechanisms in place to enable the PF to be a stand-alone tool. Lastly, the support for the definition of improvement actions needs to be present as action must follow measurement, the ultimate goal of applying a PF.

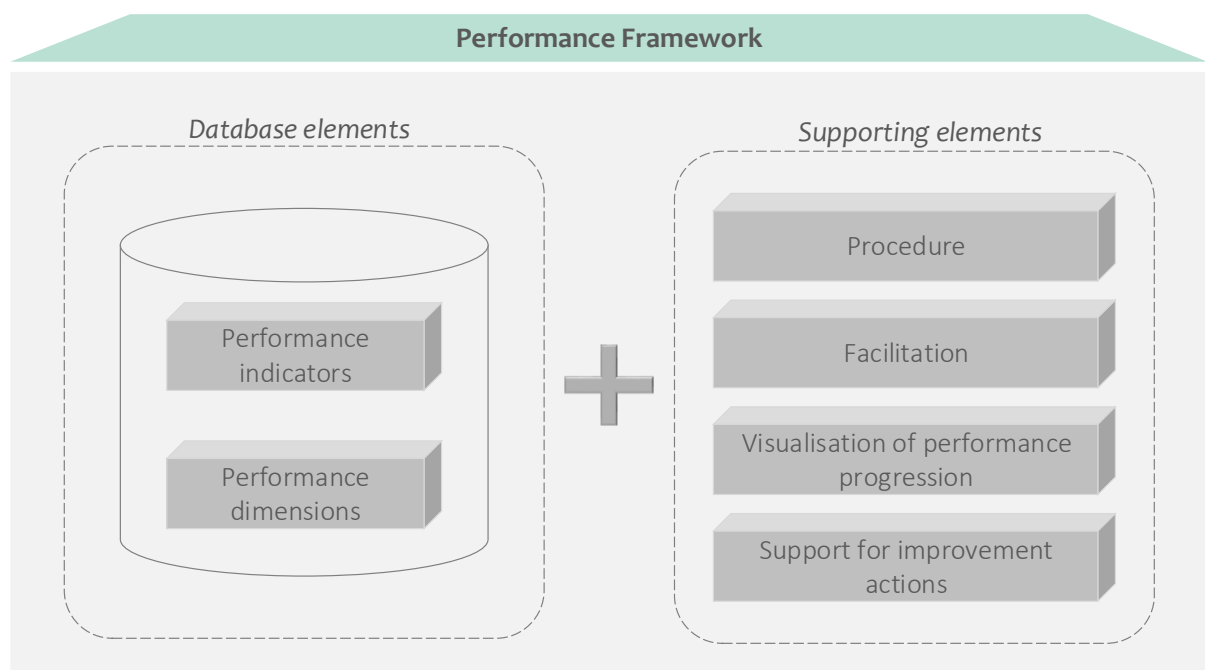


Figure 2.15. Representation of the elements of a PF.

These elements can be used as the guiding design requirements to build a PF and, therefore, useful in reviewing existing PFs. Therefore, in the next section, these discussed elements – PIs, dimensions, (the database elements); and procedure, role of facilitators, visualisation of progression and improvement actions (the supporting elements) – are used to review existing PFs.

2.3 EXISTING INNOVATION PERFORMANCE FRAMEWORKS

Having discussed the pertinent definitions for the measurement and management of innovation performance from both technology and innovation management and managerial accounting literature, this section is devoted to presenting the main PFs addressing the innovation process described in the two literature streams.

For the selection of relevant PFs to be reviewed in this section, the same criterion applied to innovation process models (section 2.1.2.1) is used here. The relevance here is indicated by the level of details provided by the authors concerning the database elements – 1) PIs and 2) dimensions – and supporting elements – 3) procedure, 4) facilitation, 5) visualisation of performance progression and 6) improvement actions). A PF should present at least two critical elements from the six mentioned to be considered a PF (Franco-Santos et al., 2007). Note that for the selection of process models, the issue was a large number of reference models, whereas the issue now is the level of details, i.e., the required elements to be considered a PF. To provide some perspective, a study on PFs for the manufacturing and production processes identified more than 50 distinct PFs (Ravelomanantsoa, Ducq, & Vallespir, 2019), while the latest study on PF for the innovation process identified seven references (Henttonen et al., 2016).

At this point, it is important to emphasise that this research focuses on PFs to be applied at the organisational level. However, there are other PFs applied in the national or regional level, or even cross-countries, e.g., the Frascati manual for developing national R&D statistics (OECD, 2002). Although these high-level PFs present relevant contributions, they are not suitable for companies and support decision-making to improve the innovation process, especially for SMEs (Maravelakis, Bilalis, Antoniadis, Jones, & Moustakis, 2006). The existing PFs are reviewed for this work chronologically, as follows.

2.3.1 FRAMEWORK FOR SELECTING R&D PRODUCTIVITY INDICATORS

One of the first PFs to be proposed in the literature is the framework for selecting PIs for the innovation process by Brown & Gobeli (1992). Because the literature produced at this time was mainly focused on technology as the main driver of innovation, this PF presents a technocentric view on the innovation process. As such, the resulting PF is conveyed as a closed system within the R&D departmental limits.

As mentioned earlier, the description of the PF covers the following elements: 1) indicators; 2) dimensions, and supporting infrastructure; 3) procedure; 4) facilitation; 5) visualisation of progression and 6) improvement actions, as are described next:

- 1) Indicators: the PF presents examples of indicators, emphasising the 'top ten' KPIs as the 'best practice' ones to measure the productivity in terms of quality, quantity, timeliness and cost of R&D departmental results.
- 2) Dimensions: the PF considers the performance dimensions of: resources; project management; people; planning of innovation; new product development; outputs, and division results/outcomes, all from a typical manufacturing perspective.
- 3) Procedure: this PF suggests the following activities for the procedure: clarify the responsibilities and context of the R&D activities in the company; identify strategic goals; identify the hierarchy of activities (managerially oriented); identify categories to be measured; identify the PIs; develop instruments to measure; identify a shortlist of indicators to be easily monitored; capture them; assess performance changes over time, and establish improvements in the PF. All these activities were carried out in a case study in a large company.
- 4) Facilitation: it is implied in the PF that the procedure should be performed by researchers/consultants in conjunction with practitioners from the company.
- 5) Visualisation of performance progression: the authors acknowledge that it may take several years for an R&D department to develop enough stability, and critical mass to achieve high levels of performance, but they do not address possible evolutionary levels.
- 6) Improvement actions: the PF incorporates steps to identify improvements in the product itself and production. However, most likely because of the techno-centric bias, the PF does not consider the impacts of improvement on innovation as a process.

This PF is a descriptive framework, in which the authors categorised examples of R&D productivity indicators, a 'top ten' KPIs shortlist, within seven dimensions, based on a case study. Their contribution relies on the fact that R&D was neglected in terms of performance measurement in the 1990s, with many practitioners only seeing the amount of investment/spending going into projects, with no measurements of tangible results. Nonetheless, this PF has a few shortcomings, such as a bias on the techno-centric view on the innovation process and the lack of visualisation on performance progression (item 5).

2.3.2 TECHNICAL INNOVATION AUDIT

The technical innovation audit developed by Chiesa et al. (1996) evaluates the company's performance to determine to what degree there are appropriate business processes in place for innovation (by building a scorecard) and to what degree each practice meets known best in class or world-class standards at the time (via an in-depth study). Thus, the PF was designed to provide a benchmark opportunity for senior management to identify new practices to improve performance. This PF's elements are the following:

- 1) Indicators: the audit presents 40 indicators across distinct dimensions to build a scorecard. These PIs seem to be widely applied in the literature, but the PF does not address whether they were retrieved from prior work or already used in the companies. In addition, it is not clear if these indicators are as exhaustive as possible, or if they are 'best practice' KPIs from the authors' perspective.
- 2) Dimensions: the PF presents the following dimensions of performance: inputs (strategy); systems; tools and resources; organisational culture; and a further dimension addressing the innovation process itself considering concept generation, production process, technology acquisition and product development.
- 3) Procedure: this PF shows evidence of the procedure being applied and tested in several SML cases, with the following steps: set up facilitators; form a small team to audit the company's processes; collect data for the audit (scorecard); meeting to discuss initial findings; interview key stakeholders; meeting to validate the outcomes of the audit; discuss identified gaps between the current performance (in-depth) and the desired state, and finally, identify areas for improvement, prioritise actions and assign responsibilities.
- 4) Facilitation: the PF was designed as a stand-alone tool. However, the research shows that an in-depth audit may be too complex for stand-alone use and requires greater training and expertise for the facilitator than the typical company can provide.
- 5) Visualisation of performance progression: the PF provides a hierarchy applying 1 to 4 evolutionary levels for each dimension, along with the graphical representation of the gaps between current and best practice for each performance dimension.
- 6) Improvement actions: the in-depth part of the PF enables the analysis to identify current and best practices to identify improvement actions. Nevertheless, there is no

straightforward procedure nor explanation of how these actions are identified and how they relate to the evolutionary levels used.

The number of citations of this PF highlights its contribution to theory (Spanò, Allini, Caldarelli, & Zampella, 2017). Nevertheless, one point that needs more clarification in the PF refers to the definition of improvement actions and how they relate the evolutionary levels. Furthermore, the dimensions used need to be further updated in order to avoid stagnation due to emergence new concepts, as already pointed out by Neely (2005), and to include new dimensions, such as sustainability among others.

2.3.3 PERFORMANCE FRAMEWORK FOR INTEGRATED INDICATORS

Werner and Souder (1997) developed a conceptual PF showing an integrated approach for PIs that combine multiple objectives, explicitly assimilating quantitative and qualitative indicators. As expected, this PF is focused on the R&D department outcomes. The elements for this PF are as follows:

- 1) Indicators: the authors present examples of the eight most frequent PIs reported in the R&D literature at the time, mostly composed of quantitative nature but with some qualitative PIs.
- 2) Dimensions: the dimensions presented in the PF are related to: financial planning, project effectiveness, technical abilities and R&D productivity.
- 3) Procedure: the authors do not prescribe a procedure *per se*, as this PF is purely conceptual. What they do suggest are generic recommendations for use; for instance, the use of qualitative indicators in the early stages of the innovation process, and quantitative indicators in the later phases. In addition, the authors recommend establishing a procedure to reach consensus in the use of qualitative metrics.
- 4) Facilitation: the participants in the application of the PF must be chosen carefully for their knowledge and expertise. The authors also suggest a small team of four or five people, as the reliability may be maximised in small panels of relevant employees.
- 5) Visualisation of performance progression: the progression of performance is not characterised in the PF, but the authors note the importance of accommodating distinct performance levels that a company might present.

- 6) Improvement actions: the proponents recognise the importance of benchmarking best practices and identifying improvement actions to find the way toward the best in class. However, they do not provide the procedure nor recommendations to do it.

This PF by Werner and Souder (1997) aims to integrate PIs from qualitative and quantitative nature, which is an attempt not yet addressed explicitly in the previous PFs mentioned here. However, the PF still needed to address the supporting elements such as procedure and visualisation of the performance progression, which are almost absent from the PF and the definition of improvement actions needs support.

2.3.4 PERFORMANCE FRAMEWORK FOR TECHNOLOGY RESEARCH

This PF was designed by Loch and Tapper (2002) for the technology research department of a large industrial company. The PF was developed to enable the creation of a measurement system to support strategic alignment, evaluation of performance, operational control, prioritisation of projects and incentives.

- 1) Indicators: the PF indicates 28 PIs formulated in the industry in which the PF was being developed. These indicators were defined based on three main outputs in the company's strategy directed at research, technical services and equipment manufacturing and development.
- 2) Dimensions: the performance dimensions in which the PIs are organised in the PF are: new technologies and breakthrough concepts, customer support, knowledge repository and external reputation.
- 3) Procedure: the authors suggest an initial diagnosis, with a particular emphasis on the involvement of practitioners and then benchmark of best practices. Afterwards, efforts should be spent in integrating and communicating the results of the measurement, followed by an analysis and prioritisation of the improvement actions.
- 4) Facilitation: the authors clearly emphasise the role of a facilitator to lead the implementation as well as the involvement practitioners, especially R&D, to take part in the measurement process.
- 5) Visualisation of performance progression: as a result of the measurements, the authors arranged the PIs into a radar graph to illustrate all the dimensions abovementioned and their level of performance achieved.

- 6) Improvement actions: the radar representation enables the visualisation of the current performance and the definition of the desired performance. Nevertheless, the support provided for the identification of improvement actions is limited to this acknowledgement and the saying that “prioritisation of actions is important”.

This PF, presented by Loch & Tapper (2002), introduces two vital contributions. The first relates to the facilitator’s role, with a clear recommendation of practitioners’ involvement in the measurement process. The second contribution refers to the use of radar representation to illustrate and communicate performance to the company. In contrast, the procedure and the support of improvement actions need further development.

2.3.5 NEW PRODUCT DEVELOPMENT BEST PRACTICE FRAMEWORK

The PF developed by Kahn, Barczak, and Moss, (2006) helps managers identify the next steps, in terms of action plans, toward implementing best practices in the innovation process. The PF accomplishes this through three main functions: 1) benchmark performance; 2) monitor process proficiency; and 3) support in identifying the next level of practices to implement. The PF elements can be characterised as follows:

- 1) Indicators: although the PF mentions PIs and performance measurement, they are not presented, nor is the guidance to design or select them discussed.
- 2) Dimensions: the PF has the following dimensions: strategy; portfolio management; process; market research; people; and metrics and performance evaluation. The dimensions, though, are not built on the top of indicators, but merely constructed around the verification of best practices (based on ‘yes/no’ questions).
- 3) Procedure: the procedure provided is based on a questionnaire applied across a range of companies, both SMEs and large companies, with closed questions asking if a specific best practice within the used dimensions is applied in the company.
- 4) Facilitation: the application of the procedure proposed in this PF (the questionnaire) is made only by the researchers/consultants.
- 5) Visualisation of performance progression: a visualisation of evolutionary performance levels for the dimensions established in the PF is given considering four levels: level 1 characterising poor practices, and level 4, best practice mastery.

- 6) Improvement actions: because the performance levels are characterised by poor practices all the way up to good practices, the pathway towards improvement is supported to an extent, but without further steps to guide their implementation.

This PF a useful characterisation of best practices; however, an opportunity of using PIs with greater detail and refinement that can lead to more significant changes in the company remains unexploited. Additionally, the path toward improvement is not that clear after assessing the current performance of the organisation. In the end, the benchmarking is limited to the verification that the company in question follows a best practice or not (based on a dichotomous answer 'yes/no' in the questionnaire).

2.3.6 BALANCED INNOVATION FRONT-END MEASUREMENT FRAMEWORK

The proponents of the balanced innovation front-end measurement PF, Berg et al. (2008), aim to assess innovation performance in the IFE. It was a conceptual PF, later applied to several companies. Nevertheless, it still is not clear if SMEs were included. The elements of the PF are the following:

- 1) Indicators: the PF presents 16 indicators related to financial, patents, personnel, time management, market rates and technical attributes. Nevertheless, the selection of those indicators is not justified in either the literature or practice in the companies.
- 2) Dimensions: the PF introduces five dimensions divided into sub-dimensions: market (market growth/orientation, customer understanding); process (opportunity identification, data collection, idea generation, concept idea/formal project plan); outcome (goods, services, customer interaction)/ impacts (market share, profitability, customer satisfaction); social environment (innovativeness, creativity, ability to implement), and physical environment ('spatials', information and communications technology systems). Even though they seem to be comprehensive, not much can be done with the available PIs, as they do not correspond to these dimensions nor is more explanation given.
- 3) Procedure: the PF also present five loosely explained steps: definition of the nature of the companies' discontinuous innovation environment; selection of measurement criteria; selection of data sources; data collection and analysis of results.

- 4) Facilitation: it is not clear if the PF is designed to be a stand-alone tool or meant to be supported by the researchers/consultants. In fact, the procedure is not sufficiently discussed in research to help in either direction.
- 5) Visualisation of performance progression: the PF uses the concept of maturity levels to address the progression of performance. The evolutionary levels for process management are the same used by the capability maturity model integration (CMMI)¹⁶ which is typically applied for software development: 1) initial ('*ad hoc*'); 2) repeatable; 3) defined; 4) managed; 5) optimising. Even so, there is no attempt to relate these levels with the dimensions or the PIs mentioned.
- 6) Improvement actions: as the procedure of the PF is loosely explained steps; there is a lack of discussion on improvement, with no indication on how to evaluate the performance measured with the PIs, the dimensions and the evolutionary levels.

Overall, this PF may contribute with more dimensions and their division into sub-dimensions, but it overlooks a significant part of the supporting elements. First, the indicators presented in the research need further justification. Second, the link between the PIs, dimensions and the levels used to characterise the performance progression is missing. Third, the supporting element for the improvement actions is not discussed at any point in the PF, making the use of the framework for improving performance challenging (Cunha, 2011).

2.3.7 REFERENCE FRAMEWORK FOR R&D

The PF developed by Chiesa et al. (2009) explored the interplay between measurement objectives, performance dimensions, and contextual factors in the design of an R&D measurement system. This PF counts with a theoretical basis and empirical analysis in multiple large technology-intensive firms. The PF elements can be characterised as:

- 1) Indicators: the authors present an overview of 55 PIs identified in their empirical analysis, already in use by the companies of their study.
- 2) Dimensions: the PF applied the basic dimensions established in the balanced scorecard (Kaplan & Norton, 1992): financial, customer, innovation and learning and business processes.

¹⁶The Capability Maturity Model Integration (CMMI) is a model composed of best practices that addresses the development and maintenance of software (rarely used for hardware) through the characterisation of distinct maturity levels (Chrissis et al., 2003).

- 3) Procedure: the PF does not explicitly provide a procedure, but it hints at a number of steps addressed as objectives: motivate researchers and engineers and improve their performance in R&D activities; monitor the progress of R&D activities with respect to resource consumption targets, milestones and technical requirements; evaluate the performance (especially profitability) of R&D activities and their contribution to the company's economic value.
- 4) Facilitation: the authors mention researchers and engineers as the facilitators for applying the PF.
- 5) Visualisation of performance progression: the progression of performance is not characterised in this PF, but the authors mention that innovation performance may progress through different stages and that these stages may need further support.
- 6) Improvement actions: the authors briefly discuss that a diagnosis of the current performance state can be useful for the process improvements. However, no further indications are given to support the definition and implementation of improvement actions.

The empirical nature of this PF is particularly interesting for innovation managers that may find useful insights to use the PIs and dimensions in which they operate. The authors also recognise the importance of a diagnosis to promote and communicate performance evaluation. Nevertheless, the use of the four basic dimensions of the balanced scorecard restricts the vision of the innovation process. Additionally, the lack of a procedure is another limitation of this PF.

2.3.8 MULTIDIMENSIONAL FRAMEWORK OF INNOVATION

This PF is designed to offer a perspective on innovation performance based on several dimensions (Crossan & Apaydin, 2010). It is built from a systematic analysis of research on innovation, and as a result, the PF integrates a significant volume of research in the area. However, even though this PF can be considered a conceptually consolidated PF, it is entirely theoretical, since no empirical application nor validation was done. The elements that form this PF can be characterised as follows:

- 1) Indicators: the PF presents several indicators (78) for all the dimensions mentioned subsequently. These PIs were retrieved based on a systematic literature review, which gives a sound theoretical foundation for the PF.

- 2) Dimensions: the PF conveys the following dimensions: leadership; managerial levers;¹⁷ innovation strategy; knowledge management; organisation and culture; portfolio management; project management; people, and market.
- 3) Procedure: the PF does acknowledge the process-based character of the innovation and the need to have a procedure. However, the PF does not provide a procedure nor applies the PIs in companies, as it is purely conceptual.
- 4) Facilitation: the authors stress that their aim is to provide a practical tool for by both scholars and practitioners, but the conceptual format of the PF does not provide support for such an application (no reference to implementation or facilitators).
- 5) Visualisation of performance progression: the concept of performance progression is mentioned in the study; however, it is not addressed in the PF.
- 6) Improvement actions: there is a short discussion on continuous improvement, but no guidelines nor support to define improvement actions are included in the PF.

The PF presented by Crossan and Apaydin (2010) is a good example of the execution of a systematic literature review to provide a broad multidimensional framework for the innovation process. Nonetheless, two main supporting elements are missing from the PF proposal, the procedure to help managers in practice and the support for improvement actions. In addition, the lack of empirical validation also hinders the potential applications and further contributions of this PF.

2.3.9 FRAMEWORK TO DEVELOP INNOVATION KEY PERFORMANCE INDICATORS

This recent PF proposed by Lakiza et al. (2018) explores the steps associated with implementing innovation PIs. The authors emphasise three basic conditions in order to apply the PF; something often overlooked in past research, which resonates with the methodological discussion of this work. The conditions for a company to apply the PF are a minimum maturity level of innovation processes, strategic alignment addressing innovation to an extent, and commitment to innovation. The PF elements can be described as follows:

- 1) Indicators: the PF presents 37 indicators. Remarkably, these indicators are still very much based on productivity, which could conceal the true nature of innovation activities intermediary results and hinder future opportunities.

¹⁷Managerial levers are mission, goals, and strategy; structure and systems; resource allocation; organisational learning and knowledge management, and organisational culture (Crossan & Apaydin, 2010).

- 2) Dimensions: a discussion about dimensions is absent, but the PIs suggest implicit directions toward productivity (e.g., financial, operational, process, portfolio).
- 3) Procedure: the PF introduces the following steps applied in a large manufacturing company: meet the main stakeholders; understand what functions the PIs need to perform and how the company would use them; understand what successful innovation process means to them; select performance dimensions; cluster topics raised from the company into the dimensions; propose PIs; gain feedback and validate; assess the performance of the innovation process; implement PIs by stages depending on the innovation process performance; propose encouraged practices to improve the performance of the selected indicators, and finally, implement the improvement actions to achieve the desired behaviour.
- 4) Facilitation: the authors do not explicitly address the facilitators' role, but the study's outline suggests the active participation of the practitioners and researchers in the development and application of the PF.
- 5) Visualisation of performance progression: the authors argue that the implementation and use of PIs may present distinct evolutionary levels. However, the study does not deepen on how this would work for the PF.
- 6) Improvement actions: the authors make it clear that the evaluation of performance needs to identify where there are needs to be attended to, and what the actions to be taken to improve performance. Therefore, the PF guides the establishment of improvement practices for the company to achieve the desired state.

The PF proposed by Lakiza et al. (2018) is presented in this literature review because of two main contributions. One refers to the explicitly addressing the requirements to apply the PF, namely minimum maturity level of innovation processes, strategic alignment, and commitment to innovation. The second contribution relies on the emphasis given to the definition of the desired state and the definition and support for implementing the actions to improve performance.¹⁸ Nonetheless, the PF presents a limited view on dimensions and the visualisation of progression.

¹⁸Further three PFs from consulting companies were reviewed, only superficially, as the information was limited (most likely to protect their know-how). The first was unidimensional, focusing on open innovation (Erkens et al., 2014). The second presented seven dimensions, but improvement actions were not supported (it is up to the company to find actions) (COTEC & Deloitte, 2018). The third one only deals with technological innovations ("The readi-watch offering," 2019).

2.3.10 ANALYSIS OF EXISTING PERFORMANCE FRAMEWORKS

As mentioned before, the use of PFs helps managers operate the ‘fuzziness’ of the innovation process (Cooper, 2006; Crawford & Di Benedetto, 2011; Nilsson & Ritzén, 2014). In this way, the PF works as a systematic approach that enables the measurement and evaluation of the company’s capability associated with the process of developing new ideas into commercialised products/PSS (Becheikh et al., 2006; Dziallas & Blind, 2018).

A supporting element of the PFs that deserves special attention in this review is the procedure. The procedure not only demonstrates if the PF were actually developed and tested in practice (Chiesa et al., 1996; Kahn et al., 2006) but also shows the commonalities and lessons learned among existing PFs (Pigosso, 2012). Thus, an analysis of the procedures of the reviewed PFs in the previous section was carried out to build Table 2.4. This comparison is based on the grouping of similar activities or steps following the logic of a PF application: PF initiation for gathering data to identify the current situation (also called ‘diagnosis’ or ‘audit’); definition of PIs; implementation of the measurement *per se*, and proposition and implementation of improvement actions.

The second column of Table 2.4 refers to the PF initiation of data gathering to identify the current situation, designated as a diagnosis or an audit. It is notable that most PFs offer steps for this endeavour. There are only two PFs that do not provide activities: Kahn et al. (2006) and Werner & Souder (1997). Two main points should be highlighted here. The first point refers to the fact that a diagnosis/audit should make an effort to understand the core activities of the innovation process performed at the analysed company (e.g., Chiesa et al., 1996). The second point is that the level of performance should be not only measured but also evaluated (e.g., Loch & Tapper, 2002).

Further on, the definition of PIs in the procedure of the reviewed PFs presented as much detail as the diagnosis/audit. Practically all PFs, but two (Chiesa et al., 2009; Crossan & Apaydin, 2010), presented steps for the definition of PIs. Most activities for defining PIs are very similar to PFs from the manufacturing productivity research domain (Nudurupati, Bititci, Kumar, & Chan, 2011b). It is worth mentioning that the degree of details may vary among the PFs reviewed, with frameworks such as the balanced innovation front-end measurement by Berg et al. (2009) showing little information for managers while others, e.g., the framework to develop KPIs by Lakiza et al. (2018), presenting a more detailed approach.

LITERATURE REVIEW

Table 2.4. Comparison of the procedures of the reviewed PFs.

	Diagnosis/Audit	Definition of PIs	Implementation of PIs	Improvement actions
Framework for selecting R&D productivity indicators by (Brown & Gobeli, 1992)	– Clarify the responsibilities and context of R&D activities in the firm – Identify strategic goals – Identify the hierarchy of activities (managerially oriented) – Identify dimensions to be measured	– Identify the indicators – Develop measurement instruments – Identify a shortlist of PIs which could be easily monitored	– Capture the performance in the measurement system	– Assess performance changes over time – Establish improvements in the PF
Technical innovation audit by (Chiesa et al., 1996)	– Sep up facilitators – Form a small team to audit the company's processes	– Collect data for the audit review meeting to discuss initial findings – Interview key stakeholders interviews	– Meet to validate the outcomes of the audit – Discuss identified gaps between the current performance (diagnosis) and the desired state	– Identify areas for improvement – Prioritise improvement areas – Assign responsibilities
Performance framework for integrated indicators by (Werner & Souder, 1997)		– Use of qualitative indicators in the early phases of the innovation process – Quantitative indicators in the later phases	– Establish a consensus procedure for the treatment of qualitative indicators	
Performance framework for technology research by (Loch & Tapper, 2002)	– Identify and understand the innovation process (phases and activities) – Understand the role of R&D – Summarise business strategy – Cascade strategy into R&D strategies	– Identify the relevant performance dimensions – Formulate a set of PIs for the existing portfolio	– Enable learning in the implementation (not imposed)	– Enable benchmarking – Set up 'best practice' targets – Prioritisation of improvement actions

LITERATURE REVIEW

Table2.4. Comparison of the procedures of the reviewed PFs (continued).

	Diagnosis/Audit	Definition of PIs	Implementation of PIs	Improvement actions
New product development best practice framework by (Kahn et al., 2006)			– Apply a questionnaire to verify whether best practices applied in the company within the dimensions considered	
Balanced innovation front-end measurement by (Berg et al., 2009)	– Define the nature of the companies' discontinuous innovation environment	– Select of performance dimensions – Select data sources	– Collect data	– Analyse results
Reference framework for R&D by (Chiesa et al., 2009)	– Motivate researchers and engineers and improve their performance in R&D activities		– Monitor the progress of R&D activities with respect to resource consumption targets, milestones and technical requirements – Evaluate the performance of R&D activities and their contribution to the firm's economic value	
Multidimensional framework of innovation by (Crossan & Apaydin, 2010)	– (No procedure is given, but the authors recognise the process-based approach for the diagnosis)		– (No procedure is given, but the authors recognise the need to have a procedure to evaluate performance)	
Framework to develop innovation key performance indicators by (Lakiza et al., 2018)	– Outline the measurement initiative – Meet the main stakeholders – Understand what functions the PIs need to perform and how the company would use them	– Understand what successful innovation process means to the company – Select performance dimensions – Cluster topics raised from the company into the dimensions – Propose KPIs – Gain feedback and validate PIs	– Assess the performance of the innovation process; – Implement KPIs by stages depending on the innovation process performance	– Propose encouraged practices to improve the performance of the selected indicators – Implement the improvement actions to achieve the desired behaviour

Having defined the PIs, the next cluster of activities of the procedures refers to measuring performance. It is interesting to note that the PF more thorough in terms of steps is the one proposed by Chiesa et al. (2009). Nonetheless, suppose one examines the nature of the steps in this PF and compares to the others, one might notice that the steps are mostly generic, with activities such as “monitor the progress” and “evaluate performance”. Moreover, the evaluating performance is not properly addressed in most of the PFs, as the how-to evaluate performance is not fully supported, almost like a ‘black box’ (McCarthy & Gordon, 2011). For instance, questions like ‘what to compare the actual performance to’; ‘how to define the desired performance’ and ‘how to define improvement actions remain unanswered.

The final cluster of activities of the procedure of the reviewed PFs refers to the improvement actions. As mentioned earlier, only measuring the performance does not guarantee improvement. For this, action must follow measurement. However, it is possible to observe in Table 2.4 that this cluster presents less support from the literature, evidenced by three PFs with no activities for this at all (Chiesa et al., 2009; Crossan & Apaydin, 2010; Werner & Souder, 1997). Now, two PFs can be highlighted here. In particular, Brown and Gobeli (1992) demonstrated the central relation between evaluating performance and proposing improvement actions already in the 1990s, that, remarkably, was fully addressed until Lakiza et al., (2018) PF fully addressed improvement actions. In fact, the connection between performance and action is almost missing from other PFs (e.g., Berg et al., 2009; Loch & Tapper, 2002), as their procedure provides little guidance on this matter.

Another critical part of the review concerning the procedure revolves around the issue of techno-centric take on PFs. From the existing PFs reviewed, the ones proposed until the early 2000s clearly adopt a techno lens to see the innovation process by focusing on the outputs of the R&D area, department or unit (Adams et al., 2006). The view on innovation starts to change when the OECD establishes and disseminates the definition of innovation as a significant change in either technical specifications or user-friendliness. Therefore, the frameworks proposed by Kahn et al. (2006), Berg et al. (2009), Chiesa et al. (2009), Crossan & Apaydin (2010) and later on Lakiza et al. (2018), are not constrained to the technological bias of considering innovation exclusively as an output of the R&D, but a process with a multidimensional nature.

This techno-centric bias is a known limitation of PFs proposed for the innovation process already recognised in the literature. Along with this limitation, other issues can be addressed as well, as illustrated in Table 2.5. Thus, another issue discussed in the literature is the lack of formal theoretical basis to propose the PFs, with a few PFs being developed based on loosely researched methods, with no structured research or empirical evidence (Bach, 1994; Biberoglu & Haddad, 2002). This issue can be further evidenced by the absence of consensus determining the critical performance dimensions to be considered in a PF. Another limitation that can aggravate this issue is the little documentation or research available on how to develop a PF that is theoretically sound and tested in practice (de Bruin, Freeze, Kaulkarni, & Rosemann, 2005). This shortage can be found, for example, in the balanced innovation front-end measurement framework (Berg et al., 2009), since the PIs and dimensions used in the PF not justified by analysing the research literature nor the practice.

Table 2.5. Main issues related to existing PFs.

Issues	References
Techno-centric bias towards the measurement and management of the innovation process.	(Adams et al., 2006; Becheikh et al., 2006; Crossan & Apaydin, 2010; Dziallas & Blind, 2018)
Lack of formal theoretical basis in the development of PFs.	(Bach, 1994; Biberoglu & Haddad, 2002)
Little documentation on the theoretical foundation of the developed PF tested in practice.	(de Bruin et al., 2005)
Insufficient information produced by the performance evaluation activities to support the planning and implementation of improvements.	(Brattström et al., 2018; Iversen, Nielsen, & Norbjerg, 1999)
Lack of description of how to identify possible action plans/ changes to management practices.	(Pfeffer & Sutton, 1999)
Stagnation of the PFs in relation to new concepts and dimensions.	(Klimkó, 2001)
Most PFs based on best practices are not suitable/tested for SMEs.	(Biberoglu & Haddad, 2002; Boly et al., 2014; Dziallas & Blind, 2018)
The adoption of PFs encourages too much bureaucracy.	(Herbsleb & Goldenson, 1996)
Difficult to differentiate whether the PF is an accurate reflection of reality or a mere projection of an artificial view.	(Klimkó, 2001)

One more issue pointed out by the literature as criticism is evident in the presentation of some existing PFs in the previous sections. It refers to the insufficient information produced to support the planning and implementation of improvement actions (Brattström et al., 2018; Iversen et al., 1999). This deficiency is closely related to the lack of description of how to perform possible changes to processes and activities (Pfeffer & Sutton, 1999). The PFs that do present more detail to support the company in planning and implementing improvement

actions are the framework for selecting R&D productivity indicators by Brown & Gobeli (1992) and the framework to develop innovation KPIs by Lakiza et al. (2018).

A further limitation of many PFs, and to some extent an issue for all management tools, is that they may be stagnated in time, with outdated definitions or lacking critical new internal and external conditions (Klimkó, 2001). For instance, existing PFs, even the most recent one, overlook possible dimensions that may impact innovation performance environment, such as servitisation (Markham & Lee, 2013). Even though it is difficult for a management tool to be up-to-date without relying on extensive communities of practices, new management tools build on top of accumulated knowledge have a head start (Kohlegger et al., 2009).

Most PFs are based on best practices, related to process improvement practices derived from favourable results of studies in large companies, and therefore, are not applied in SMEs (Biberoglu & Haddad, 2002). This issue was already addressed in the research gap (section 1.1.3, Table 1.1), when several authors identified the need to include SMEs in the development process of new PFs (Boly et al., 2014; Dziallas & Blind, 2018). The only PFs which presented evidence of taking into account SMEs are the technical innovation audit proposed by Chiesa et al. (1996) and the new product development best practice framework by Kahn et al., (2006).

Finally, there are two remaining issues in the literature. Herbsleb & Goldenson, 1996 point out that adopting PFs may encourage too much bureaucracy, hindering people from being flexible and dynamic. This might be true to a degree, especially if a system with too many requirements and little room to customisation is in place. Nevertheless, countless studies have identified that the advantages of using a PF outnumber the disadvantages (cf. Adams et al., 2006; Chiesa et al., 1996; Crossan & Apaydin, 2010; Henttonen et al., 2016). In addition, PFs can also be challenged whether they are an accurate reflection of a truly existing development in reality, or merely a projection of an artificial view which would limit the understanding of the companies (Klimkó, 2001). This is a limitation common to any endeavour to represent reality in some form, from a management tool to an accurate modelling system, that should not hinder researchers in the creation of new studies (Neely, 2005).

2.3.11 DEVELOPMENT OF PERFORMANCE FRAMEWORKS

Certainly, as alluded earlier in this work, the most relevant PFs reviewed in this chapter come from two diverse main streams of literature – technology and innovation management, and

managerial accounting. Therefore, it would not be surprising for researchers from these different disciplines to build their PFs on different theoretical bases and employ diverse research methods in their development.

Neely (2005) already argued that, despite the different research methods applied in the development of PFs, there is a shift in the research literature to more methodological sound pieces, which suggests increasing academic professionalism of the research field. Taking the existing PFs reviewed here as illustrative examples, it is possible to observe an increasing combination of theoretical and empirical development along the studies (see Table 2.6). This combination is particularly interesting to address the limitations of PFs mentioned earlier, the lack of formal theoretical basis for their development (Bach, 1994; Biberoglu & Haddad, 2002) and most PFs not being theoretically sound and tested in practice (de Bruin et al., 2005).

Table 2.6. Development of existing PFs.

Performance frameworks	Theoretical development	Empirical development
Framework for selecting R&D productivity indicators (W. B. Brown & Gobeli, 1992)	✗	✓
Technical innovation audit (Chiesa et al., 1996)	✓	✓
Performance framework integrated indicators (Werner & Souder, 1997)	✓	✓
Performance framework for technology research (C. H. Loch & Tapper, 2002)	✓	✓
New product development best practice framework (Kahn et al., 2006)	✓	✓
Balanced innovation front-end measurement framework (Berg et al., 2009)	✓	✓ Participatory
Reference framework for R&D (Chiesa et al., 2009)	✓	✓ Participatory
Multidimensional framework of innovation (Crossan & Apaydin, 2010)	✓ Systematic review	✗
Framework to develop innovation key performance indicators (Lakiza et al., 2018)	✓ Structured review	✓ Participatory

On a closer look, the theoretical development is progressing from a traditional narrative literature review to a more structured one to provide a comprehensive take on the necessary constructs (Crossan & Apaydin, 2010). These systematic and structured reviews consist of reproducible research methods to review the literature in order to obtain a meaningful and representative collection of studies to map existing and preceding knowledge

(Biolchini, Mian, Candida, & Natali, 2005). Quality of reviews is improved through transparency, a broader range of studies included, increased objectivity and reduction of implicit researcher bias by encouraging researchers to engage more critically with the quality of evidence (Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007). The results of such an approach provide not only comprehensive but also more representative theoretical proposals (Barquet, 2015; Pigosso, 2012).

Additionally, the empirical development is becoming more focused on participatory research methods, such as case study and action research, that, according to Lakiza and Deschamps (2019), provide a better understanding of the application of the PF in the companies and an impactful solution for the real users. A case study is a research method that aims to understand if/how a developed theory works in practice within organisations, enabling to test the theory using empirical conditions, but without applying an interventionist approach (Voss, Tsikriktsis, & Frohlich, 2002). Action research, in contrast, can be defined as a research method in which a scientific approach is applied to study the resolution of key organisational problems inside companies with the active participation and intervention of the people involved with these problems, allowing the development of theory in action (Coughlan & Coughlan, 2002). These research methods simply noted here, and along with systematic literature review, they are properly discussed in the chapter on methodology.

The challenge now for the research community is to build on previous research and, at the same time, take the research agenda forward. However, if new studies fail to do so, then research risks becoming trapped by solutions proposed for problems of the past. One way of exploring the nature and impact of this challenge is by using a comprehensive research approach combining the advantages of a systematic literature review, case study and action research, a discussion presented in Chapter 3 “Methodology”.

2.4 REMARKS

In conclusion, both technology and innovation management and managerial accounting have received considerable attention over the last three decades, which has resulted in growing bodies of literature. On the one hand, studies from technology and innovation management collectively outline the critical role of having a systematic approach toward the innovation process to manage down the amount of risk and uncertainty as one goes from idea generation in the IFE to the product/PSS disposal in EoL. On the other hand, managerial accounting studies

present the foundation on which performance measurement processes are built. Together these studies provide valuable insights into how performance measurement can support and enable the improvement of the innovation process.

A variety of PFs to measure process performance exist and the ones relevant for evaluating the performance of the innovation process have been examined. On closer inspection; however, it becomes clear that these PFs are not enough to respond to the open calls for new research. New PFs need to provide a holistic view on relevant dimensions (Dziallas & Blind, 2018; Henttonen et al., 2016; Lee & Markham, 2016), accommodate 'best practice' PIs and further steps to select more according to the company's strategic drivers (Brattström et al., 2018; Lee & Markham, 2016), and be applied in small/medium-sized companies (Boly et al., 2014; Dziallas & Blind, 2018). More importantly, new PFs need to go beyond measurement to support the identification of gaps between current and desired performance and to generate key information that can be used in the definition of improvement action plans (Boly et al., 2014; Brattström et al., 2018; Dziallas & Blind, 2018; Henttonen et al., 2016; Lee & Markham, 2016).

This study, therefore, puts to use the fundamentals discussed in the reviewed literature. This work aims to propose all the composing elements for a new PF, i.e., the database and supporting elements that can help a manufacturing company measure and evaluate innovation performance by diagnosing their current situation and then defining the most suitable action plans. This proposition is only possible by following a sound methodology, combining theoretical and empirical development, which is the topic discussed in the next chapter.

3 METHODOLOGY

The main purpose of research is to inform action, develop and prove a theory, and ultimately contribute to creating knowledge in a field of investigation (Ahlström, 2016). Within this context, knowledge can be defined as the information that has been analysed and organised in order to make it understandable and applicable to problem-solving or decision-making situations (Turban & Frenzel, 1992).

This work is positioned within the research field of operations management (OM).¹⁹ This field concerns with the study of processes and operations in the transformation of products/services (Karlsson, 2016). Among the OM topics, the innovation process is one of the most researched areas. Thus, it can be said that both technology and innovation management and managerial accounting literature are contributing bodies to the OM. Research within this field is typically pragmatic and conducted in close proximity to industry (Voss et al., 2002). According to Ahlström (2016), the key challenge for researchers in this field is to create knowledge that generates value for both academia and practice alike.

In this sense, this work aims to contribute to innovation measurement and management on two fronts. Firstly, this study can be beneficial for researchers who need a swift identification of relevant studies and possible insights into the state-of-the-art innovation measurement concerning existing PFs and indicators. Valid and relevant PIs and frameworks can free subsequent researchers from the need to redevelop these measurement tools. Secondly, this research can also provide further support for senior and middle management of manufacturing companies, such as innovation coordinators and managers, as the resulting PF is a management tool. This tool can help managers in the innovation measurement and ensure that improvement actions follow measurement.

It is hoped that this chapter may provide some guidance for any reader less familiar with established methods in qualitative research. First, the methodological aspects are discussed in section 3.1, followed by the research design in section 3.2. The outline of the research activities is given in section 3.3. Section 3.4, in turn, presents the strategies applied to select the participating companies. Lastly, the validity and rigour of the research method are presented in section 3.5. Then, this chapter concludes with summary remarks.

¹⁹OM is also known as operations research, mostly in the US (Bertrand & Fransoo, 2016).

3.1 METHODOLOGICAL ASPECTS

According to Karlsson (2016), the considerations around methodological aspects will typically vary depending on the volume and maturity of existing knowledge in the collective body of research in OM. Because of the cumulative character of knowledge and the sequential development of the research field, he suggests four phases of the development of knowledge: exploratory, descriptive, explanatory and prescriptive.

Initially, with little to base theoretical development on, studies are exploratory. Research focusing on concepts, classifications and definitions characterise this phase. After many exploratory studies, an increasingly better description of the object of study emerges, and the research can be said to have entered the descriptive phase. Following this, the growing number of descriptive studies build a solid foundation for more explanatory research, which enables the development of models to understand how one condition or variable will cause a specific effect. Then, based on the accumulated knowledge from analytical models, prescriptive research starts to elaborate on studies of management tools, such as normative models and checklists, to implement those in practical cases and give advice (Karlsson, 2016).

In this sense, the expected journey of knowledge development is to explore before describing, identify the components before establishing the relations between them, and understanding the relations before foreseeing the effects, to finally, be able to prescribe models. Following this reasoning, this research can be classified as prescriptive, since it proposes the development of a new analytical tool, the PF, to support the companies in measuring and managing the innovation process. In addition, from the perspective of the PF itself, as a new tool, the research is also exploratory, as this work is investigating the application of this tool for the first time.

Research can also be classified according to the nature of reasoning undertaken to solve the research problem: inductive, deductive or abductive research (Karlsson, 2016). This is related to the starting point assumed by the researcher to approach the object of study and the logic adopted. Inductive research in OM starts with collecting data and observations empirically to discern patterns within those observations, aiming to formulate a proposition or a new theory. In turn, deductive research begins with developing a conceptual structure based on existing knowledge and theoretical foundation and seeking to test the proposition, confirming or rejecting. In this approach, often, the theory developed with the new knowledge

is assumed to be established as a valid explanation after being tested and corroborated. Abductive research, in a way, combines inductive and deductive. It starts with a real concluded situation, and then it goes to the theories that can help explain it. The process becomes deductive to see if the explanation, or theory, seems reasonable.

Nevertheless, a theory²⁰ can never be proven to be true by a finite number of observations, no matter how many confirmatory instances have been performed (Karlsson, 2016). A theory requires only one contradictory observation to be falsified. Thus, a theory can never be proven as completely true since there is always a possibility of falsifying it. Building on this, the logical thinking of the hypothetic-deductive approach proposed by Popper is that while theories can never be proved to be true, they can be falsified (Birkinshaw, Hamel, & Mol, 2008). To test the theory, hypotheses or propositions are created and attempted to be falsified through a series of empirical applications and tests (Gill & Johnson, 2002).

In this present study, the proposition advocated is that the measurement and evaluation of the innovation capability of a manufacturing company can be supported by a PF, initially in the form of conceptual structure, based on existing knowledge. Then, this conceptual structure will be applied in real cases to test and refine the theory within the hypothetic-deductive approach. When the tested framework is corroborated, the theory can be established as valid (unless/until is falsified in the future). To that end, the definitions of the methodological aspects help guide the research design that needs to present a methodological fit between the prescribed and exploratory characteristics of this research and the hypothetic-deductive approach.

3.2 RESEARCH DESIGN

The choices made in the design of the research reflect the researcher's view on the object of study and its surroundings, i.e., the philosophical position. This work conforms to the methodological framework shown in Table 3.1 proposed by Meredith, Raturi, Amoako-Gyampah, & Kaplan (1989) that indicates the methods available according to the philosophical position adopted by the researcher(s). It represents a continuum with two endpoints: the positivist researcher (deductive) and the interpretative researcher (inductive).

²⁰A theory can be defined as a set of propositions of an object of study. Each proposition in the theory consists of concepts and specifications of relations between these concepts. Such relations are assumed to be true for the object of study. They can, therefore, be seen as predictions of what will happen in instances of the object of study under certain circumstances (Dul & Hak, 2008).

Theorems and modelling can be found in the deductive extreme, aiming to reconstruct or replicate the object reality. Here, the positivist researcher sees reality as objective; the world is external to the individual. The goal is to discover the detached truth and provide conclusions that are replicable and generalisable. The interpretative researcher, on the other hand, assumes that reality is socially constructed. Research becomes dependent upon the researcher as a participant. Ethnography and introspective reflection as available methods for inductive treatment of reality. Generally, the application of research methods from both endpoints is not common in OM research, as they can be hard to execute in the organisational context and may not offer the fruitfulness of data collection alternative methods. Nonetheless, the middle ground shows a variety of methods more commonly applied in OM, such as field studies and experiments, interviews, surveys, case studies, action research, which enable contributions to both theory and practice.

Table 3.1. Methodological framework (adapted from Meredith et al., 1989).

		Natural			Non-natural
		Direct observation of the object	People's perception of the object	Reconstruction/Replication of the object	
Deductive	Axiomatic/Positivist			Theorems Normative modelling Descriptive modelling	
	Positivist/Empiricist	Field studies Field experiments	Structured interview Survey Systematic literature review	Prototyping/ physical modelling Quasi experimentation Simulation	
	Interpretative	Case studies Action research	Historical analysis Literature review Delphi method Interviews Expert panels Future scenarios		
Inductive	Critical theory	Ethnography	Introspective reflection		

Among these middle ground methods, case study has been consistently the most prevailing for testing a new theory (Karlsson, 2016). It involves the up-close and direct examination of the object under investigation, observed in its natural everyday setting in the organisations (Eisenhardt & Graebner, 2007; Voss et al., 2002). Thus, in cases in which the proposition is to be tested (or to be refuted in the case of hypothetic-deductive approach), the preferred research strategy for testing is multiple instances of an experiment in a controlled environment (Karlsson, 2016). The second-best is a case study when experiments are not possible (Dul & Hak, 2008). Since it is not possible to test the proposition with a highly

controlled experiment for this work, the relevance of the case study as a research method for theory testing is reinforced.

What is often seen as a valuable variant of case study, but with a twist of interpretative positioning, is action research (AR). AR uses a scientific approach to study the resolution of critical organisational problems with the participation of the people involved with these problems, rather than in laboratory conditions in which researchers can exercise a great deal of control and manipulate variables (Gill & Johnson, 2002). In an AR study, the researcher(s) acts upon beliefs and prior theories in order to collect and interpret data to enable changes to the organisation (Coughlan & Coughlan, 2002). For this, the method produces a richness of data and details that other methods cannot provide, with the support of interviews, observations, surveys and more, to develop and improve theory in this natural setting before testing it (Maestrini, Luzzini, Shani, & Canterino, 2016; Rytter, Boer, & Koch, 2007).

In the case that the subject under investigation is observed in its natural everyday setting, the success of the new theory needs to be assessed (Farris, Van Aken, Letens, Ellis, & Boyland, 2007). The assessment should evaluate the applicability, usability and usefulness of the theory support in practice (Blessing & Chakrabarti, 2009). In OM, applicability refers to the conditions of the study given by the context in which the new tool is to be used whereas usability relates to the extent to which the tool can be applied by specified users to achieve the defined goals. Usefulness, in turn, addresses how successful is the theory developed in achieving the formulated aims of the proposition. An overall assessment can only be truly measured in the intended situation, and in many instances as possible. More importantly, Blessing & Chakrabarti (2009) argue that usefulness assessment can be based on the analysis of the same empirical cases used to develop and test the theory.

Furthermore, any new theory to be further developed in AR or tested through case study is initially developed from theoretical foundations based on literature reviews (Ahlström, 2016). These reviews can be systematic with a structured and reproducible method built around a central issue that allows the analysis, synthesis of previous discovery in an orderly fashion (e.g., Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007) or the traditional narrative approach (Ahlström, 2016), as in Chapter 2. Unlike narrative reviews, systematic reviews apply appropriate bibliometric techniques to make sure the findings are representative and relevant, often discussed within the results section (Ahlström, 2016).

Therefore, given the range of available research methods as well as methodological aspects related to the nature of this work previously discussed, the research design comprises literature reviews, AR, and case study. These methodological choices are compatible with the exploratory and prescriptive nature of the research carried out here. They also have been proven to be a methodological fit with the hypothetic-deductive approach in previous research (e.g., Barquet, 2015; Pigosso, Rozenfeld, & McAloone, 2013). Figure 3.1 shows the research design proposed for this research.

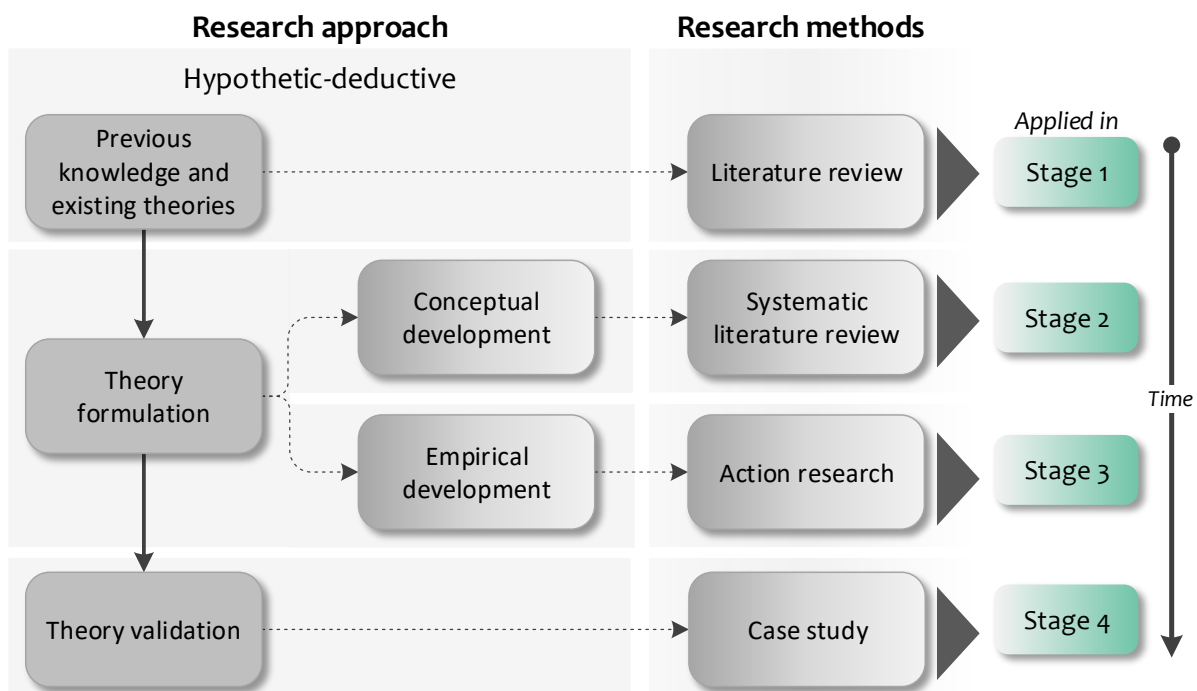


Figure 3.1. Methodological choices for the research design.

The literature is initially reviewed to gather previous knowledge and existing theories (stage 1). Based on the findings, the theory formulation is performed, combining conceptual and empirical development. The conceptual development²¹ is based on a systematic literature review to elaborate on the content of the conceptual version of the PF (stage 2). Following this, an improved version of the PF is empirically developed in distinct companies via AR (stage 3). Finally, to validate the new theory, i.e. that the PF could support companies in measuring innovation performance and defining improvement actions, a case study is conducted followed by an overall assessment based on applicability, usability and usefulness of the PF. For this, the research activities are outlined next.

²¹Some authors also use 'theoretical' development instead of conceptual development of a model or PF (Pigosso, 2012).

3.3 RESEARCH METHOD

This section outlines the activities of the research method. The activities in stage 1, presented in section 3.3.1, gather initial evidence to formulate research objectives and the research design (Figure 3.2). Then, the activities in stage 2 involve a systematic review of the literature to elaborate on a synthesis of the PF elements (section 3.3.2). Stage 3 activities are presented in section 3.3.3 when the empirical development takes place, resulting in the improved and final version of the PF. Lastly, the activities in stage 4 are outlined in section 3.3.4, addressing the test of the final version of the PF and its overall assessment.

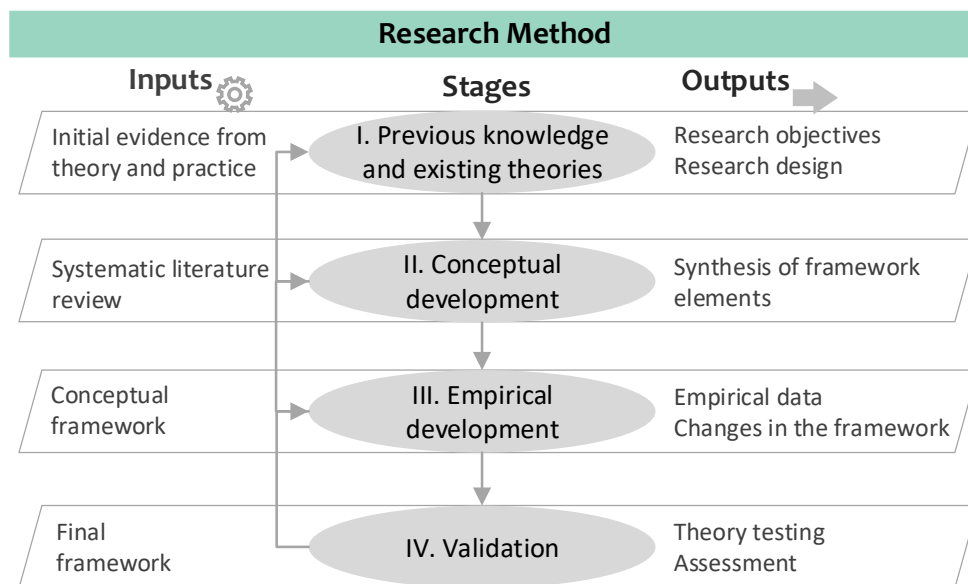


Figure 3.2. Summary of the research method with the four stages.

3.3.1 STAGE 1: LITERATURE REVIEW OF PREVIOUS KNOWLEDGE AND EXISTING THEORIES

In stage 1, the initial evidence from both theory and practice is identified and analysed to formulate a realistic and worthwhile research objective and a research design. Thus, the literature is searched to clarify the overall research objective and research gap. An initial description of the existing situation is then produced based on evidence collected from theory and practice. There are four main activities within this stage as follows (see the outline of all research activities in Figure 3.3):

- **A1.1) Review the literature on technology and innovation management:** this activity involves reviewing one of the central bodies of literature related to the research. The review comprehends the discussion on the concept of innovation, the process

involved, its phases and main characteristics when developed in manufacturing companies. The results of this review were presented in section 2.1.

- A1.2) Review the literature on managerial accounting: this step reviews another main body of literature known as managerial accounting to deal with definitions related to performance measurement, its main functions, individual PIs, sets of PIs and performance dimensions, measurement environment, and the definition of a PF. The results were already presented in section 2.2.
- A1.3) Identify the critical elements required for the PF: the literature is analysed to identify the critical elements required to conceptualise a new PF. These elements are not only the foundation for the PF proposal, but they also guide the scope and definition of the systematic literature review (SLR) to be performed in the next stage. The results are described in section 2.2.4.
- A1.4) Identify and review PFs from the literature: the goal of this activity is to identify existing PFs that may address the innovation process within the two central bodies of literature previously mentioned. The existing PFs reviewed are either conceptual or practical so that evidence from both theory and practice are considered. This review outlines their common elements and how the authors define them, followed by a comparative analysis (see section 2.3 for results).

3.3.2 STAGE 2: CONCEPTUAL DEVELOPMENT OF THE PERFORMANCE FRAMEWORK

In stage 2, with a clear vision of the desired research outcome, the research sets out to review the literature in a more structured way to search for building blocks to develop the PF conceptually. In this sense, a systematic review is conducted with the purpose of creating a description detailed enough for the theoretical version of the PF, effectively and efficiently as possible. Stage 2 presents five main activities that are detailed as follows:

- A2.1) Map the available literature on the theoretical domain systematically: this activity consists of a systematic bibliometric mapping of the available literature on the theoretical domain of PFs. This is achieved through a systematic literature review (SLR), i.e., a reproducible and structure research method to review a meaningful collection of studies to map existing knowledge and create synthesis. The protocol of the SLR is presented in Appendix I, while the bibliometric results of the literature mapped are discussed in Appendix IV.

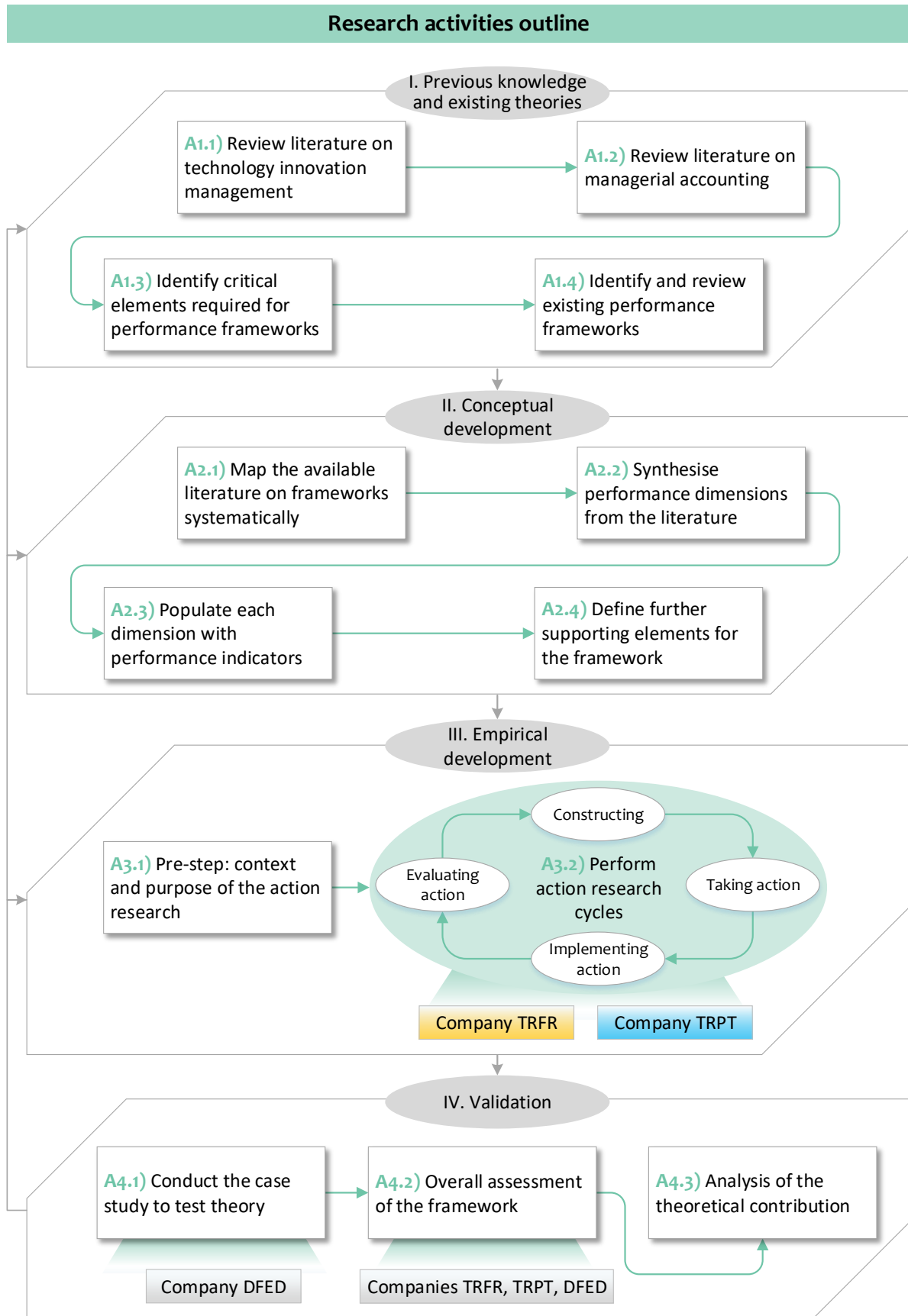


Figure 3.3. Outline of the research activities performed.

- A2.2) Synthesise performance dimensions from the literature: one of the main elements of a PF are performance dimensions. Therefore, the purpose of this activity is to identify, collect and synthesise from the literature via the SLR, the performance dimensions empirically demonstrated to be significant in the innovation measurement and management. These resulting dimensions are explained and discussed in section 4.2.1.
- A2.3) Populate each dimension with performance indicators: another critical element is the indicators. Hence, this activity aims to populate each previously identified dimension with PIs also retrieved from the literature via the SLR. The discussion on the retrieved PIs is presented in section 4.2.2, but because of its considerable size, the full database of 259 indicators is only shown in Appendix V.
- A2.4) Identify and characterise further supporting elements: once the database elements (dimensions and indicators) are synthesised and collected, the next step concerns with the definition of further supporting elements identified as critical to the development of a new PF, as defined in activity A1.3, and presented in section 2.2.4 of the “Literature review”. The results for these elements are presented as follows: initial procedure (section 4.3.1), facilitation (section 4.3.2), visualisation of performance progression (section 4.3.3) and support for improvement actions (section 4.3.4). Note that the research design informs that these supporting elements are further developed in the AR, enabling the capture of real insights from the practice, and then tested in the final case study.

3.3.3 STAGE 3: EMPIRICAL DEVELOPMENT OF THE PERFORMANCE FRAMEWORK

The increased understanding of the existing knowledge from the previous stage enables the PF conceptual development. This conceptual form represents the prior knowledge as well as the researcher’s own views on how addressing one or more factors in the existing situation would lead to the realisation of the established research objective. Unlike the previous stage, the third stage is empirical, with the application of the PF’s conceptual version in an AR. The goal of this stage is to further improve the PF based on the practical experience of applying it in two companies. As a result of the AR, a final version of the PF is developed to be tested in stage 4.

The AR employed in this research follows the methodology presented by Coughlan & Coughlan (2002). This methodology is composed of a pre-step (context and purpose) and a cyclical four-step process of: constructing the current situation of the company and relevant problems; planning action, in which questions like “what needs to change”, “how to support the change” and “how to develop commitment with the employees” are answered; implementing action drawn from answering the previous questions are put in practice; and evaluating action means to evaluate and reflect upon the accuracy of implemented actions taken, which may lead to further new cycles. The activities are described as follows:

- A3.1) Pre-step: context and purpose: this step comprises the following tasks:
 - Obtain knowledge about the company: to understand the context in which the company is inserted, when general data about the organisation and its business are gathered;
 - Determine the scope of the AR: it includes definitions on how the AR is going to be carried out and on the what main outcomes that the company and the researcher can expect from the AR;
 - Gain access in the company: this task aims to ensure access for the researcher in the company, including access to documents and relevant employees, in order to perform the steps of the AR.
- A3.2) Perform the action research cycles: the PF is applied in the companies according to the conceptual development carried out in stage 2. At each AR cycle, the behaviour of the PF is verified, opportunities for improvements are identified jointly with the company and implemented in subsequent cycles. AR involves:
 - Constructing: this step aims to gather data from the organisation’s current state with the support of document analysis,²² interviews, observations, with a view to making them available for analysis and articulate the theoretical foundations for action;
 - Planning action: defines the way in which the action is going to be executed. This includes providing answers to questions such as: “what needs to change?” and “how to support the change?”

²²Form of qualitative analysis in which documents of the company (e.g., corporate plan, annual reports, operational planning documents, reference models) are interpreted by the researcher to give voice and meaning around an assessment topic.

- Implementing action: involves the implementation of the actions planned in the previous step in collaboration with relevant key members of the company typically in focus groups²³ and the search for insights in the outcomes (both expected and unexpected) resulted from these actions.
- Evaluating action: encompasses the reflection on the outcomes of the action and a review of the cycle. To support this, an evaluation questionnaire is developed following research on evaluating management models and frameworks (Barquet, 2015; Pigosso et al., 2013). The questionnaire can be seen in Appendix III, and its methodological discussion is presented in section 3.5.2.

To assist the AR execution and provide academic consistency, journal keeping is a useful mechanism for recording data and interpreting it systematically during the cycles (Coughlan & Coughlan, 2002). The journal used in this research compiles: cycle number; date; AR activity; actions planned; actions implemented; results; lessons learned; and emerging questions to be addressed in the next cycle. In this way, the step for evaluating actions includes a collective milestone to analyse the results, lessons learned and emerging question, that in the end, determines the need for a new cycle. It means that a subsequent AR cycle should be performed whenever needed and, consequently, new elements of the management tool should be developed. To preserve confidentiality, the journal maintained during the research cannot be shared in this document, but the overall structure can be seen in Appendix II.

Finally, the execution of AR in different companies can be either simultaneous or sequential. The sequential approach is recommended if the researchers and participants wish to concentrate on implementing changes in the participating company and in the developed tool before proceeding to a new AR cycle (Gillon, 2018). With this sequential approach, it can also be easier to engage employees and stimulate ownership among them.²⁴ Therefore, the decision here is to perform the AR sequentially in this work. Section 5.1 presents the results of the AR in the first company, section 5.2 for the second company, and section 5.3 presents the PF improvements during the AR (5.3.1), followed by the consolidated version of the PF (5.3.2).

²³In OM research, focus groups are a small, but demographically diverse group of people, that perform tasks within a studied topic of investigation guided by facilitators, mostly conducted in workshops (Morgan, 1997).

²⁴The 'division' of the researchers' attention and efforts simultaneously into a number of companies may have an effect on the level of engagement and ownership felt by the practitioners from the companies (Gillon, 2018).

3.3.4 STAGE 4: TEST OF THE PERFORMANCE FRAMEWORK

In order to validate the final version of the PF, the framework was applied in a case study for theory testing in the fourth stage of this research. Dul and Tony Hak (2008) define a case study as a qualitative research method applied in companies to understand how/if a particular theory developed works in practice, aiming to test the theory in real settings. The main difference from AR is that case study does not apply an interventionist approach during the research (it may, however, indicate future recommendations). Thus, the goal in stage 4 is to try to refute a theory by testing it via the execution of the case study. The following activities are involved in this stage:

- A4.1) Conduct the case study: to ensure proper application of the PF in the company, access and commitment of the company's areas, which are essential to the development of the research, must be ensured. Additionally, the role that the researcher should play during the development of research must be clearly defined. The case study is conducted following the steps and instruments for data gathering defined by the procedure of the PF, to test it. The results of the case study are presented in sections 6.1.
- A4.2) Overall assessment of the framework: the results of the case study together with the analysis performed in AR enable the verification of the confirmation or rejection of the proposition advocated in this research. For this, the PF is evaluated in terms of applicability, usability and usefulness according to Blessing & Chakrabarti (2009). The results of this activity are presented in section 6.2. The data analysis research is qualitative, i.e. a non-statistical test of the correctness of the proposition is carried out, as demonstrated as valid in such circumstances in previous research (Pigosso, 2012). A more detailed methodological discussion about the validity and rigour is given in section 3.5.
- A4.3 Analysis of theoretical contribution: after the assessment of the PF value to the practice, the contributions to the academy are analysed. For this, a specific literature review is performed to identify comparison criteria for frameworks expressing their value in academic studies. These criteria help compare and identify distinguishing and common features of the proposed PF and the existing ones. Results are discussed in section 6.3.

3.4 SELECTION OF PARTICIPATING COMPANIES

The degree of confidence in a theory developed in a specified domain, i.e., its 'generalisability', can be enhanced by repeated tests of the hypothesis or proposition (Dul & Hak, 2008). In a single test, in turn, a theory cannot be 'proven' to be correct, but it can have the potential to increase its validation in further studies. A failure to find rejections in many different attempts provides further confidence that the new theory might be generalisable for that particular domain (Eisenhardt & Graebner, 2007).

In this sense, multiple cases can generate a more sound theory as the test of the proposition is deeply grounded in diverse empirical evidence from several companies. Even though case numbers are typically small, a few additional cases can significantly affect the quality of the emergent theory. For instance, adding three companies to a single-case is modest in terms of numbers, but offers further analytic power (Eisenhardt & Graebner, 2007). Thus, theory-building from multiple cases typically yields a more robust theory than a single case. Therefore, to improve the confidence of the proposition validation in this research, two cases are used for the conduction of AR, followed by a case study to test the theory developed. Previous research has proven that three cases can be enough to develop a new PF (e.g., Brattström et al., 2018; Medori & Steeple, 2000; Pigosso, 2012). Thus, even though the application of the PF in three companies cannot be exhaustively conclusive neither provide an overall generalisation of the results, it can enhance the validity of the developed theory.

According to Eisenhardt & Graebner (2007), the sampling strategy for selecting participant companies should be intentional in order to illuminate and extend the domain in which the research is positioned. Thereby, the strategy in this research considers the industry and sectorial particularities as they strongly influence the nature of innovation activities (Chiesa et al., 1996; Pavitt, 1990). Innovation has had a central role as a major driver of success in the manufacturing sector (Tidd et al., 2005). This understanding remains valid until nowadays in this industry (EU, 2016). Moreover, Tidd et al. (2005) argue that technology-intensive manufacturing firms, with technological knowledge accumulated by the design, creation and operation of complex production systems, have similar posture towards the innovation process. This means that improvements are developed incrementally, often associated with the performance evaluation and further diffusion of best practices throughout the company.

As exposed in section 1.1.3 (“Research gap”), and reinforced in the discussion of existing PFs (in section 2.3), SMEs are somewhat overlooked in research developing PFs. In this way, SMEs companies classified under the section C (manufacturing) of the ISIC classification, following an innovation process with a minimum level of formalisation, and aspiring to improve innovation process performance are, therefore, the target group for whom the research is designed. These companies can benefit from the results of the PF application in terms of helping managers in the structuring the performance measurement and subsequent evaluation of gaps to define and implement improvement actions according to the company’s current situation and strategic drivers.

It is important to note that SMEs have an advantage in the management of their innovation process as they have flat structures with fewer management layers than large companies, and thereby, more flexible and adaptable to changing market needs (Alegre, Sengupta, & Lapiedra, 2013; Hudson Smith & Smith, 2007). In turn, large companies are more likely to invest in innovation since they can allocate more resources than SMEs (Becheikh et al., 2006; Kleinknecht, 1987). Nonetheless, SMEs, more small than medium-sized companies, may face the challenge of information deficits due to the lack of capital (Becheikh et al., 2006). That is why past research on PFs has focused favourably to specific types of organisations, mostly large companies (Biberoglu & Haddad, 2002).

Table 3.2 presents the summary of the participating companies in this research, selected according to the target profile. First, Company TRFR is a medium-sized European manufacturer of power transformers, classified under category 27 of the ISIC classification. The application of the PF throughout the AR counted with 12 key employees from seven distinct areas and more than 600 hours of work for 13 months. The results of this company are presented in section 5.1. The second AR case is Company TRPT, a medium-sized company that develops operating systems and sensors for railways (ISIC 26 division). This case involved 13 people from nine areas and more than 300 hours of joint work for six months. The results for Company TRPT are discussed in section 5.2. Finally, Company DFED is a European diet feeder machinery manufacturer (ISIC 28 division). The case study relied on seven people within six distinct areas for two months. The results are presented in section 6.1.²⁵

²⁵The key employees participating from all three companies are from senior/middle management. Thus, this research respected the ratio between management and operational staff, maintaining the range of 6%-7%.

Table 3.2. Summary of the participating companies.

	Company TRFR* (TRansFormeRs)	Company TRPT* (TRansPorT)	Company DFED* (Diet FEeDers)
Sector classification and division based on the ISIC classification	C: 2710 Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	C: 2651: Manufacture of measuring, testing, navigating and control equipment	C: 2821 Manufacture of agricultural and forestry machinery
Company size	Medium	Medium	Medium
Areas/departments involved in the research	7 areas	9 areas	6 areas
People involved in the research	12 participants	13 participants	7 participants
Hours of work informed by the AR journal	623 hours	328 hours	-
Research method	Action research	Action research	Case study
Project duration	13 months	6 months	2 months

*The identity of the companies has been protected in this work.

3.5 QUALITY AND RIGOUR IN THE RESEARCH METHOD

Quality in research refers to all aspects of the scientific process of conducting the study. It particularly concerns the methodological fit between the research methods and the research objectives, including the selection of relevant research topics, the assessment of the research outcomes, and protection against systematic bias (Ahlström, 2016). Quality in qualitative research methods translates in the OM research field into being a relevant and rigorous study (Karlsson, 2016). For this, there are strategies employed to address potential issues in data collection, analysis and interpretation that might compromise the insights and conclusions drawn. The next sections outline those strategies taken in this research to ensure quality.

3.5.1 RIGOUR IN QUALITATIVE RESEARCH

The rigour for achieving quality in qualitative research evolved from those used in quantitative research. However, this does not mean that qualitative research should be judged from the same point-of-view, especially when considering AR and case studies (Coughlan & Coughlan, 2002; Yin, 2003). Instead, researchers widely accept that one cannot control all variables that influence a specific organisational situation as real-world company settings are full of choices (Karlsson, 2016). While it may be impossible to ensure strict objectivity in qualitative research, it does not mean that rigour should not be established. Credibility, transferability and reliability are the most common aspects to be considered to guarantee rigour and, consequently, confer quality (Buganza & Verganti, 2006).

Firstly, credibility refers to the ‘believability’ of the findings in qualitative research. There are two main strategies to ensure that the research is conducted believably and credibly (Blessing & Chakrabarti, 2009). One strategy is to pursue a prolonged engagement until the researcher(s) have gained a full understanding of the phenomena investigated. The present work involves more than 950 hours of continuous work in companies TRFR and TRPT, demonstrating a prolonged engagement with the companies. Peer debriefing is another strategy to ensure that the interpretation of qualitative data is faithful. Thus, each company case counted with at least one internal facilitator and two researchers to perform debriefing sessions after data collection, analysis and interpretation meetings. Additionally, presentations of the research results were discussed in relevant seminars and conferences.

Secondly, transferability in qualitative research is similar to generalisability in quantitative research. It relies on the proper analysis of the context and reality of the company and the use of multiple instances to test the developed theory (Blessing & Chakrabarti, 2009). This work relies on the ‘context and purpose’ step before in each AR company case (discussed in section 3.3.3), with the identification of the innovation process characteristics. This research also offered each AR company reports detailing descriptions of the application of the PF and results, enriched with relevant direct quotes from participants to enhance further transferability so the readers can make informed decisions. Additionally, even though the cases used in this research cannot provide generalisation, according to Dul & Hak (2008), they can enhance the transferability of the theory. Thus, the main purpose of this study is not to generalise but to increase understanding of innovation measurement and management, focusing on the development and testing of a working tool.

Thirdly, reliability aims to guarantee that if a later researcher followed the same research methods as described by an earlier researcher and conducted the same case all over again, the later should arrive at the same findings and conclusions²⁶ (Yin, 2003). Thus, the purpose resides in minimising the errors and biases of the research (Blessing & Chakrabarti, 2009). The general way of approaching reliability in qualitative research methods is “to conduct research as if someone is always looking over your shoulder”. Thoroughly documenting the cases, research procedures and the results is a good place to start. In

²⁶Note that the emphasis is on doing the same case again, not replicating the same results of one case by doing another (Yin, 2003).

addition, Coughlan & Coughlan (2002) present seven critical control points so that the resulting AR presents reliability (as much as qualitative research can get). These control points were also extended to the case study. The points are shown in Table 3.3, along with the strategies applied in the present work.

Table 3.3. List of critical control points and the strategies taken in this research.

Critical control points by Coughlan & Coughlan (2002)	Strategies applied in the research
1. Purpose and rationale should be firmly established to both specific theory and practice.	The twofold development of the research, stage 2, with the conceptual development and stage 3 empirical development, supports the purpose and rationale behind this research.
2. The operational, organisational and academic context should be aligned and current.	This research is based on not only recent references to indicate the research gap (section 1.1.3) but also research activities (e.g., A3.1) to ensure context and purpose fit between companies and the research.
3. Methodology and methods of inquiry define the roles played by the researchers.	For each stage of this research, activities are outlined (section 3.3.3). Additionally, each case counted with two academic researchers and one internal facilitator within the company with well-defined roles.
4. Design of data collection and generation methods inform how cycles of action and reflection are performed.	The data collection instruments are planned according to the state-of-art methodology studied. For instance, the research method enables specific milestones to reflect after each research activity during the AR (see section 3.3.3).
5. Narrative of events is described, including intended and unintended outcomes.	The narrative is captured through journal keeping throughout the entire AR cases (as discussed in section 3.3.3). See Appendix II for further examples. ²⁷
6. Analysis of the narrative is undertaken in light of experience gained, judgments made, and the theory is done collaboratively.	Each case counted with two academic researchers and one company facilitator as well as specified meetings for debriefing and reflecting upon the results of the actions taken.
7. Discussion extrapolates to a broader context and articulates the contributions to both specific theory and practice.	This discussion is substantiated by an evaluation questionnaire after applying the PF in the participating companies based on framework assessment criteria in stages 3 and 4.

So, these critical points are addressed within the design of the research method, for example, points 1, 3 and 7. Additionally, further methodological procedures are developed to support the management of these critical points, such as journal keeping (addressed in points 4 and 5) as well as methodological activities, such as the ‘context and purpose’ step in the AR (point 2) and the collaborative reflection on the insights (point 6). Thus, all these precautions are taken to ensure that rigour is an integral part of the research work, and, as a result, the findings are relevant to the academic community. Further discussion on the overall assessment of the PF performed during the theory validation in stage 4 is presented next.

²⁷Again, because of confidentiality reasons, the full extent of the journals maintained during this research is not shown here, but a redacted example can be seen in Appendix II.

3.5.2 RIGOUR IN THE ASSESSMENT OF THE PERFORMANCE FRAMEWORK

The validation of the developed theory depends on its assessment. Tools of practical nature can only be truly assessed in the intended situation, i.e., with the users, in practice, and as many instances as possible (Blessing & Chakrabarti, 2009). As previously mentioned, although qualitative research methods cannot provide generalisation regardless of the number of cases, they can deliver a rigorous assessment to enhance the validity of the theory developed (Dul & Hak, 2008). For this, Chiesa et al. (1996) argue that the assessment of case-oriented tools should be based on the tool's applicability, usability and usefulness.

In general, Blessing and Chakrabarti (2009) define applicability as the analysis of the study conditions given by the context in which the new tool is applied. Contextual conditions must be clearly defined to select the participating companies as well as the definition of research procedures. Usability, in turn, relates to the extent to which the developed tool can be applied by specified users to achieve the defined goals (Blessing & Chakrabarti, 2009). For case-oriented research focused on PFs, Chiesa et al. (1996) propose a simplified usability analysis, especially when there is no software development involved (Chiesa et al., 2009). They suggest that the analysis should concentrate on achieving the defined goals, implementing action plans, and a discussion on the final format of the developed tool, i.e., whether the PF is stand-alone or a supported by facilitators.

Further analysis of the PF assessment concerns its usefulness. Usefulness in the context of a managerial tool involves the tool's ability to realise the expected impact defined by measurable success criteria (Blessing & Chakrabarti, 2009). Therefore, usefulness analysis is often based on questionnaires for collecting information about the user's evaluation of the tool against the criteria. Accordingly, this research applies the evaluation questionnaire previously used to evaluate managerial tools, including management models and frameworks, in the companies participating in the development (e.g., Barquet, 2015; Pigosso et al., 2013). Because of previous applications, this questionnaire has demonstrated construct and content validity, as discussed next.

The construct validity is concerned with whether the content in the questionnaire do measure what they intended (Alegre, Lapiedra, & Chiva, 2006). Basically, it is an indicator of how meaningful the questionnaire is when used to measure the usefulness of the framework. The items of the questionnaire have been previously examined by experts and agreed upon

and applied in preceding peer-reviewed applications (e.g., Barquet, 2015; Issa, Pigosso, McAlloone, & Rozenfeld, 2015; Pigosso, 2012). Thus, by applying the questionnaire in a similar context, where a PF is being evaluated by the users from the companies participating in the research, the construct validity can assume to be correct and sufficient (Alegre et al., 2006).

The content validity, in turn, refers to whether a question represents a concept's full definition. If some aspects are missing from the measurement, the validity could be endangered. Content validity is assumed to be correct when the questionnaire has been constructed according to the literature (Alegre et al., 2006). For the evaluation questionnaire applied in this work, pre-tests were carried out in previous applications (e.g., Barquet, 2015; Issa, Pigosso, McAlloone, & Rozenfeld, 2015; Pigosso, 2012). The measurement items are retrieved from the criteria firstly defined by Vernadat (1996) for evaluating management models or frameworks and used for many years. They address the PF's: 1) utility, 2) consistency, 3) scope, 4) precision, 5) broadness, 6) objectivity, 7) clarity, 8) depth, 9) coherence, 10) instrumentality, 11) simplicity and 12) forecast for next steps. Because the questionnaire is firmly grounded in the literature, it is safe to assume it has content validity.

The analysis of the questionnaire results is based on the within-group interrater reliability, which is also popularly known as 'level of agreement'. This method enables the analysis of the level of agreement amongst answers made by a small group of respondents²⁸ on a specific item assessed in a questionnaire (James, Demaree, & Wolf, 1984). Therefore, this method contemplates the degree of alignment and similarity between responses given by the participants. Its application, though, must satisfy three conditions:

- 1) The questions should be the same among respondents;
- 2) There must be a discrete scale common to all respondents;
- 3) Respondents should interpret the scale in the same way.

Conditions 1 and 2 were guaranteed using an identical questionnaire for all participants, and condition three was ensured by applying it after a workshop, with a thorough explanation of the evaluation. Each of the 12 questions had a four-point scale to measure the participants' evaluation: (1) "unsatisfactory", (2) "needs improvements"; (3) "satisfactory" and (4) "very satisfactory", following Issa et al. (2015) and Pigosso et al. (2013) questionnaire

²⁸The bias is expected to be minimal for a small group of judges and essentially negligible for a large number of judges (10 or more) (James et al., 1984).

formulation. Their analysis also indicates that a “satisfactory” score is sufficient evidence of positive feedback from the evaluators.

The within-group interrater reliability (or level of agreement), as proposed by James et al. (1984), varies between zero and one: the closer to one, the stronger the agreement amongst the responses, i.e. the more consistent the evaluations are. Several authors in the technology and innovation management body of literature adopt the empirical threshold of 0.70 to indicate a sufficient agreement level (Caetano & Amaral, 2011; Farris et al., 2007). The following equation is used to calculate interrater reliability ($r_{wg(i)}$), where i denotes each score given by the respondents ($i = 1, 2, \dots, n$) to the question under analysis:

$$r_{wg(i)} = 1 - (SD^2_i / \sigma_i^2)$$

where SD is the standard deviation of the given scores by the respondents for each question and σ^2 is the expected variance due to random error. The variance is calculated assuming that the scores granted to each question have a uniform distribution, i.e. the scores have the same probability. Variance is then calculated according to the following equation:

$$\sigma_i^2 = (A^2 - 1)/12.$$

where A is the number of possible answers available to the evaluators; in this case, $A = 4$, with scores varying from 1 to 4.²⁹

The results of the usefulness evaluation of the PF and the respective analysis of the within-group interrater reliability are discussed in section 5.1.2.3 for Company TRFR, section 5.2.2.3 for Company TRPT (AR companies), and section 6.1 for Company DFED (case study company). The discussion is built upon the responses given by 18 employees. As aforementioned, the data analysis in this research is qualitative, i.e., a non-statistical test of the correctness of the proposition is carried out. This number of respondents appears to be sufficient for the analysis of the usefulness, for its analysis is based on not only individual responses to a question but also the level of agreement. Additionally, previous research with a similar number of respondents (and less) achieved an appropriate level of representativeness (e.g., 11 respondents in Caetano & Amaral, 2011, two respondents, in Barquet et al., 2016; one respondent from each of the two companies, Issa et al., 2015).³⁰ The full extent of the scores given to the evaluation questionnaire is shown in Appendix XIII.

²⁹(1) “unsatisfactory”, (2) “needs improvements”; (3) “satisfactory” and (4) “very satisfactory”.

³⁰These examples of research were published in peer-reviewed journals Technovation (Impact factor: 5.25), Journal of Cleaner Production (Impact factor: 6.395) and peer-reviewed conference, e.g., Procedia CIRP.

The profile of the respondents is compiled on the following demographics: areas/departments (self-reported),³¹ role in terms lower, middle, senior management or specialists, as well as their tenure in the company (see Figure 3.4). Most respondents (71%) had been in their respective company for more than five years and in a middle/senior management position. Thus, they were, therefore, well-positioned to respond to the questionnaire. Note that the profile shows 18 participants for the questionnaire, but the total number of practitioners actively involved in this research from the three companies is 32.



Figure 3.4 Profile of evaluation respondents (n=18): a) areas; b) roles and, c) tenure.

Finally, it is important to highlight that the validation of the PF is not based only on the assessment of 18 practitioners, despite its relevance. The assessment is also grounded in the continuous evaluation during the 950 hours of AR conducted in two manufacturing companies, corroborated by several research procedures, such as document analysis, semi and structured interviews, focus-groups in workshops plus the results from a third case study, explained in the remaining of this work. The results of the cases, together with the evaluation questionnaire, enable the confirmation or rejection of the proposition advocated in this research in relation to the PF. The data analysis in this research is qualitative, i.e. a non-statistical test of the correctness of the proposition is performed.

³¹The technology role is focused on the development of the mature technology to be incorporated into the product. Technology radar, in turn, is a specialised position within technology, which focus on monitoring scientific databases, preparing roadmapping events and feeding up information to R&D and new business development.

3.6 REMARKS

This chapter described the methodological decisions made throughout this work as the researcher integrated complementary yet distinct research methods in order to fulfil the research objectives established in the research.

In summary, the PF is developed in the context of the hypothetic-deductive approach combining the conceptual and empirical development, with the active participation of the researcher. At first, a theoretical approach is adopted to have in-depth knowledge and understanding about the issue, define the main elements of the PF and elaborate the content of its conceptual version. For this, the research method adopted is a systematic literature review. Then, the conceptual version of the PF is further developed in action following an empirical approach, with the conduction of AR in two manufacturing companies. Finally, to test the theory developed in this research, i.e. that the PF can support manufacturing companies in measuring innovation performance and the definition of improvement plans, a case study for theory-testing is carried out.

At this point, it is important to highlight, once again, the choice of conducting AR for the empirical development of the PF. Even though AR is not a typical choice for the engineering field, a recent study made by Lakiza & Deschamps (2019) argues that AR holds great potential for helping bridge the gap between research and practice in the manufacturing industry, especially in innovation contexts. As AR involves the recipients of the research results directly in the research itself, the practitioners and managers, this method provides a richness of evidence and experience that other research methods cannot capture. Thus, AR can overcome common limitations of research, such as difficulties experienced by researchers in translating research findings into tangible solutions in the industry and the incapacity of managers in using research findings to improve their organisations.

In the following chapters, the results of each research stage outlined in the methodology are presented in detail. The conceptual development of the PF, stage 2, is presented in Chapter 4, followed by the description of the empirical development of the PF from stage 3, in Chapter 5. Chapter 6 presents the testing the PF in the case study, its overall assessment, and the contributions of the PF to the academic community. Finally, Chapter 7 presents the conclusions, final remarks and indications of future research.

4 CONCEPTUAL DEVELOPMENT

This chapter presents the conceptual development of the PF with the definition of its elements, following the research method established in section 3.3. Hence, this works reviews the literature in a more structured manner to extract the database and supporting elements required for a PF, having clearly defined these elements in Chapter 2.

Figure 4.1 illustrates the sections in which the results of the activities from stage 2 of the research method are discussed. First, section 4.1 presents a general overview of the initial iteration of the PF, followed by the discussion of the database elements (section 4.2) that includes both dimensions (4.2.1) and indicators (4.2.2). Then, the supporting elements are presented in section 4.3 as follows: initial procedure (4.3.1), facilitation (4.3.2), visualisation of performance progression (4.3.3), and support for improvement action (4.3.4). This chapter finalises with summary remarks on the conceptual development (4.4). Further details and bibliometric data on the results the SLR are presented in Appendix IV.

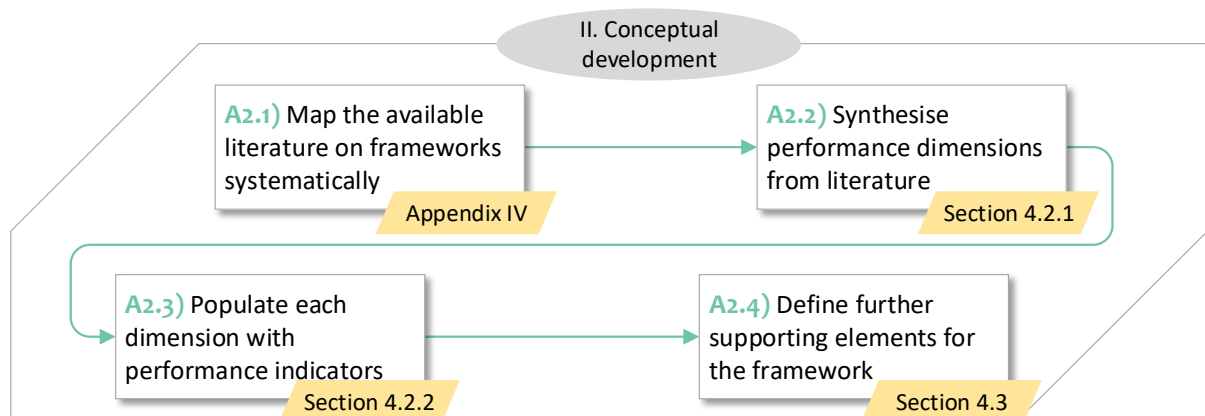


Figure 4.1. Location of the results for stage 2 of the research method.

At this point, it is important to reinforce that the use a SLR is becoming increasingly relevant for the development of PFs (Lakiza et al., 2018). Moreover, this systematic review plays a critical role in a situation where an AR is going to be performed next (Braz et al., 2011; Caetano & Amaral, 2011; Lakiza & Deschamps, 2019; Turner, Bititci, & Nudurupati, 2005). The results from a SLR can provide the researchers with the required tools to not only understand the context of the action-oriented research but also to support the decisions at the time of action.

4.1 PERFORMANCE FRAMEWORK OVERVIEW

The PF proposed in this work embodies an evolutionary approach to support manufacturing companies in the effective measurement of the innovation capability and the definition of appropriate courses of action to improve performance. It means that in the application of the PF, there is a gradual learning process to be followed in the performance measurement process – it is not possible to tackle all improvement gaps at once. In this way, with this evolutionary approach, the conceptual version of the PF can provide to the manufacturing companies:

- A comprehensive view on relevant performance dimensions for measurement of the innovation process;
- A provision of reliable and valid PIs from the accumulation of previous research to free subsequent researchers from the need to redevelop these measurement instruments;
- An initial step-by-step procedure, also assisted by the other supporting elements, to enable the measurement of performance and definition of improvement actions;
- An evaluation of performance concerning weaknesses and strengths across a range of dimensions relevant to the innovation process, and,
- A common language and a shared vision across the organisation on innovation measurement.

To provide these benefits to the companies, the PF is grounded in a triple foundation sustained by the database and supporting elements. Figure 4.2 illustrates this initial outlook on the PF proposition. This foundation is based on: 1) the database elements, composed of dimensions and PIs; 2) the process, with the supporting elements of the PF: initial procedure, facilitation (i.e., the way the procedure is applied), visualisation of performance progression and support for improvement action, that together to allow the 3) continuous improvement principles applied in the context of the innovation process.

According to the managerial accounting literature, the definition of the database elements is sufficient to confer the structural feature to a PF (Folan & Browne, 2005; Franco-Santos et al., 2007). Several authors go even further by saying that proposition of such elements may be enough for the proposition of new PF (e.g., Adams et al., 2006; Crossan & Apaydin, 2010; Dziallas & Blind, 2018). Nevertheless, this work takes the extra step and proposes a complete PF to answer the open call for new research that emphasises the need to

incorporate the evaluation of performance and the support for the definition and implementation of improvement actions.

The second foundation refers to the performance measurement process, composed of the PF supporting elements. In the same manner, as the first foundation, the procedure alone is enough to confer the procedural feature to a PF (Folan & Browne, 2005; Franco-Santos et al., 2007). Nevertheless, the other supporting elements of facilitation, visualisation of the performance progression and support for improvement actions are indispensable for the proposition of a comprehensive PF. Note that, as explained in Chapter 3 (“Methodology”), these supporting elements are first conceptually elaborated from the analysis of reviewed PFs and existing literature. However, they are improved in action during the empirical development and, then, tested in the case study.

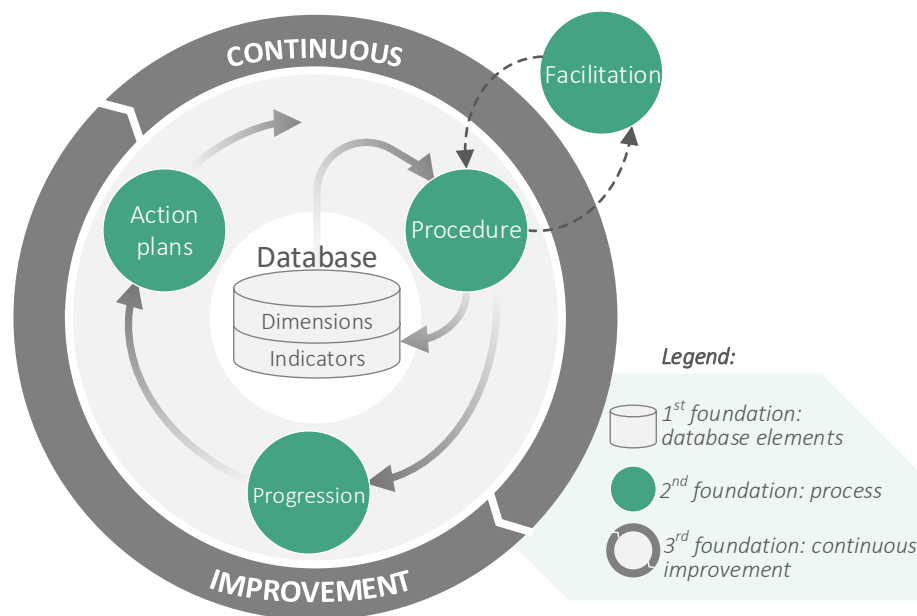


Figure 4.2. Foundations of the PF.

The third foundation relates to the continuous improvement of the innovation process. The principles of the continuous improvement should permeate the development of the elements of a PF, so its users are able to commit to this ongoing, long-term approach (Morisawa, 2002). Thus, taking into consideration the essence of continuous approach, the PDCA cycles (Plan, Do, Check and Act), for instance, the progression of the performance supports ‘check’ activities, where the evaluation of performance can be tracked across distinct performance levels, and the support for improvement actions corresponds to ‘act’ activities of implementing action plans to improve performance.

4.2 DATABASE ELEMENTS

To create a comprehensive collection of dimensions and PIs for the PF, a SLR was performed applying a state-of-the-art procedure. In contrast to the narrative review from Chapter 2 (“Literature review”) that renders definitions to build the research background, the goal of the SLR is to identify, collect and synthesise the dimensions and populate each of those dimensions with PIs demonstrated to be significant in the innovation measurement.

This research follows Brereton et al. (2007) and Tranfield, Denyer, & Smart (2003) SLR procedure. It comprises three deliberate steps of planning, execution and analysis, aiming to improve the quality of reviews with transparency, a broader range of studies included, increased objectivity and reduction of implicit researcher bias. Further details on the SLR protocol can be found in Appendix I. The steps are summarised as follows:

- The planning step involved the definition of the keywords to search for the PF database elements. Papers from experts from technology and innovation management literature were used to identify initial keywords that were further refined in iterative cycles of development and testing in the selected academic electronic databases, Web of Science (WoS) and Scopus. These databases were chosen due to their advanced web search mechanisms, high volume of indexed publications and proven relevance.
- In the execution step, the criteria for searching the articles were defined. The articles should have been published in English and peer-reviewed journals and conference proceedings. The defined search string was used to find relevant articles; until mid-2018 (when the AR started) and subsequently updated in 2019. The search fields in WoS and Scopus covered engineering, management, business, planning development, economics, operations research, computer science, multidisciplinary sciences, social sciences and mathematical methods.
- In the analysis, the identified articles were thoroughly read and assessed. Articles needed to present a process-based view, and a clear linkage between performance success (customer satisfaction, sales/profit, or schedule performance) and the proposed dimension/PIs. The articles were also assessed over quality, seeing problem definition, research background, method, results and contributions, and insights. Furthermore, the citations and reference lists were checked to identify any additional relevant articles related to the topic (cross-referencing).

The SLR yielded an initial sample of 1.068 publications using the search string (see Figure 4.3). From this pool, the relevant publications were selected by analysing their titles and abstracts against the criteria. In total, 93 articles thoroughly read matched the inclusion and quality criteria. Additional 30 cross-referenced publications were included through an analysis of citation and references. The combined selection of 123 papers covers a diverse disciplinary background, e.g., engineering design and technology management, operation research with a focus in R&D, and business and organisation management. The bibliometric analysis of these papers can be seen in Appendix IV. For instance, the industry analysis indicates that manufacturing accounts for 81% of the papers, with 9% focused R&D in machinery, electronics and automobile industry and complemented by 9% including the service sector.

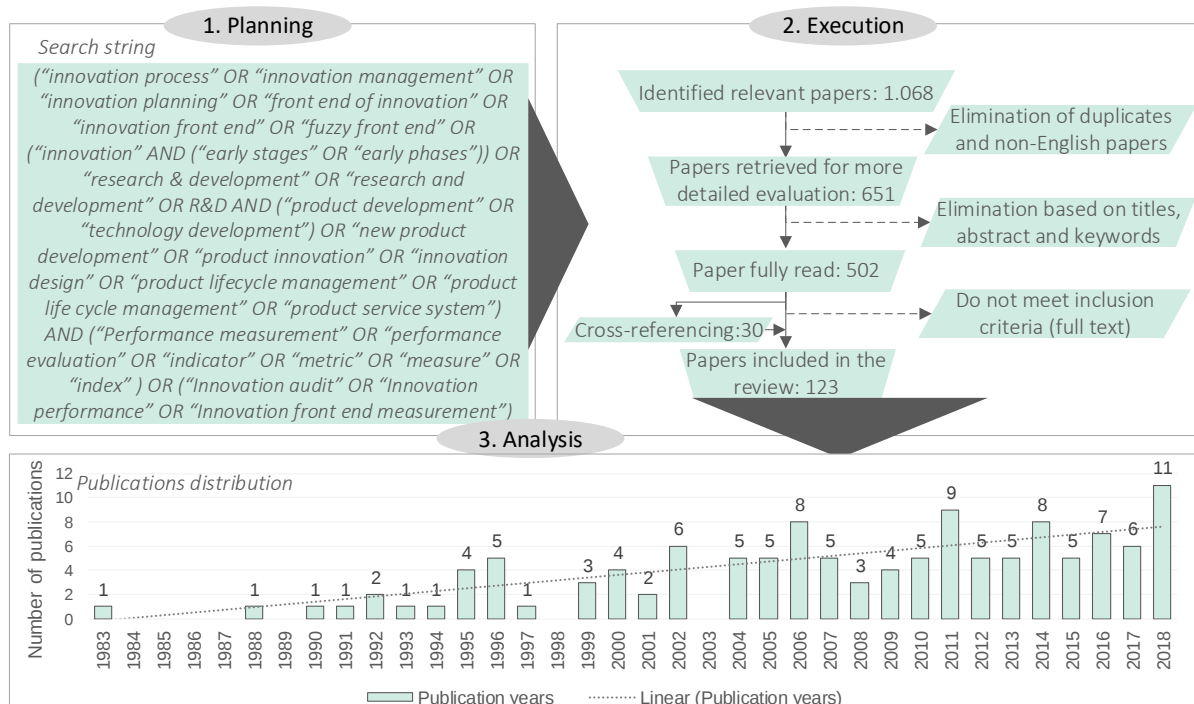


Figure 4.3. Summary of the SLR steps (more details in Appendix IV).

The synthesis of the dimensions and PIs presented over the next sections were captured in electronic spreadsheets. The dimensions and terminology used in the respective studies were collected as wells as the PIs general specifications, e.g., title, formula/scales, purpose and measurement units. In this way, this work identified, catalogued and clustered dimensions to synthesise them into a higher level of categories, following (Costa et al., 2014; Dziallas & Blind, 2018). An independent two-stage evaluation was also performed to assign further classifications for the PIs (leading/lagging, rapid assessment/in-depth). Note that these classifications are validated in the AR by the employees from the participating companies.

4.2.1 DIMENSIONS OF PERFORMANCE

It is important to recall the concept of performance dimension applied in this research. Dimensions are typologies used to classify relevant PIs to the domain in question, facilitate their operationalisation and ensure that no critical dimension is missing from the PF (Cooper & Kleinschmidt, 1995; Markham & Lee, 2013). As a consequence, dimensions are also considered as the broad field or category to which an indicator belongs to (Becheikh et al., 2006; Dziallas & Blind, 2018).

The compilation of performance dimensions retrieved from the SLR is shown in Table 4.1. The first studies addressing dimensions were during the early 1990s until early 2000s, and they mainly focused on R&D project management (e.g., Brown & Gobeli, 1992; Chiesa et al., 1996; Cooper & Kleinschmidt, 1995, 2007; Rogers, Ghauri, & Pawar, 2005; Verhaeghe & Kfir, 2002). The emergence and consolidation of dimensions occurred in the late 2000s, with studies from Adams et al. (2006) and Crossan & Apaydin (2010) and continues to grow nowadays (Akroush & Awwad, 2018; Dziallas & Blind, 2018). More recently, though, further studies treat dimensions as collections of managerial practices which can support innovation measurement and management learning (Barczak & Kahn, 2012; Guimarães, Severo, Dorion, Coallier, & Olea, 2016; Markham & Lee, 2013; Panizzolo, Biazzo, & Garengo, 2010).

After screening the relevant literature, nine distinct clusters of dimensions are defined as they empirically demonstrated to be significant in the innovation process. These dimensions retrieved systematically from the literature needed to fulfil certain requirements. First, they needed to demonstrate a clear link to innovation success (increase in customer satisfaction or sales/profit, or schedule performance) and then be cited several times to be relevant to the study.³² Together, these dimensions determine the innovation process and the resulting outcomes. Note that these dimensions may be addressed by different expressions in the respective publications, such as 'organisational factors' (e.g., Cooper and Kleinschmidt, 1995; Chiesa, Coughlan and Voss, 1996; Verhaeghe and Kfir, 2002; Rogers, Ghauri and Pawar, 2005), or even 'collection of best practices' to measure and manage the innovation process performance (e.g., Panizzolo, Biazzo and Garengo, 2010; Barczak and Kahn, 2012; Markham and Lee, 2013; Akroush and Awwad, 2018).

³²Prior studies carrying out categorisations argue that dimensions should achieve 'theoretical saturation' in the literature, i.e., the point of significant data recurrence and failure to surface new data (e.g., Adams et al., 2006); and that can be already with at least 6 recurrent citations in a relevant group of papers.

CONCEPTUAL DEVELOPMENT

Table 4.1. Compilation of performance dimensions for the innovation process.

Studies	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9
(W. B. Brown & Gobeli, 1992)	Strategic planning				Project management	Technology planning and development			
(Cooper & Kleinschmidt, 1995)	Strategy		Organisation structure			Technology development	Development teams		
(Chiesa et al., 1996)	Strategic leadership	Systems/tools training for knowledge development			Project management	Technology acquisition			
(Werner & Souder, 1997)	Strategic planning of financial aspects				Project Effectiveness	Technical abilities and productivity			
(C. H. Loch & Tapper, 2002)	Strategic planning of innovation	Knowledge repository				Planning of technologies	Project teams		
(Verhaeghe & Kfir, 2002)	Strategic leadership	Systems and tools training			Project management	Technology acquisition	Teamwork		
(Rogers et al., 2005)	Strategy	Systems and tools	Integration/cultural commitment		Project management				
(Adams et al., 2006)	Innovation strategy	Knowledge management	Organisation structure/culture	Portfolio management	Project management		People	Market	Networking for collaborations
(Becheikh et al., 2006)	Innovation leadership	Competence and knowledge	Organisational structure and culture		Project management	R&D activities and inputs		Market	Networking Surrounding environment
(Berg et al., 2009)	Strategy definition	Data collection, idea generation, pattern recognition		Formal selection and planning of projects	Formal project planning	Planning technology profitability		Market growth, orientation, customer understanding	Social environment Sustainable development Service/products development

CONCEPTUAL DEVELOPMENT

Table 4.1. Compilation of performance dimensions for the innovation process.

Studies	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9
(Chiesa et al., 2009)	Financial (with strategy definition)	Learning and innovation (knowledge development)		Internal processes (portfolio decisions)	Internal processes (project planning)	Internal processes (technology development)		Customer/ market perspective	
(Crossan & Apaydin, 2010)	Innovation strategy	Knowledge management	Organisation and culture	Portfolio management	Project management		People	Market	
(Panizzolo et al., 2010)	Innovation strategy				Project management		Development team	Market	Design for the environment Service innovation
(Barczak & Kahn, 2012) (Kahn et al., 2006)	Strategy		Culture	Portfolio system	Project management		Team proficiency	Market	
(Markham & Lee, 2013)	Strategy	Knowledge management	Culture	Portfolio management	Project management	Technology management		Market	Openness Sustainability Servitisation
(Guimarães et al., 2016)	Strategic orientation	Knowledge management	Culture and structure				R&D team		Alliance for collaborations Sustainability
(Akroush & Awwad, 2018)	Financial strategy	Knowledge sharing					Team competency	Marketing	
(Dzillas & Blind, 2018)	Innovation strategy	Competence and knowledge	Innovation culture and organisational structure		Project management	R&D activities and inputs		Market	Networking Environment Service capability
Resulting dimensions	Innovation strategy	Knowledge management	Organisation and culture	Portfolio Management	Project Management	Technology Management	Team Management	Market	Innovation Environment

Note that not all the studies addressed here present PFs. In fact, sometimes they only address dimensions; that is the case for Becheikh et al. (2006).

The nine dimensions identified are collectively exhaustive, meaning that a PF should include the measurement within all of them. The dimensions can be further detailed into *sub-dimensions*, as illustrated in Figure 4.4. In addition, the dimensions can be either company-specific or contextual dimensions, as multiple internal and external elements affect the ability of companies in the innovation process, explained in Chapter 2 (“Literature review”). The company-specific dimensions, which include those that are particular to a company affecting its organisational innovation internal capacity, are presented first:

- Innovation strategy (IS): this dimension relates to the coordination of a company’s innovation efforts in its business units (BUs), divisions, or individual projects to achieve long-term innovation goals. It is built upon on company’s *strategic orientation* and *leadership* sub-dimensions to establish aligned and coordinated innovation efforts.
- Organisation and culture (OC): the dimension relates to the *organisational structure* that regulates how rules, hierarchies, and responsibilities are coordinated among staff, directly and indirectly, involved in the innovation process and the *culture* denotes the beliefs and values system within which they work.
- Knowledge management (KM): this dimension refers to the generation of ideas and their *management*, the gathering of information to enrich and inform decisions concerning those ideas (*information flows*), and the maintenance of a *knowledge repository* are support management.
- Portfolio management (PFM): this dimension embraces the selection of projects ideas supported by the use of *evaluation tools* to achieve a strategical fit between the available resources and the company goals and drivers and reach a *balance* of the innovation projects in the company’s portfolio.
- Project management (PM): this dimension deals with the application of *project management tools* to support the conduction of new projects, with *coordination* amongst departments and functions, which in turn enables the achievement of the established project’s requirements with *efficiency*.
- Team management (TEAM): management of teams is considered an essential dimension for the management and improvement of innovation performance. It is built upon two critical sub-dimensions, *cross-functionality* of development teams (also called multidisciplinary) and team *stability*.

CONCEPTUAL DEVELOPMENT

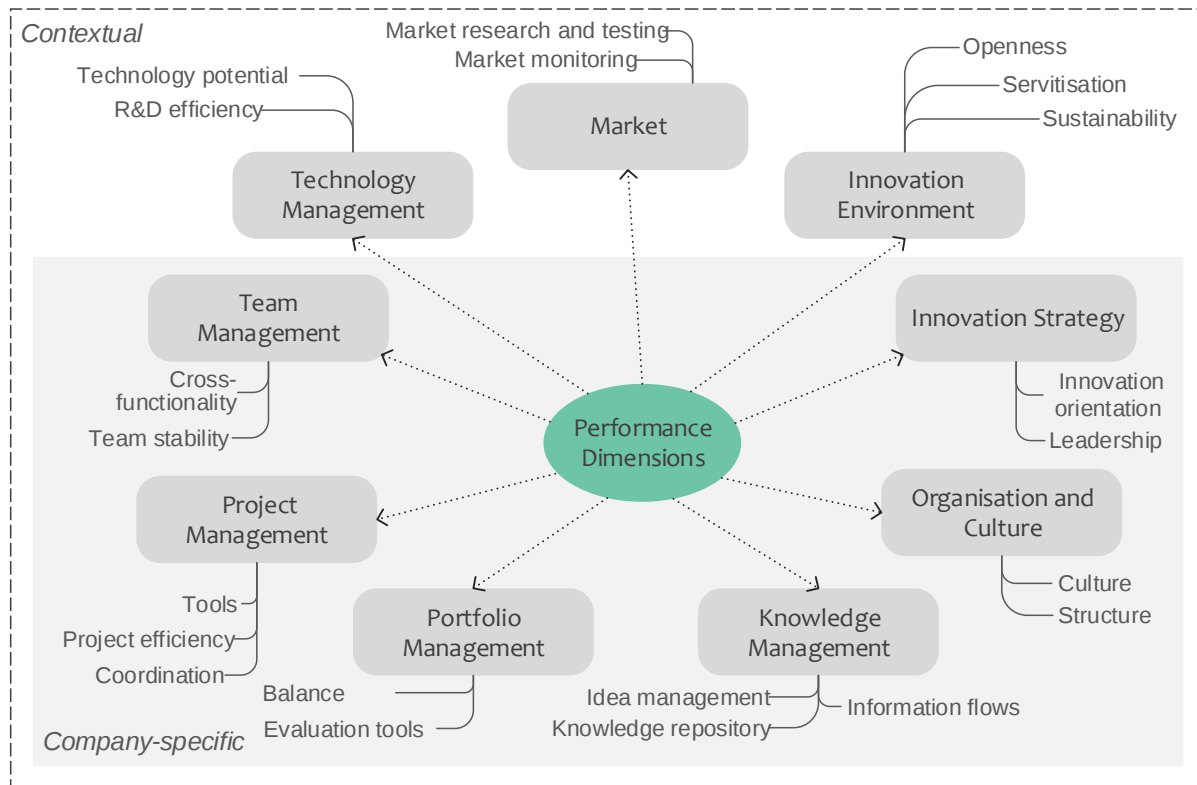


Figure 4.4. Illustration of the dimensions and sub-dimensions of the innovation process.

On the other hand, contextual dimensions are related to a company and its surrounding environment, meaning that external elements have a more significant influence in this type of dimension (Becheikh et al., 2006; Dziallas & Blind, 2018):

- **Innovation environment (IE):** as companies are adaptive systems that adjust to the surrounding environment; they need to react to current external forces to improve innovation performance. Now, these forces relate to *openness*³³ to enable external collaborations, *sustainability* and *servitisation* of physical products.
- **Technology management (TM):** this dimension encompasses the anticipation of the *potential of new technologies* in order to propose programs for developing competencies for the innovation process and enable *R&D efficiency* (if it is applicable to the company).
- **Market (MA):** this dimension includes *market research and testing* of the new product/PSS concepts during development in addition to *monitoring the market* during

³³Openness is also called open innovation. The definition and discussion of this concept can be seen in section 2.1.4, in the "Literature review" Chapter.

distribution, delivery and use of the product, to include issues such as product/material disposal and other EoL strategies.

It is necessary to highlight that these dimensions may overlap with other disciplines of the company (e.g., strategic planning, quality control, procurement, supply chain, amongst others) that can go beyond the frontiers of the innovation process. In this way, it is imperative that companies adopt a process-based approach to deal with the innovation process, avoiding operational 'silos'. For this, companies need to consider all the nine dimensions compiled here as they are essential to measuring the innovation process.

Lastly, while it may initially appear as overly simplistic to say that for managing the innovation managers need to take care of the innovation strategy, organisation and culture, knowledge management all the way to market dimension, the literature review demonstrates that no single PF has used all these dimensions together (see Table 4.1). Furthermore, as noted by Dziallas & Blind (2018), the identification of a range of performance dimensions for a PF is essential for better use of relevant indicators, discussed next.

4.2.2 PERFORMANCE INDICATORS

The next fundamental step toward improving innovation measurement is to identify and make explicit the existing PIs. Putting them all together provides an overview and allows them to be categorised. Thus, having defined the pertinent dimensions, the SLR initiated the mapping and identification of indicators. The PIs included here in the PF needed to fulfil specific requirements as defined in section 2.2.2.1 (in the "Literature review"), that is, they needed to present the definition of title, purpose or formula and scales in the corresponding studies where they were proposed. In addition, this work complemented the remaining elements, such as the unit of measurement, 'related to' (other PIs often associated with the indicator in question), benchmark values and type of indicators (classifications).

It worth mentioning that the systematic review was concerned with not only with studies proposing PIs but also works in which authors measure innovation performance for benchmarking studies, case studies or even surveys. For clarity, it should be noted that indicators dealing exclusively with technicalities of the product/PSS addressed in the respective studies, such as specific physical characteristics (e.g., "space occupied for the new machine"), or specifics or materials, and components ("hazard ratings from material safety data sheets"), were not considered.

In total, 259 unique PIs were retrieved from the relevant publications. Table 4.2 displays their distribution among the dimensions. The project management dimension has the highest number of PIs (43), representing 17% of the total. The second most populated dimension is technology management (35 PIs), scoring 14% of the total. Both figures are understandable because of the role played by techno-centric R&D literature from the 90s in the dissemination of project management and technology-related indicators. KM indicators have gained attention for the last two decades (34), with a representation of 13% in relation to the total of PIs. Later studies also included indicators associated with the innovation environment dimension (32), with particular attention dedicated to indicators related to openness (i.e., open-innovation activities).

Table 4.2. Distribution of the indicators among the dimensions.

Performance dimensions	Number of indicators	Distribution (%)
Innovation strategy (IS)	24	9%
Knowledge management (KM)	34	13%
Organisation and culture (OC)	25	10%
Portfolio management (PFM)	16	6%
Project management (PM)	43	17%
Technology management (TM)	35	14%
Team management (TEAM)	29	11%
Market (MA)	21	8%
Innovation environment (IE)	32	12%
Total	259	100%

Conversely, indicators for team management (29) and organisation and culture (25) dimensions have been consolidated for a while, but they are not widespread, representing reasonable rates of 11% and 10%, respectively. Interestingly, although innovation strategy is a constantly cited dimension, this does not directly translate into a higher number of indicators. This dimension represents 9% of total PIs, with 24 indicators in the sample, showing moderate efforts in the literature to propose these indicators. The remaining indicators for the market (21) and the portfolio management (16) dimensions are slightly underrepresented and may require further attention in the future proposition of new PIs. Portfolio management, in particular, was often overlooked, as demonstrated by the fact that it was only in 2003 that the Project Management Institute (PMI) started producing guidelines and certifications for this, in contrast, to project management guidelines being first published already in 1987.

4.2.2.1 TOP-CITED PERFORMANCE INDICATORS

The full extent of the 259 indicators is available in Appendix V, because of its considerable size. There, the PIs are presented with their respective identification code [ID], dimension, title, purpose, formula/scales, unit of measurement, and additional elements such as the classifications, citations and references. In this section, a simplified discussion of the database is given, focused on the top-cited PIs. The highest number of citations for a PI in the database was eight. Based on this, Figure 4.5 presents the distribution of citations among the PIs against their accumulated percentage. It is possible to observe that 20% of all citations are already achieved with PIs from eight to four citations.

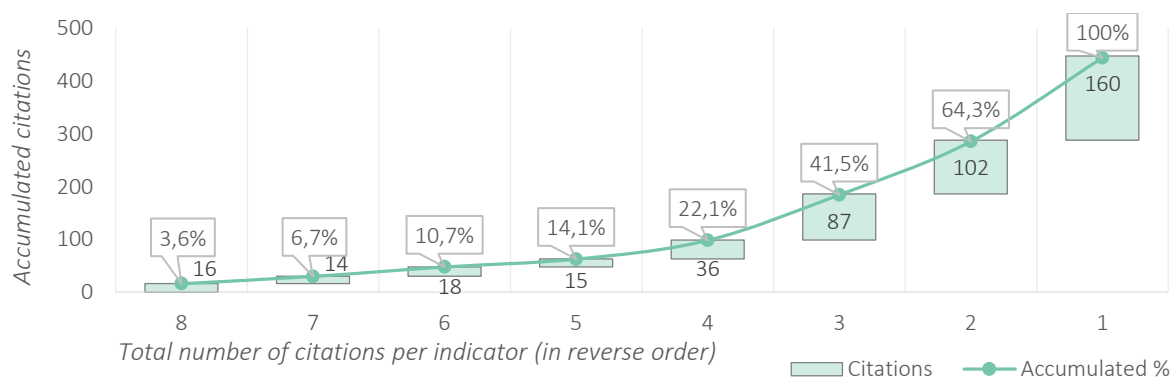


Figure 4.5. Graph of the PIs accumulated citations.

One of the most top-cited indicators relates to patents (see Table 4.3). Patent indicators have been widely accepted as a proxy for innovation in the literature, since Kleinknecht (1987) work. For traditional technology-based companies, patent indicators might be useful to compare competitor position and incentives for R&D personnel but depending on a company's strategy; patent data is not the best approach. Authors have been questioning the rationale behind the use of patent data since their utility may not be equally valid for all companies (e.g., Crossan & Apaydin, 2010). Clearly, patent-related indicators are not able to help in those industries where they do not feature, as not all innovations are patented. For companies where patents are still relevant, the indicator [KM11] enables the comparison between the knowledge production (number of patents developed) *versus* knowledge acquisition (number of patents brought in), and therefore, classified in the knowledge management dimension.³⁴

³⁴Further five patent-related indicators are classified in the technology management, related to R&D efficiency. See the PIs database in Appendix V.

Another top-cited indicator that also refers to knowledge management is the rate of generated new ideas according to formal *versus* informal activities [KM1]. Although there are several indicators related to the number of ideas available for addressing idea generation, this PI is able to indicate the extent to which companies are using different generative tools (e.g., brainstorming, roadmapping, competitor analysis) (Adams et al., 2006; Gerlach & Brem, 2017; Lee & Markham, 2016). As research has long demonstrated that formal idea generation leads to higher success rates (recently corroborated again in Eling et al., 2016), this indicator can potentially encourage more formal generation activities (Markham & Lee, 2013). This PI can also be associated with the “Rate of product ideas reviewed or approved (per phase)” [KM2], so the company can see the conversion rates over time.

Table 4.3. Top- cited indicators retrieved from the literature.

Dimensions	[ID] Title of the indicators	# Citations	Accumulated %
Knowledge management	[KM11] Numbers or value of patents developed in the company (<i>versus</i> brought in)	8	3,6%
Project management	[PM2] Project efficiency comparisons between budget and actual performance achieved (project costs, project duration, revenue forecasting)	8	
Innovation strategy	[IS1] Level of awareness of innovation goals	7	6.7%
Knowledge management	[KM1] Percentage of ideas actively generated by formal/informal activities	7	
Project management	[PM9] Time-to-market accuracy	6	10.7%
Project management	[PM31] Quality of communication within projects	6	
Project management	[PM32] Time-to-market management	6	
Innovation strategy	[IS2] Spending reflects the innovation strategy	5	14.1%
Project management	[PM12] Average cost per innovation project	5	
Market	[MA15] Market monitoring proficiency	5	
Technology management	[TM22] R&D intensity (absolute & relative)	4	20%
Innovation strategy	[IS3] Innovation long-term planning	4	
Innovation environment	[IE4] Number of collaborations with customers, suppliers, competitors, universities	4	
Knowledge management	[KM2] Rate of product ideas reviewed or approved (per phase)	4	
Portfolio management	[PFM11] Innovation portfolio strategic alignment	4	
Project management	[PM6] Project execution success	4	
Team management	[TEAM3] Cross-functional training	4	

One more highly cited PI, designated as [PM2], is based on comparisons between planned and achieved parameters of innovation projects (costs, duration, revenue forecasting) in the project management dimension. Moreover, additional five indicators from the project management dimension are amongst the top-cited ones. They relate to the quality of communication within projects [PM31], time-to-market [PM9]/[PM32], average project cost [PM12] and project execution success [PM6]. The high incidence of these PIs among the top-cited may be explained by the research focus on project efficiency, especially in the 1990s and early 2000s, and the role played by of the PMI in the dissemination of these PIs.

The innovation strategy indicator most commonly cited is the “Level of awareness of innovation goals” [IS1]. This indicator provides insights into the role of leadership in disseminating innovation strategy. It can help innovation managers have a view on the innovation efforts being made that contribute to the company long-term innovation goals, along with indicator [IS3]. A further indicator related to the innovation strategy dimension is “Spending reflects the innovation strategy” [IS2] that illustrates innovation strategy planning and the arrangements made to make investments in innovation projects.

The remaining dimensions present only one PI among the top-ten, as highlighted:

- “Market monitoring proficiency” [MA15] represents a top indicator for the tracking information after launch, especially during the use phase of the product.
- “R&D intensity” [TM22] is the top-cited indicator for technology management, expressed as the ratio between expenditures in R&D or R&D professionals and the total. This PI was clearly designated for large companies with R&D extensive departments and bigger budgets than SMEs (Dzallias & Blind, 2018).
- “Number of collaborations with customers, suppliers, competitors, universities” [IE4] stands for innovation environment top PIs, which is focused on openness.
- “Innovation portfolio strategic alignment” [PM11] is the predominant PI for portfolio management, relating to the balance between the innovation projects portfolio and the company’s strategic, enabling the visualisation of the coherence and consistency in the selection of projects.
- “Cross-functional training” [TEAM3] is the top-cited PI for team management. It allows insights into complementary skills and the integration between commercial and technical roles, a deficiency well-known in innovation teams (Cooper, 2006).

Remarkably, there is relatively little emphasis on indicators to deal with organisation and culture dimension, as no examples of this nature are present among the top-cited ones, even though, this dimension represents 10% of the identified PIs. The possible reason is that measurement values for more intangible dimensions, like the organisation and culture, are hard to capture, and consequently, more challenging to be proposed in academic studies, and then cited. Nevertheless, the fact that they are less cited does not mean that these PIs are not relevant enough to be considered in the PF. Indeed, several studies demonstrate the need to include these PIs in the mix of dimensions (Adams et al., 2006; Bose, 2004; Crossan & Apaydin, 2010). Thus, this research provides further support in this sense, by categorising PIs to make sure all critical dimensions are addressed in the PF.

4.2.2.2 CATEGORISATION OF PERFORMANCE INDICATORS

The categorisation of the PIs relates to their required specification ‘type of indicator’ defined in section 2.2.2.2 (of the “Literature review”). As explained then, the categorisation means classifying the PIs to facilitate their use. In this sense, PIs can be classified as quantitative or qualitative. Indicators can also indirectly and directly measure innovations, being classified as leading (input-oriented) and lagging (output-oriented PIs), respectively. A few times; however, PIs can have both characteristics at the same time. Additionally, relevant scientific studies classify PIs into rapid assessment, used in previous diagnosis or audits, easy to capture with application typically encompassing small and large firms, or in-depth PIs that are resource-consuming to capture and most commonly applied after a diagnosis.

An overview of the database classifications reveals more qualitative (117) than quantitative indicators (107) (see Table 4.4). This is consistent with observations from prior research (cf. Dziallas & Blind, 2018). One explanation is that the retrieved indicators refer to both non-technological and technological innovations. Another reason is the emerging focus on service industries³⁵ that leads to more intangible aspects to measure, and, consequently, the proposition of further qualitative PIs. Note that 35 indicators from the database do not present any formula and scales information, even though their respective authors presented title and purpose. Hence, whenever possible, these PIs were complemented with formulas and scales, so their use is also supported.

³⁵The service sector represents 9% of the samples identified in the studies selected via the SLR, as much as machinery, electronics and automobile industry. See discussion on the bibliometric study in Appendix IV.

Table 4.4. Overview of the distribution of the indicators' classifications.

	Rapid assessment indicators			In-depth indicators			Total
	Leading	Lagging	Leading/lagging	Leading	Lagging	Leading/lagging	
Quantitative	17	1	8	56	16	13	107
Qualitative	6	-	2	92	8	5	117
No formula	-	-	-	30	4	1	35
Subtotal	23	1	10	178	28	17	
Total		34			225		259

Table 4.4 also shows that lagging (1 rapid PI and 28 in-depth PIs) are less frequent than leading indicators (23 rapid PIs and 178 in-depth PIs). Lagging indicators typically related to, for instance, the number of new products launched, and revenue, so they can play an important role in the measurement of the performance only after applying improvement actions. Thus, leading PIs should be used during the improvement cycles with the application of the PF as they have been recognised in research as actionable, easily influencing the innovation process results (e.g., Costa et al., 2014). That is why dimensions, such as organisation and culture and knowledge management, unsurprisingly, entail more leading indicators, as these dimensions do not directly deal with the innovation process results.

Further results also show the division between rapid assessment (34) and in-depth indicators (225), as expected. Recall that rapid assessment indicators provide a quick overview of a dimension, ideal to be used in a diagnosis (Chiesa et al., 1996; Czuchry & Yasin, 2001), and easy to capture (Lee & Markham, 2016). Their application in research typically includes both small and large firms (Czuchry & Yasin, 2001). Conversely, in-depth indicators are resource-consuming to capture. Accordingly, these PIs are more accessible to large companies, thereby, more common in this setting (Chiesa et al., 1996; Czuchry & Yasin, 2001)

The synthesis of the rapid assessment is shown in Table 4.5. The PIs are presented with their dimensions, titles, and further classifications. Note that the low number of rapid assessment indicators resonates with the number of relevant studies addressing SMEs (see the discussion in the studies' sampling characterisation in Appendix IV). Remarkably, more quantitative PIs than qualitative are found among the rapid indicators, different from the characterisation of the database as a whole. This indicates that diagnosis or audits from the selected studies via the SLR are more reliant on quantitative PIs. In contrast, more leading (23) and leading/lagging PIs (10) than lagging (1) were identified as expected, as the database presents more leading than lagging and they are more useful in improvement cycles.

CONCEPTUAL DEVELOPMENT

Table 4.5. List of rapid assessment PIs across the dimensions, and further classifications.

Performance Dimensions	[ID] Title of the indicators	Leading (LEAD) Lagging (LA)	Qualitative (QL) quantitative (QT)
Innovation strategy (IS)	[IS1] Level of awareness of innovation goals	LEAD	QL
	[IS2] Spending reflects the innovation strategy	LEAD/LAG	QL
	[IS3] Innovation long-term planning	LEAD	QL
	[IS16] Top management support for innovation	LEAD	QL
Knowledge management (KM)	[KM1] Percentage of ideas actively generated by formal/informal activities	LEAD	QT
	[KM2] Rate of product ideas reviewed or approved (per phase)	LEAD/LAG	QT
	[KM16] Diversity of knowledge sources	LEAD	QT
	[KM27] Time-off for creative things and generation of tacit knowledge	LEAD	QL
Organisation and culture (OC)	[OC1] Organisational climate for innovation	LEAD	QT
	[OC9] Work environment support for innovation	LEAD	QL
Portfolio management (PFM)	[PFM1] Formalised portfolio management	LEAD	QT
	[PFM10] Portfolio balance use	LEAD	QT
	[PFM11] Innovation portfolio strategic alignment	LEAD	QT
Project management (PM)	[PM1] Commitment of resources for new product projects	LEAD/LAG	QT
	[PM23] Degree of use of project management tools	LEAD	QT
	[PM24] Frequency of post-launch reviews	LEAD	QL
	[PM31] Communication within projects	LEAD	QT
	[PM32] Time-to-market management	LEAD/LAG	QT
Technology management (TM)	[TM2] Level of new technologies monitoring	LEAD	QT
	[TM12] Importance of intellectual property (IP) for protecting technology development	LEAD/LAG	QT
	[TM13] Degree of technology tools used	LEAD	QT
	[TM22] R&D intensity	LEAD/LAG	QT
Team management (TEAM)	[TEAM1] Cross-functional team	LEAD	QT
	[TEAM2] Identifiable project team leader	LEAD	QT
	[TEAM3] Cross-functional training	LEAD	QT
	[TEAM5] Dedicated innovation group	LEAD	QT
	[TEAM17] Team innovative behaviour	LEAD	QT
Market (MA)	[MA1] Degree of use of market research tools	LEAD/LAG	QT
	[MA11] Product testing proficiency	LEAD/LAG	QT
	[MA15] Market monitoring proficiency	LEAD/LAG	QL
Innovation environment (IE)	[IE1] Recognition of open innovation opportunities	LEAD	QT
	[IE2] Exploitation of open innovation opportunities	LEAD/LAG	QT
	[IE12] Servitisation diversification strategy	LAG	QT
	[IE21] Sustainability criteria for innovation in new product development	LEAD	QT

The main implication of this categorisation is that these 34 PIs could work as a checklist of indicators covering the critical performance dimensions that provide an overview of the current performance of the innovation process in a diagnosis. For instance, the PIs for the innovation strategy dimension encompass the two sub-dimensions, strategic orientation and leadership, indispensable in the IFE. The strategy orientation relies on indicators [IS2] “Spending reflects the innovation strategy” and [IS3] “Innovation long-term planning”, while leadership is supported by PIs [IS1] “Level of awareness of innovation goals” (a top-cited indicator) and [IS16] “Top management support for innovation”.

The knowledge management dimension, in turn, depends on the PI [KM1], already presented as a top-cited indicator to measure idea generation according to formal/informal methods in the front-end, and [KM2] “Rate of product ideas reviewed or approved” to analyse conversion rate of ideas into projects and, indirectly, the information flow. A further KM PI measures the diversity of knowledge sources used in the innovation process, as in industrial and academic sources, with the indicator [KM16], complemented by a PI for indicating the use of time dedicated for creative things and generation of tacit knowledge [KM27].

The organisation and culture dimension includes two rapid assessment indicators, one expressed as “Organisational climate for innovation” [OC1] referring to relevant support in experimentation, risk-taking and a constructive conflict culture. This PI is complemented by the second indicator “Work environment support for innovation” [OC9], which aims to address the structure in place in reference to rewards systems and resources provided for the conduction of innovation-related activities.

The portfolio management dimension, in turn, is supported by the PI [PFM1] addressing a formalised portfolio assessment, [PFM10] for the portfolio balance in terms of returns/risks of selected projects, and [PFM11] for the strategic alignment of these projects. These mentioned PIs are related to the IFE and the beginning of the development. In addition, since most portfolio management methods applied in companies are based on financial return analysis; therefore, these PIs also take this into account in their measurement.

The importance of the project management dimension has been widely recognised in the technology and innovation literature, especially due to the active role of the PMI. Its rapid assessment PIs cover the commitment of resources to innovation projects [PM1], use of tools project management [PM23], project post-reviews [PM24], communication within projects

[PM31] and time-to-market management [PM32]. As seen in the previous section, this dimension is by far the most populated with indicators. However, several PIs still have a techno-centric bias, a legacy from R&D project management literature.

Furthermore, the technology management dimension includes the PI “Level of new technologies monitoring” [TM2], which is relevant to tech and non-tech companies, as both need to follow up potential technologies that may impact their IFE and development activities. Further PIs related to technology potential are “Importance of intellectual property (IP) for protecting technology development” [TM12] and “Degree of use of technology tools” [TM13]. In contrast, the last rapid assessment PI “R&D intensity” [TM22] deals with R&D magnitude of investment, already discussed as a top-cited PI.

The team management dimension is introduced in terms of cross-functional allocation [TEAM1] and training [TEAM3]. Cross-functionality is a well-researched, even for SMEs with fewer layers, where each team members should bring complementary competencies (Cooper, Edgett, & Kleinschmidt, 2004; Dayan & Di Benedetto, 2009). The second sub-dimension relates to team stability and counts with the rapid assessment PIs of “Identifiable project team leader” [TEAM2], “Dedicated innovation group” [TEAM5], and “Team innovative behaviour” [TEAM17] that jointly can give a better perspective on this matter.

The market dimension includes PIs for an outline of the performance of market research and user testing for understanding customers, competitors, and macro-environmental forces in the marketplace. Both rapid PIs “Degree of use of market research tools” [MA1] and “Product testing proficiency” [MA11] provide an overview of the tools applied in the IFE. At later stages, the PI [MA15] “Market monitoring proficiency” provides a complementary view of the sub-dimension market monitoring.

Finally, the innovation environment has three sub-dimensions. First, openness presents the PIs “Recognition of open innovation opportunities” [IE1] and “Exploitation of open innovation opportunities” [IE2], indicated by activities dedicated to finding collaborations, and projects with external parties, respectively. The second sub-dimension refers to servitisation, which relies on the PI [IE12] “Servitisation diversification strategy” to illustrate the coordinated efforts to incorporate PSS into product offers. Finally, to have a quick view on the sustainability sub-dimension, the suggested PI is “Sustainability criteria for innovation in new product development” [IE21], based on the use of sustainability criteria in the IFE.

4.3 SUPPORTING ELEMENTS

As explained in Chapter 2 (“Literature review”), section 2.2.4, the supporting infrastructure of a PF should comprise 1) a procedure to apply the PF, 2) facilitation definitions, 3) visualisation of the performance progression and 4) the support for defining improvement action plans, which, in the end, is the ultimate step to achieve process improvement. In the following sections, the supporting elements for the PF are defined in its conceptual format.

4.3.1 INITIAL PROCEDURE

The function of a procedure is to guide the application of the PF and establish a continuous improvement agenda for the measuring and evaluating performance of the innovation process in the company. This initial proposal for the procedure is based on the analysis of the procedures adopted in existing PFs.

This procedure is the one used at the beginning of the AR. As explained earlier in Chapter 3 (“Methodology”), this conceptual outline is important for action-oriented research to prepare researchers with resources to enable them to better understand the setting of real-life application and support decisions at the time of planning, implementing and evaluating action in the AR cycles (cf. Lakiza & Deschamps, 2019).

The initial procedure is organised in two main stages: diagnosis of the company’s current situation and deployment of action plans to improve performance, as illustrated in Figure 4.6. The rationale behind the construction of this procedure is based on the common steps of the procedures presented in the existing PFs order to support the framework initiation for gathering data to identify the current situation (the diagnosis); definition of PIs; implementation of the measurement *per se*; and, proposition and implementation of improvement actions, as defined in section 2.2.4. The first stage can be described as follows:

- 1) Outline the application and set up specific goals: most PFs (e.g., Brown & Gobeli, 1992; Chiesa et al., 1996; Lakiza et al., 2018) start the application with outlining the importance of continuously measuring the innovation process to gain support from the main stakeholders and establish the main needs of the company.
- 2) Meet the stakeholders involved: meeting the participation of stakeholders is not only essential to define the goals but also to give access to key employees and data inputs for measuring the PIs (Chiesa et al., 1996; Lakiza et al., 2018; C. H. Loch & Tapper, 2002).

- 3) Define the dimensions and PIs to be measured: this step aims to determine the relevant dimensions to be measured and select the appropriate PIs for the company to measure the dimensions. Previous PFs highly indicate that this could be based on a pre-defined compilation of PIs (Berg et al., 2009; W. B. Brown & Gobeli, 1992; Chiesa et al., 1996; Lakiza et al., 2018; C. H. Loch & Tapper, 2002; Werner & Souder, 1997).
- 4) Measure the PIs: here, all the measurements are made. Two main tasks are involved: the collection of data from the company's documents/systems and the assessments from key employees involved in the factor being measured (Chiesa et al., 1996; Lakiza et al., 2018; C. H. Loch & Tapper, 2002).
- 5) Evaluate performance: this step is the 'black box' of most PFs. Despite mentioning gap analysis of the current and desired performance, existing procedures do not include further guidelines. It means that the analysis is solely based on the participants' know-how (no support from the PFs), which entails more effort to find ways to analyse the measurements and acquire this knowledge and experience, that, in turn, can lead to likely discouragements and unexpected results.

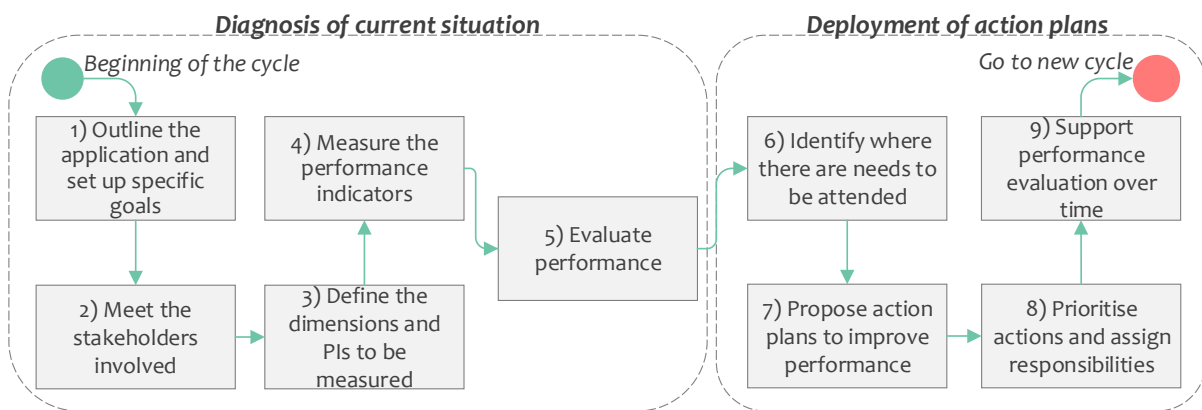


Figure 4.6. Initial procedure of the PF to begin the AR.

After the initial evaluation of performance, there is a natural pause to validate the findings and decide to go forward (or back and perform another cycle of diagnosis), similar to a decision-gate. The second stage of the conceptual PF, aiming for the deployment of action plans, involve:

- 6) Identify where there are needs to be attended: the gap analysis should support the identification of improvement gaps. However, as there is no formal structured support, this step is rather superficial or exclusively based on the participants' know-how. Only

Chiesa et al., (1996) and Lakiza et al. (2018) PFs presented some insights into this step, but to a limited degree.

- 7) Propose action plans to improve performance: this step is indicated by most PFs (e.g., Chiesa et al., 2009; Lakiza et al., 2018), but without major support, it is often performed in an *ad hoc* basis. Nevertheless, managers find the definition of action plans especially difficult, even when they identify the gaps that need improvement (Pigosso, 2012). The support for this step is further discussed in section 4.3.4.
- 8) Prioritise actions and assign responsibilities: since the companies have limited resources and time, the gaps identified should not be tackled at once. Existing PFs acknowledge the need to prioritise, but they leave at the discretion of the company to prioritise as well as the task to assign who is responsible for the action implementation (e.g., Chiesa et al., 1996; Lakiza et al., 2018; Loch and Tapper, 2002).
- 9) Support performance evaluation over time: the final step revolves around developing instruments to support performance in a continuous manner. Two PFs put to use distinct levels of performance going from poor to best practices to characterise the progression of the performance (Chiesa et al., 1996; Kahn et al., 2006), but these do not relate with the PIs measured, leaving space for a better definition of this step.

4.3.2 FACILITATION

The next supporting element associated with the development of a new PF concerns the facilitation, which relates to the decision of developing either a stand-alone solution or a PF supported by facilitator(s). This decision entails then making the necessary preparations in the PF for either alternative.

From the discussion about the existing PFs, only a few do not address the issue of facilitation. Several PFs implicitly indicate the support of facilitators to apply the PF. For instance, Lakiza et al. (2018) suggest the active participation of facilitators with practitioners and researchers in applying the PF. Additionally, the frameworks proposed by researchers such as Chiesa et al. (2009), Brown & Gobeli (1992), and Berg et al. (2009), mention that researchers and engineers responsible for the innovation process are needed to apply the PF. Because these PFs address this element implicitly, there is an absence of discussion and instructions about preparations and implications over facilitation.

On the other hand, two frameworks claim that their solutions were designed to be stand-alone use, i.e., without the support of external facilitators. In the first case; however, the research already identified that the PF was too complex for stand-alone use and required greater training and expertise than the typical company can provide (Chiesa et al., 1996). The second PF was designed to be stand-alone by innovation managers (Crossan & Apaydin, 2010). However, this last framework was a conceptual exercise, with no empirical testing in companies, so no real implications nor discussion about the stand-alone decision were provided.

Further PFs do acknowledge the importance of having external facilitator(s) in addition to employees enrolled in the PF application. Werner & Souder (1997), for instance, emphasise that the facilitators (called 'reviewers') must be chosen carefully for their knowledge and they must be experts in their fields. The authors also suggest a core team of four or five people, comprised of both external facilitators and practitioners of the company, to maximise reliability. Furthermore, Loch & Tapper (2002) underline that the practitioners of the R&D department should be a part of the measurement process along with the facilitators. Kahn et al. (2006) also emphasise that the application of the steps of the procedure should be led by the facilitators; meanwhile, the employees from the company should be a part of the application team.

Therefore, for the application of the new PF developed in this research, the external facilitators have the role of applying the measurement instruments and leading the procedure steps. Likewise, a core team should be created, composed of the facilitators (either internal or external) and key stakeholders from the company. The stakeholders must be chosen carefully for their knowledge. Recommendations specify that they must be experts in their fields (indicated by the time in the company, e.g., 5-10 years). Finally, their areas should be related to the innovation process, but not limited to, for example, innovation coordination, R&D, product engineering, process engineering, new business development, marketing, services, quality, among others.

4.3.3 VISUALISATION OF PERFORMANCE PROGRESSION

The next supporting element for PFs consists of visualising performance progression, closely related to the continuous approach for process improvement (Morisawa, 2002). For this, evolutionary approaches of business process improvement showing the progression of

performance across the considered dimensions are the go-to solution in other domains, e.g., eco-design implementation and software management (Hammer, 2007).

The evolutionary approach can be characterised by the application of distinguishing levels defined to portray the progression of components or the entirety of the process itself, across a number of dimensions to facilitate benchmark (Klimkó, 2001). To simplify, this approach is described with a limited number of levels, typically four to six, as demonstrated in the PFs of Chiesa et al. (1996) and Kahn et al. (2006). These levels are sequentially ordered, from an initial level up to an ending level, considered the level of 'excellence' (Klimkó, 2001). A closer look in the existing PFs for the innovation process reveals that most of them apply four levels, as in Chiesa et al., (1996) and Kahn et al., (2006). As a starting point, the PF adopts the four-level range, from one to four, to indicate the progression of performance that a company might present. This range is chosen because it is easier to understand, but the final configuration depends on the AR results.

The characterisation of each performance level can be qualitative ('soft') with the description of practices of increasing sophistication as the levels of performance increase, or quantitative ('hard') with benchmark values of the PIs, depicting gradually increasing performance (e.g., Barczak & Kahn, 2012; Chiesa et al., 1996; Kahn et al., 2006). The use of both types of characterisation enables a more structured way to characterise the progress of performance in a PF (Pigosso et al., 2013).

To define the 'soft' characterisation, the studies identified in the SLR presenting evolutionary levels were mapped. For instance, most authors present the characteristics of distinctive practices within four levels for several dimensions (e.g., Barczak & Kahn, 2012; Chiesa et al., 1996; Kahn et al., 2006). Others, such as Cooper, Edgett, & Kleinschmidt (2000) and (N. Anderson & West, 1996), in turn, present only initial and ending levels for innovation strategy and portfolio management, and organisation and culture dimensions, respectively. A few others also present five levels: Klimkó (2001) for knowledge management, and Cagnin, Loveridge, & Butler (2005) and Rapaccini, Saccani, Pezzotta, Burger, & Ganz (2013) for innovation environment. As their description of the initial and second levels were very similar, they were clustered together.

Some of the characteristic practices collected have undergone adjustments in their wording, ensuring alignment and conceptual compatibility between the levels and different

authors. In addition, an analysis of redundancy was performed, eliminating contradictory or required characteristics based on the number of occurrences. Thus, each dimension and sub-dimension have distinguishing practices that describe the evolution that a company can present progressing through performance in the innovation process. The characterisation of the levels for the first two dimensions, innovation strategy and knowledge management, is presented in Table 4.6, because of the considerable size (one or more characteristics for 21 sub-dimensions across four levels). The full extent is given in Appendix IV.

For instance, the dimension of innovation strategy presents the following ‘soft’ characterisation referring to the sub-dimension innovation orientation (designated as code IS-IO-1 see Table 4.6): level 1 “No innovation/new product goals explicitly established in the strategy”; level 2 “Unclear innovation/new product or unclear alignment between these and the strategy”; level 3 “Innovation/new product goals clearly stated and aligned with the organisational strategic plan”; and, level 4 “Mission plan help define strategic areas for new opportunities and establish clear innovation/new product goals in the strategic plan”. The required characteristics for the knowledge management dimension follow the same logic, each sub-dimension presenting one or more distinctive ‘soft’ characterisations (see Table 4.6).

For the ‘hard’ characterisation of the evolutionary levels, the performance effects captured in the PIs were identified. This means that the PIs classified under the rapid assessment category were further studied and mapped in benchmarking studies to find the evolution of companies in terms of performance progression. Thus, each sub-dimension required characteristics has a corresponding indicator with benchmark values. These benchmark values were compiled and employed as a first attempt to differentiate the performance levels using a numerical scale. Remarkably, several benchmarking studies identified in the SLR presented a characterisation of four levels performance to differentiate between poor and top-performing companies (e.g., Cooper & Edgett, 2014a; Cooper & Kleinschmidt, 1995; Dubiel, Durmusoglu, & Gloeckner, 2016; Eling et al., 2016; Killen, Hunt, & Kleinschmidt, 2008; Lee & Markham, 2016; Markham & Lee, 2013).

CONCEPTUAL DEVELOPMENT

Table 4.6. Examples of the 'soft' characterisation of the performance levels.

Performance Dimension	Level 1	Level 2	Level 3	Level 4
Innovation strategy	IS-IO1-1: No innovation/new product goals explicitly established in the strategy. IS-IO2-1: New projects are identified during the budget process and resources allocated accordingly. IS-Le1-1: Leadership decisions on funding drives new project selection. IS-Le2-1: Leadership has a short-term, tactical view of the innovation process.	IS-IO1-2: Unclear innovation/new product or unclear alignment between these and the strategy. IS-IO2-2: New projects are identified during the budget process and resources allocated accordingly. IS-Le1-2: Leadership related to R&D capability dictates new project's priorities. IS-Le2-2: Leadership has short to mid-term strategic view of the innovation process.	IS-IO1-3: Innovation/new product goals clearly stated and aligned with the organisational strategic plan. IS-IO2-3: Innovation goals plans drive new project selection. IS-Le1-3: Leadership applies market studies to guide strategic plan priorities. IS-Le2-3: Leadership has mid-term strategic view of the innovation process.	IS-IO1-4: Mission plan help define strategic areas for new opportunities and establish clear innovation/new product goals in the strategic plan. IS-IO2-4: Opportunity identification is ongoing and can predict the strategic plan real-time in order to respond to market forces and new technologies. IS-Le1-4: Leadership applies market studies to identify strategies buckets of resources to facilitate innovation in prospecting future exercises. IS-Le2-4: Leadership has a long-term, strategic view of the innovation process.
Knowledge management	KM-IdM1-1: There is a flurry of innovation activities without any discipline surrounding the management of ideas. KM-InF1-1: No formalisation of the innovation process exists. There are no process owners, only occasional innovation champions. KM-R1-1: Data (e.g., criteria to evaluate ideas, projects) on past projects are irregularly stored and managed.	KM-IdM1-2: There are individuals and/or organisational units dedicated to idea management. An idea database is maintained. But ideas coming from external sources are inexistent. KM-InF1-2: There is an informal, decentralised innovation process that can be readily circumvented by anyone. Limited documentation on the innovation process. KM-R1-2: Minimum data on past projects are stored and managed.	KM-IdM1-3: A common innovation process cuts across organisational groups, where different groups use their own tailored process. KM-InF1-3: Documentation on the innovation process is available. There is apparent innovation process discipline, but time-critical projects may skip stages of the process. KM-R1-3: Records on past projects and documentation play an important role and are mandatory.	KM-IdM1-4: There is a focus of interest is to share knowledge with other organisations, and to exploit common ways of knowledge creation and idea generation. KM-InF1-4: There are formal, documented processes. There are individuals and/or organisational units dedicated to knowledge management in the innovation process. KM-R1-4: The knowledge management function improves itself continuously, in an optimising manner.

Legend for the encoding used in Table 4.6.

First grouping of letters: denotes the dimensions: **IS**- innovation strategy; **KM**- knowledge management.

Second grouping of letters: denotes the sub-dimensions: **IO**-innovation orientation; **Le**-leadership; **IdM**-idea management, **InF**-informational flows and **R**- repository.

Number: the number just beside the sub-dimension denotes the order of that characteristic, and the number at the end refers to the performance level.

Reading example: **KM-InF1-1** Characterising practice 1 for dimension knowledge management, sub-dimension information flows, for performance level 1.

It is important to note that several terms are used to classify companies in evolutionary levels³⁶ according to their innovation process performance progression at benchmarking studies. This terminology can be found mostly using just 1-4 levels (Chiesa et al., 1996; Kahn et al., 2006) or, e.g., ‘dogs’, ‘low-impact performers’, ‘solid performers’ and ‘high-impact performers’ (Cooper & Edgett, 2014a; Cooper & Kleinschmidt, 1995) or even 3 levels with ‘the best’, ‘average’ and ‘the rest’ (Lee & Markham, 2016) or ‘poor performers’, ‘average’ and ‘top performers’ (Killen et al., 2008). As in the case of the required characteristics, the performance effects have undergone slight adjustments in their original wording of the PIs, ensuring alignment and conceptual compatibility. Therefore, the PF opted the nomenclature of levels 1–4, as used in established PFs in the past.

The ‘hard’ characterisation of the four levels for the first two dimensions, innovation strategy and knowledge management, is presented in Table 4.7. Because of its considerable size, the full extent of the ‘hard’ characterisation is also given in Appendix IV. The benchmark values for the PIs, which are depicted as the averages of companies located within that level in question, worked as the natural dividers of each performance level range. Although these figures are a small sample of reality, they are a sound approximation for manufacturing companies based on previous works. For example, the PI [IS3] “Innovation long-term planning” presents the following benchmark values for the application of a 1-5 qualitative scale: level 1 ≤ 2.5; 2.5 < level 2 < 3.5, 3.5 < level 3 < 4.0 and level 4 ≥ 4.0.

Therefore, the assignment of the evolutionary levels from 1 to 4 should rely not only on evidence that depicts the ‘soft’ characterisation but also real-life measurements of the PIs to demonstrate the ‘hard’ characterisation of the company. Thus, the requirements used to characterise each level are defined as ‘soft’ and ‘hard’; meaning that each sub-dimension characteristic has a correspondent indicator. Hence, the evolution of a company throughout the levels’ progression will require the fulfilment of the pairwise requirements (both ‘soft’ and ‘hard’) of that specific performance level within each performance dimension considered in the PF. Thus, this should be valid for all the nine performance dimensions defined in section 4.2.1 for the PF.

³⁶An analysis of the characterisation of the companies’ sampling in the selected benchmarking studies was performed to ensure that the data retrieved was indeed pertaining to manufacturing companies. The characterisation of the companies that took part in the benchmarking studies investigated in the research is discussed during the bibliometric analysis in Appendix IV, and further indicated in terms of general number in Appendix VI.

CONCEPTUAL DEVELOPMENT

Table 4.7. Examples of the 'hard' characterisation of the performance levels.

Performance dimension	Sub-dimension (code)		Performance indicator	Unit of measurement	Level 1	Level 2	Level 3	Level 4	References
Innovation strategy	Innovation orientation	(IS-IO1)	[IS1] Level of awareness of innovation goals	Dimensionless/ qualitative	≤2.5	2.5<value<3.5	3.5<value<4.0	≥4.0	(Cooper & Kleinschmidt, 1995)
		(IS-IO2)	[IS2] Spending reflects the innovation strategy	Dimensionless/ qualitative	≤2.1	2.1<value<3.2	N/A	≥4.1	(Killen et al., 2008)
	Innovation leadership	(IS-Le1)	[IS16] Top management support for innovation	Dimensionless/ qualitative	≤3.6	3.6<value<3.8	3.8<value<4.4	≥4.4	(Cooper & Kleinschmidt, 1995)
		(IS-Le2)	[IS3]Innovation long-term planning	Dimensionless/ qualitative	≤2.6	2.6<value<3.2	3.2<value<3.7	≥3.7	(Cooper & Kleinschmidt, 1995)
Knowledge management	Idea management	(KM-IdM1)	[KM1] Percentage of ideas actively generated by formal/informal activities	Per cent of ideas	≤18%	18%<value<39%	39%<value<60%	≥60%	(Markham & Lee, 2013)
			[KM2] Number of ideas reviewed per phase	Per cent of time	≤19%	19%<value<40%	40%<value<75%	≥75%	(Markham & Lee, 2013)
	Information flows	(KM-InF1)	[KM16] Diversity of knowledge sources	Dimensionless/ qualitative	≤19%	19%<value<40%	40%<value<75%	≥75%	(Wang, Wang, & Horng, 2010)
	Knowledge repository	(KM-R1)	[KM27] Time-off for creative things and generation of tacit knowledge	Per cent of time	≤2.0	2.0<value<3.5	3.5<value<4.0	≥4.0	(Wang et al., 2010)

Legend for the encoding used in Table 4.7.

Dimensions: **IS**- innovation strategy; **KM**- knowledge management.

Sub-dimensions: **IO**-innovation orientation and **Le**-leadership; **IdM**-idea management, **InF**-informational flows and **R**-knowledge repository

In particular, the measurement of the PIs should be representative of the company. So, corroborating evidence should be gathered via document analysis to triangulate data whenever possible, while the measurements of the PIs should be collected from the company's documents/systems and assessments from key employees involved in the PI being measured. Key employees should be interviewed, prioritising a variety of employees from different areas and hierarchical levels to ensure a broad overview of how the innovation process is conducted in the company.

Finally, to support the visualisation of performance progression, using both 'soft' and 'hard' characteristics, the graphical representations from the literature (see section 2.2.4) were conceptually analysed. The representations, shown Figure 4.7, provide a visual diagram to display the four levels of performance that the company has the potential to attain for each of the nine performance dimensions within the 34 rapid assessment PIs. In general, the literature indicates radar is one of the most used representations, because of its easy display (cf. Pigosso, 2012); nonetheless, in this research, AR results will inform this decision.

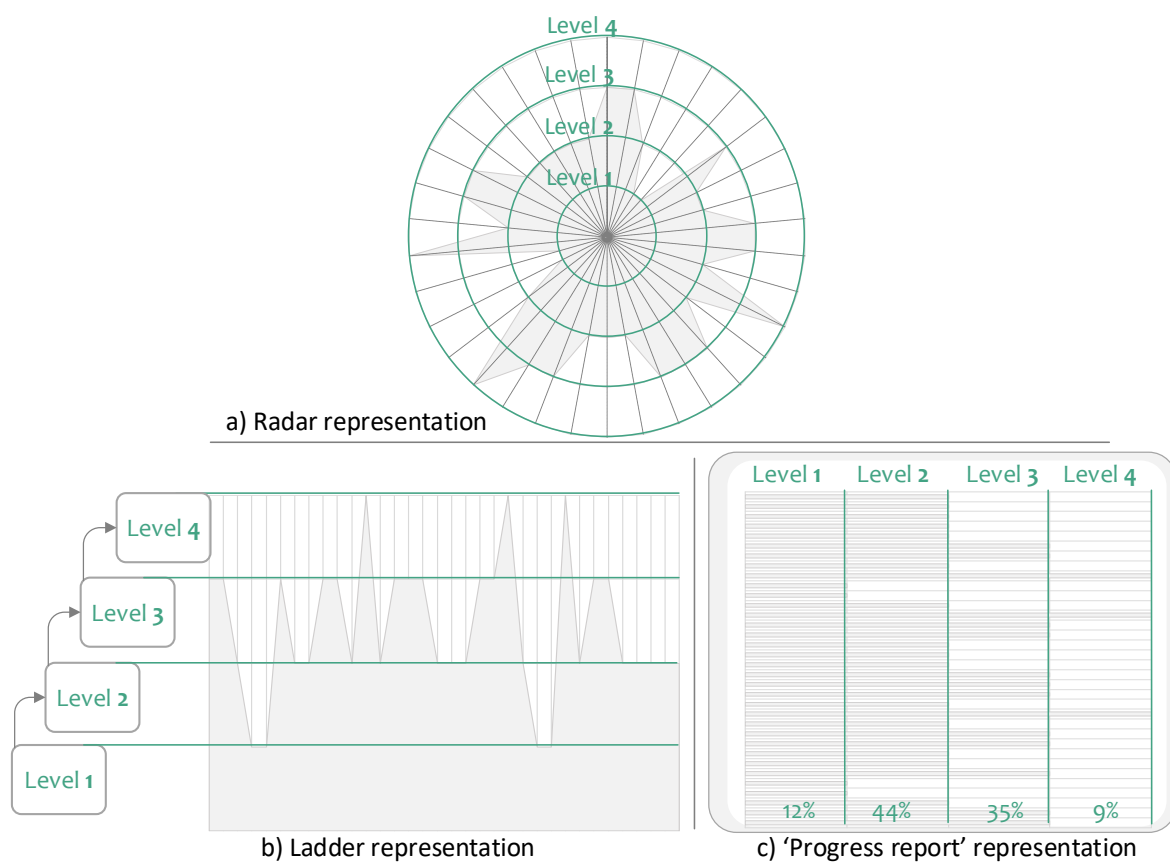


Figure 4.7. Graphical representations of the progression of performance.

By defining each level of performance, this visual resource also provides an outline of the company's innovation capability profile. The interpretation of the diagram, nevertheless, should be assisted by the facilitator(s) to identify which results are already suitable for the moment, and what dimensions need further actions to improve performance. Thus, the support for the definition of action plans is discussed next.

4.3.4 SUPPORT FOR IMPROVEMENT ACTIONS

The last supporting element to be defined for the conceptual version of the PF addresses improvement actions. Thus, to help managers define action plans to reach the desired performance, it is necessary to support the evaluation of performance and the following decisions of what are the next steps. This support goes hand in hand with the PIs specification parameters of measurement instructions, which include the guidelines for the analysis of the performance achieved and definition of appropriate actions to take after the measurement results (i.e., "what to do?" discussed in section 2.2.2.1 of the "Literature review" Chapter).

Two points must be addressed in this section to provide support in the definition of improvement actions. The first involves providing support in the analysis of the current performance and seeing what the achieved results inform the users. In this sense, the partition of the performance progression into four performance levels helps to breakdown the analysis into parts indicating the magnitude of how well the company is doing (e.g., achieving the results of performance level 3 or 4 presents a more significant improvement challenge than level 2, for example). Thus, for supporting the definition of where the company wants to go, i.e. the desired level of performance, the PF is envisioned with the implementation of one level at a time, targeting the gaps located at the lowest level, and moving up. It also entails the assumption of ongoing use of the PF with an improvement agenda to assess the current situation of the company from time to time.

The second point that needs to be addressed to enable the improvement of the innovation process is the definition of improvement action plans *per se*. For that, this research turned to the SLR again to identify and analyse the papers presenting the PIs retrieved in the search for key actions implemented by the respective studies to improve performance after the measurement of performance. This search also included cross-referencing further publications mentioned in those studies. These collected actions exclusively refer to the rapid assessment PIs because of their critical role in defining the four performance levels to display

performance progression and avoid potentially large amounts of data for the remaining 225 indicators.

These improvement actions collected from the literature refer to innovation practices related to the managerial activities of the innovation process, which favour innovation performance. They are defined at the managerial level, and therefore, they are ‘generic’ to an extent, so that they can be applied by distinct manufacturing companies, regardless of the type of products/PSS developed. A total of 45 innovation practices were obtained relating to the rapid assessment PIs. Thus, for each indicator, there are one or more practices collected. A sample of these practices are presented in Table 4.8 for the innovation strategy and knowledge management dimensions (see Appendix VII for the full list).

Table 4.8. Examples of improvement practices collected.

Code	Practice title	Performance Indicator	Reference
P01-IS-IO	Guidelines for the continuity of the innovation strategy	[IS2] Spending reflects the innovation strategy	(Lakiza & Deschamps, 2019; Nilsson & Ritzén, 2014)
P02-IS-IO	Scorecard for business planning	[IS3] Innovation long-term planning	(Kaplan & Norton, 2007)
P03-IS-IO	Management statements for innovation	[IS16] Top management support for innovation	(Melnik, Hanson, & Calantone, 2010)
P15-KM-IdM	Definition of the stakeholders’ role in the formal generation of ideas	[KM1] Percentage of ideas actively generated by formal/informal activities	(Boeddrich, 2004)
P16-KM-IdM	Consistency in the criteria of both radical and incremental ideas/projects	[KM2] Rate of product ideas reviewed or approved (per phase)	(Eling et al., 2016)
P17-KM-IF	Communities of practice (CoP) for the innovation process	[KM16] Diversity of knowledge sources	(Prencipe & Tell, 2001)
P18-KM-R	Development of a knowledge repository and management strategies	[KM27] Time-off for creative things and generation of tacit knowledge	(Bose, 2004; Prencipe & Tell, 2001).

Legend for the encoding used in Table 4.8.

Dimensions: **IS**- innovation strategy; **KM**- knowledge management.

Sub-dimensions: **IO**-innovation orientation and **Le**-leadership; **IdM**-idea management, **InF**-informational flows and **R**-knowledge repository.

In Table 4.8, the first example of improvement practice is designated by code ‘P01-IS-IO’, which refers to the innovation strategy dimension and the innovation orientation sub-dimension. It refers to the development of guidelines for the continuity and maintenance of the innovation strategy in the company, based on Lakiza et al. (2018) and Nilsson & Ritzén (2014) description of actions taken after the measurement in their respective case studies. This

innovation practice, as well as the others, are presented with their identification code, the indicator they refer to, title, goal, and a short description about the practice followed by the reference, as illustrated in Table 4.9.

These improvement practices were further classified according to the performance levels built in the PF, meaning which levels these practices are more likely to be implemented. This classification was accomplished by means of a correlation matrix in which each improvement practice was compared to the distinctive practices ('soft' characterisation) of the established four performance levels (as defined in section 4.3.3). The results of this correlation matrix enabled the classification of the performance levels that are presented with 45 practices (see Table VII.2 in Appendix VII). It is important to remember that this classification will be used during the AR to be further validated.

Table 4.9. Description of improvement practice P01-IS-IO.

Title	Development of guidelines for the continuity of the innovation strategy
Goal	To establish a better balance between day-to-day execution and future development by setting up strategic objectives to ensure that at least some amount of time and resources on future activities.
Description	This practice entails the development of guidelines for the continuous construction and maintenance of the innovation strategy in the company, including guidelines for measuring innovation with the integrated involvement of the technical and business development areas (without being limited to the R&D department). The company already present efforts in future scoping and prospection exercises (with roadmapping or similar), so the visualisation and monitoring of these efforts play an essential role in developing an organisation's capability to innovate.
Performance level	Level 3.
Reference	(Lakiza et al., 2018; Nilsson & Ritzén, 2014).

Finally, in order to support the decision-making process of prioritising which practices to implement due to resources and time constraints, this work set out to identify several criteria used to support management in the prioritisation of action plans. These criteria were retrieved from the literature with the help of the SLR. They are as follows: implementation time; strategic alignment; top management support; resources availability; cost; competitive advantage; legal compliance; and, return on investment (Comoglio & Botta, 2012; Costa, 2010; Hudson Smith & Smith, 2007; Ivanov & Avasilcăi, 2014; Pillai, Joshi, & Rao, 2002; Scuotto, Del Giudice, Peruta, & Tarba, 2017; Tung, Baird, & Schoch, 2011). Thus, these mentioned criteria can be work as a checklist of possible criteria to be applied in the prioritisation of possible action plans during the application of the PF.

4.4 REMARKS

This chapter has provided an overview of the conceptual development of the PF. It started by describing the database elements, first outlining the dimensions and then the PIs retrieved, all results from the systematic review. Then, it presented the results for the supporting elements of the PF, which included the procedure, facilitation role, visualisation of the performance and support for defining improvement actions.

Reflecting on this initial proposition of the PF enables the observation that the measurement of the performance itself is, in fact, only one side of the innovation measurement. Previous researchers have highlighted that having a supporting process of performance measurement that allows decisions to be reached can contribute six times greater to decision-making than the number of measurements performed (Lovallo & Sibony, 2010). In this way, the inclusion of the supporting elements in the development of the PF has great potential to contribute to the higher picture of decision-making and the evaluation process of performance.

This initial conceptual framework is important due to two main reasons. The first is to avoid 'reinventing the wheel' and leverage the cumulative knowledge from the literature for more informed decision-making. PIs that are reliable and valid enable free subsequent researchers from the need to redevelopment. The second is that in a situation where an AR is going to be performed next, it is imperative that researchers are equipped with the state-of-art literature knowledge, with enough information to give them support in the understanding of the setting and sensibility to capture the richness of action-oriented at the time of action in the companies.

Further learnings gained through the AR will be able to shed more light into the PF and its real-life setting. Thus, in the next section, the results of the empirical development of the PF through an AR in two distinct manufacturing companies are presented, which include the use of all the elements presented in the conceptual PF concerning the two stages of the procedure: diagnosis of the current situation and deployment of action plans to improve performance.

5 EMPIRICAL DEVELOPMENT

The conceptual version of the PF was further developed in the third stage of the research method through the conduction of AR, as described in Chapter 3. In this way, the PF was improved at the same time it was being applied in the participating companies, enabling the consideration of the feedback from the participants and valuable inputs from a real-world application to inform the empirical development of the PF.

The main goal of the AR was to develop further the database and supporting elements of the PF. As the application is intrinsically related to the procedure, the AR followed the two stages established in Chapter 4 (“Conceptual development”):

- 1) Diagnosis of the current situation of the innovation performance; and
- 2) Deployment of action plans to improve performance.

The AR was carried out in two main cycles for each participating company,³⁷ as represented in Figure 5.1, in which the conceptual PF was applied and improved in action. Each cycle covered the four AR steps; ‘constructing’, ‘planning action’, ‘implementing action’, and ‘evaluating action’, with the pre-step of ‘context and purpose’ preceding the initial cycle in each of the two participating companies.

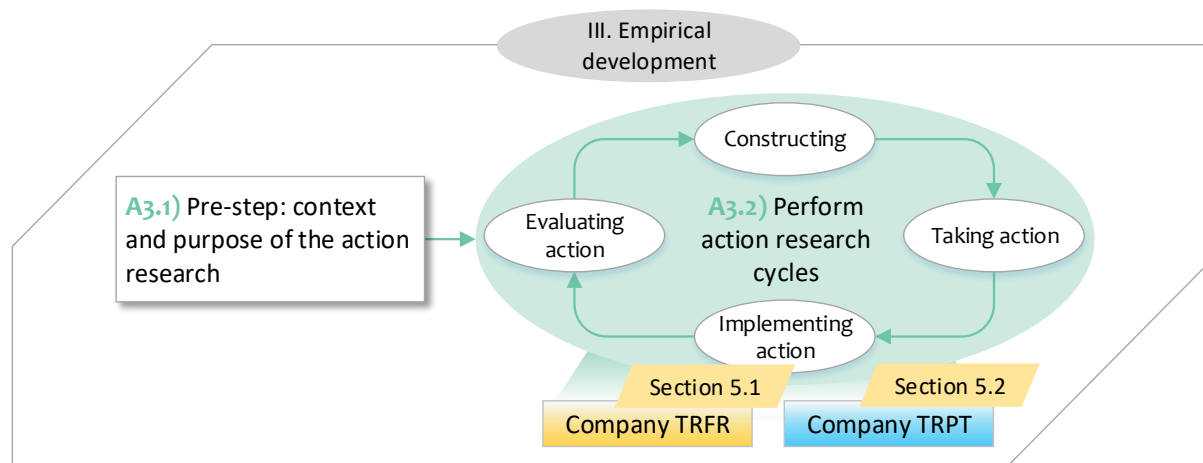


Figure 5.1. Location of the results for stage 3 of the research method.

The ‘context and purpose’ step took place at the beginning of the AR to explain the background in which the research is being conducted to the participating company and understand their motivations and expectations. The results of this step are used to describe

³⁷As mentioned in the “Methodology” Chapter, the choice in this research is to apply the PF a sequentially, first Company TRFR then company TRPT (for more details see section 3.3).

the presentation of each participating company, given as the introduction of section 5.1 and section 5.2, respectively.

The first AR cycle involved interactive rounds of data collection, feedback, and analysis to apply the PF procedure and resulted in a diagnosis of the company's current situation. Note that the 'constructing' step was carried out in the first AR cycle in each company as to understand how the company in question performed their innovation process. The results of the first cycle are presented in section 5.1.1 for the first company and section 5.2.1 for the second company.

In the second AR cycle, the diagnosis generated in the first cycle worked as the input for the deployment of action plans to improve performance stage, which is presented in section 5.1.2 for Company TRFR and section 5.2.2 for Company TRPT, respectively. At the end of this cycle, the evaluation step analysed not only the results of this cycle but also the application as a whole, i.e., how satisfied the practitioners (the users) were with the results obtained the PF. The evaluation results are presented in section 5.1.2.3 for the first company and section 5.2.2.3 for the second company.

Finally, section 5.3 highlights the key learnings and insights gained in action during the AR cycles that were incorporated into the PF (section 5.3.1). As a result of the AR, the final version of the PF is presented in 5.3.2, which is the same version applied in the case study carried out to test the theory developed.

5.1 COMPANY TRFR

Company TRFR mainly produces power transformers, being classified under division 27 of the ISIC classification (United Nations, 2008) as a manufacturer of electric motors, generators, transformers and electricity distribution and control apparatus. This European manufacturing company has more than 70 years of experience in the field, with approximately 240 employees and annual revenue between €10M and €50M.³⁸

The company has three main types of product in their portfolio: 1) power transformers – with a higher capacity; 2) mobile substations, and 3) distribution transformers – with a lower capacity. In general, the first two types of products, power transformers with higher capacity and mobile substations, are characterised as engineer-to-order (ETO) products, with a certain

³⁸Due the to the non-disclosure agreement signed with Company TRFR (**TR**ans**Forme**Rs), identification and other several sensitive information that cannot be published and were omitted from this document.

degree of customisation. The distribution transformers, on the other hand, are characterised by continuous production, with an average of 100 units produced per week.

Driven by business opportunities, clients' pressures, national innovation schemes, and by the advance of competitors, Company TRFR realised the great importance of a systematic process to measure innovation process performance. The company is currently aiming to improve its management of the innovation process within a 2020 plan to focus on products with a sustainable advantage and develop more competitive solutions and greater convergence with market trends. These characteristics provide an industrial environment and cultural support that is ideal for proposing a new PF in action-oriented research.

The participating company would get guidance for measurement and evaluation of the innovation performance. At the same time, the researcher would have the opportunity to apply the PF in practice to further develop and test it. During the AR the company would have access to a diagnosis of its current situation across several relevant dimensions and rapid assessment PIs, and a list of possible improvement actions according to the current situation of the company.

Therefore, after realising the potential benefits of the PF, a partnership was established for its application. The Company TRFR ensured support and commitment for the application, including the provision of the needed information and access to relevant employees. Furthermore, the support and commitment of the company were essential for ensuring the success of the AR.

5.1.1 DIAGNOSIS OF THE CURRENT SITUATION

The first AR cycle aims to develop the first stage of the PF further, contemplating the diagnosis of the current situation of the company. This diagnosis aims at characterising the company's innovation process performance across several performance dimensions. The next sections present the following steps performed in the first AR cycle: constructing (section 5.1.1.1), planning action (section 5.1.1.2), implementing action (section 5.1.1.3) and evaluating action (section 5.1.1.4).

5.1.1.1 CONSTRUCTING

The beginning of the AR cycle aimed to understand how the company carried out the innovation process phases in order to construct the current situation. There are two main reasons for that:

- To understand the process and vocabulary adopted by the Company TRFR; and
- To identify initial key people to be interviewed for the diagnosis.

An initial document analysis was carried out to understand how the processes were organised, documented and performed in day-to-day business. During this step, two key employees, the technology innovation coordinator and the head of technology, were interviewed to understand the processes and clarify issues that were not clear in the analysed documents. To perform these interviews, the characteristics (or 'contextual variables') of the innovation process identified in the literature review (section 2.1.4) were translated into a semi-structured interview to help identify these characteristics (see questionnaire S1 in Appendix VIII).

The comments obtained from these interviews were documented and reinforced the importance given to the innovation process and its improvement agenda. The company also provided access to further documents, such as annual reports, description of the innovation phase's activities and deliverables, and roles and responsibilities. The document analysis and these initial interviews enabled the construction of the current situation of the company, considering the five phases defined in the literature review (IFE, TD, PD, MAM and EoL) and the contextual variables of the innovation process.

Company TRFR presents the characteristics of an analyser-orientated firm, according to Miles & Snow (2003), by showing a combination of prospecting and defending strategies. It means that the company prospects new markets and opportunities for new technologies (evidenced by idea generation activities discussed later) as well as it tries to maintain the domain over a market segment, avoiding the entry of competitors by addressing quality and price of their products.

Considering the stimulus that drives the innovation process; market pull or technology push, the latter is the primary driver of innovation of the company, with most sources of ideas being from the divisional functions (R&D and technical areas). New product ideas emerging from opportunities, demands or needs identified in the market organisation are secondary.

This observation is in line with the literature, as the analyser orientation is typically presented by both drivers, with an emphasis on one of them (Miles & Snow, 2003).

One of the most significant contributors of ideas is the R&D department, followed by other technical areas (e.g., product engineering), but external sources also contributed with ideas, mostly suppliers. Additionally, universities and technical institutes, and other industrial partners sometimes play a minor role in the idea generation. Interestingly, the company is studying the feasibility of implementing an open online platform to collaborate with a broader base of entities outside the company.

The level of formalisation of the innovation process is medium-high, with well-established activities and deliverables. For instance, in the IFE, the idea generation is supported by a procedure to prospect and monitor new technologies with brainstorming techniques using SWOT analysis and competitor analysis (e.g., BCG matrix) to define the year's technology development plans. Because a graphical representation of the innovation process is a powerful tool to convey essential information, the IFE is illustrated in Figure 5.2.³⁹

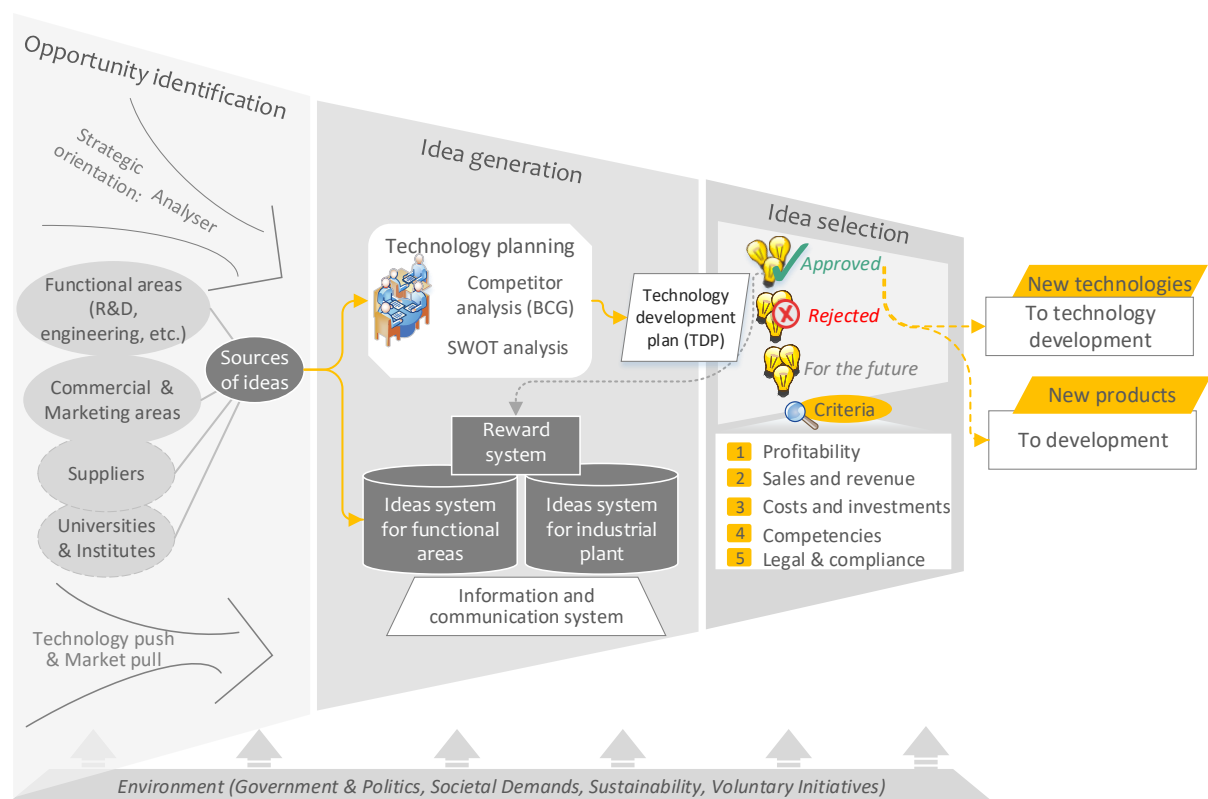


Figure 5.2. Constructing IFE in Company TRFR.

³⁹From this point on, the phases of the innovation process of the participating companies are going to be illustrated with graphical representation. These illustrations were developed for this work and not a reproduction from the companies' documentation.

Ideas are captured using an internal system to collect idea suggestions. The company has two separate systems: one for the shop-floor staff and another for all the other functional divisions. There is also a procedure in place to analyse the ideas captured from time to time, on an organised schedule headed by an innovation committee. The generation of ideas is further supported by a reward system, designed to provide monetary incentives for those ideas selected. The ideas are selected then using five types of criteria: 1) profitability and expected return; 2) future sales and revenue; 3) costs and investment; 4) competences (non-financial factors, e.g. sustainability), and 5) legal and compliance.

With the 'go' decision for a selected idea that requires the development of new technology, resources are allocated in the development stage to design and test it (see Figure 5.3), very similar to what is illustrated by Cooper (2006). In the first stage for developing technologies, 'project scoping', the aim is to plan and set up the foundation for the project, typically lasting several weeks.

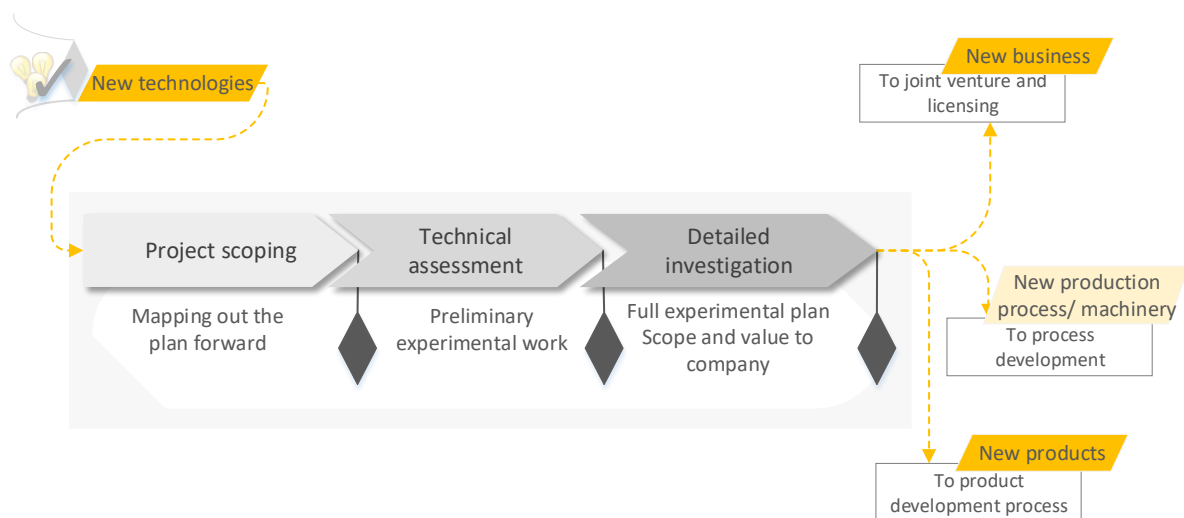


Figure 5.3. Constructing the TD phase in Company TRFR.

Then, the R&D personnel begin by demonstrating the technical feasibility under ideal conditions with experimental work (typically 3-4 months). Following this, the detailed investigation usually lasts two years to implement the experimental plan in full extension, prove technology feasibility, and define the technology's scope and value to the company. The technology can follow four possible outcomes from the last decision-gate: 1) a licensing or joint venture with other companies (rare); 2) a new product⁴⁰ (most common); 3) an improvement of the manufacturing process and, 4) future developments.

⁴⁰Note that, in this case, this last TD gate is combined with the early gate of the product development.

The product development (PD phases) begin with the conceptual design where the development team convert the concept (from the IFE) or the technology (from the TD phase) into a working product (see Figure 5.4). The work can last for several months, which leads to the detailed design. Here, if the product is engineering to order, the client would be typically involved. At that time, because of the company's product portfolio (mostly power transformers), there is a particular stage to produce and analyse a plethora of simulations and their checklists to meet regulatory and customer testing.

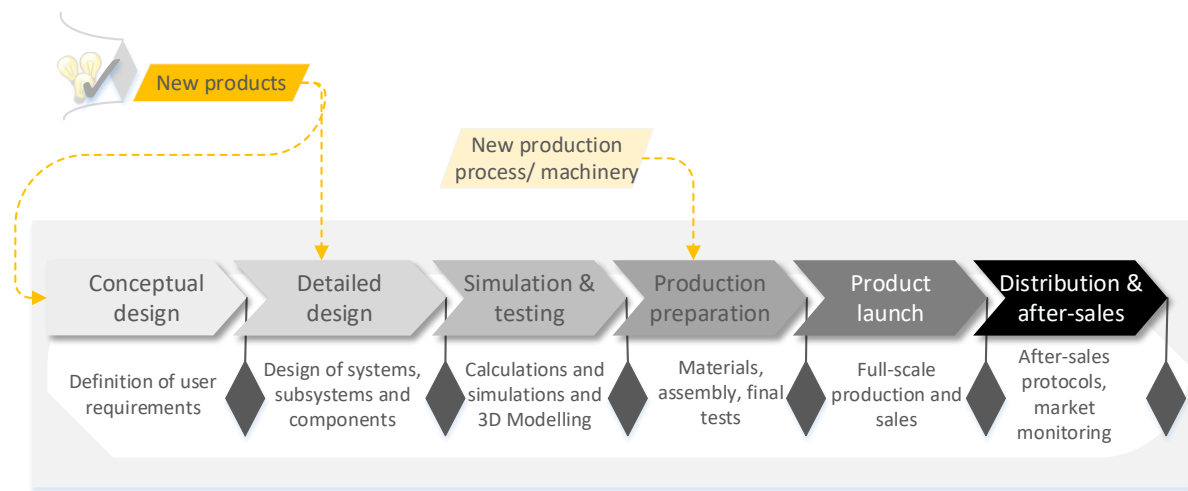


Figure 5.4. Constructing the PD phases (with MAM and EoL activities) in Company TRFR.

Further down the line, the production process is adapted when required,⁴¹ which involves pilot tests or the final assembly (for ETO products). The product is then launched into full-scale production and then shipped international, and national distribution channels while after-sales protocols and corresponding training are put into place. The company has an ongoing process for monitoring product outcomes in the market, mostly financial (revenue, sales, return on investment). Since 2016/17, they monitor sustainability indicators (environmental impacts, mostly related to the transformers noise production close to living areas and disturbances of natural areas).

Finally, the company is also implementing the principles of circular economy through after-sales protocols in their MAM activities to monitor the market. It involves the logistics of collecting used transformers to refurbish components and parts and recycle materials and EoL protocols for preparing the disposal of materials that cannot be recovered (e.g., treatments for the used transformer oil). Note that both MAM and EoL are combined into the PD phase.

⁴¹Typically, the manufacturing processes involved are materials preparation, winding, assembly, electrification of the systems and electrical equipment and final compliance lab tests on each module and critical components.

5.1.1.2 PLANNING ACTION

The goal of this AR activity was to plan how the steps of the initial procedure, as defined in section 4.3.1, were going to be carried out in the Company TRFR. These initial steps involved the following steps (reproduced in Figure 5.5): 1) outline the application and set up specific goals; 2) meet the stakeholders involved; 3) define the dimensions and PIs; 4) measure the PIs, and 5) evaluate performance.

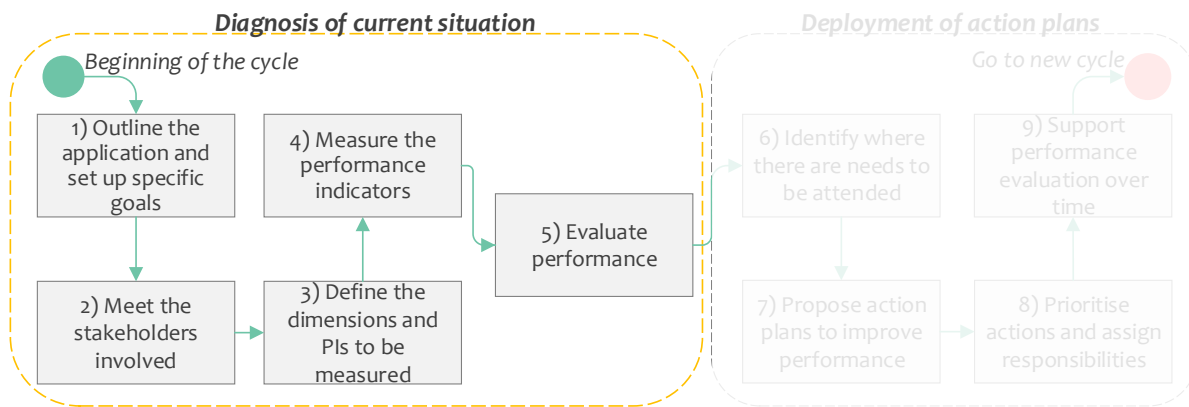


Figure 5.5. Initial procedure of the PF: diagnosis.

To support the execution of these steps, interviews and focus groups were considered the best options. Both face-to-face interviews and focus groups are valuable ways to gather data because they enable not only the collection of a myriad of information but also the creation of awareness about performance measurement among employees and a sense of shared ownership of the upcoming results (see discussion on Chapter 3).

Initially, the planning of steps to be implemented with the interviews and focus groups required the definition of the measurement instruments to measure the rapid assessment PIs and the search for evidence to corroborate the diagnosis performed. Two critical definitions were needed; one was to form a core team to implement the workshops for the focus groups, and the other was to adapt the vocabulary of the forthcoming interviews to the terminology used in the company. Thus, supporting questionnaire S2, that addresses the 34 rapid assessment PIs, was reviewed. When necessary, some terms were changed to ensure that the interviewee would understand the content of the questions and reply it accordingly (see the generic script in Appendix IX).

Secondly, the planning also involved the identification employees to be interviewed and take part in the focus groups. For this, the core team assembled to lead the PF steps

produced a stakeholder map to help on this matter (see Figure 5.6). After much discussion, it was decided that all stakeholders presenting at least a moderate level of interest, regardless of their influence, should take part. In this way, eight key employees⁴² were selected to be interviewed, representing various areas directly related to the innovation process (such as R&D, product development and process engineering), and hierarchical positions in the company to ensure a broad overview of how the innovation process performance. These key employees were also be invited to participate in the focus group.

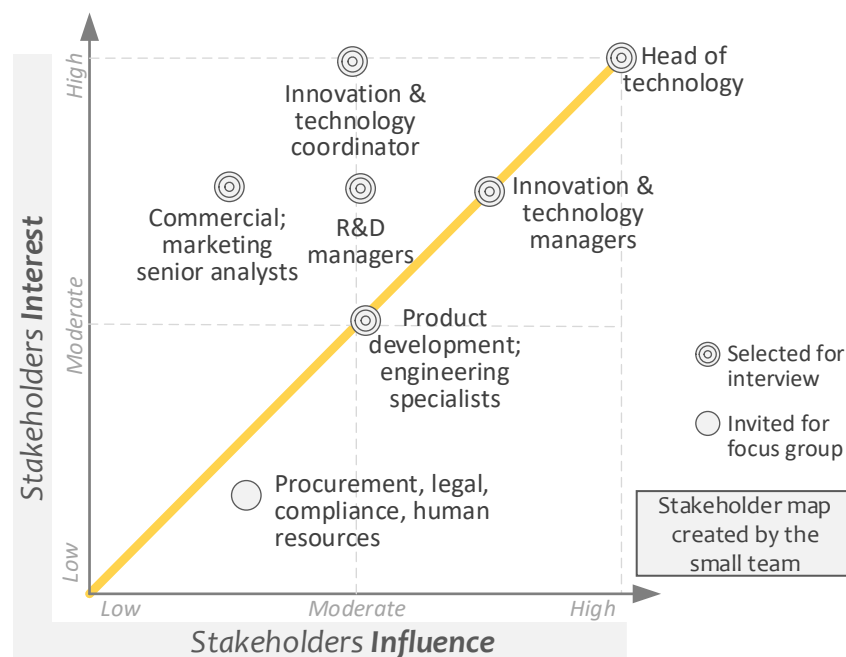


Figure 5.6. Stakeholder map for the PF application in Company TRFR.

Thirdly, the core team was then responsible for organising the schedule for carrying out the interviews, contacting the people to participate with the outline of the general context of the application and its goals, and providing the resources needed to carry out the steps of the procedure. At this point, it is important to highlight that the participating company ensured access to all the necessary resources and availability to all relevant employees identified as key in this application of the PF.

⁴²Although little practical guidance is available for defining sample sizes of interviews, Guest et al. (2006) and Morse (2000) indicate that six could be sufficient to capture meaningful results and achieve theoretical saturation (with a maximum of 25), when more data collection methods are being used (for this research, focus groups, journal keeping (observations), and survey to name a few).

5.1.1.3 IMPLEMENTING ACTION

With the planning of action prepared, the focus of this step is on implementation. It means to measure the current performance of the innovation process (with rapid assessment PIs and corroborating evidence) by carrying out interviews and then conducting the focus groups.

The core team took the lead for this first step to meet and conduct the series of interviews to gather the data, and then perform workshops to present and evaluate the data gathered. As mentioned before, eight key employees were selected to be interviewed at Company TRFR from different hierarchical levels (from the head of the department to analysts) and areas (R&D, engineering, development and more) (see Figure 5.6). In the workshops for the focus group, besides the interviewees, more employees with lower than a moderate interest in the measurement of the innovation process (e.g., procurement, legal, compliance and more) were included, resulting in a group of 12.

First, the face-to-face interviews were designed to include a brief introduction, followed by the application of the supporting questionnaire S2 (already adapted to the company's vernacular). In the interview, the employee was asked about each indicator following the script presented in Appendix IX and to provide additional evidence to justify the answer. The interviews with the 8 employees lasted 95 minutes on average.

The results of the interviews performed were tabulated in a spreadsheet, as shown in Appendix XI.⁴³ The employees' answers were analysed against not only their own commentaries but also the evidence gathered from the other interviews and the document analysis to provide coherence and consistency in the performance levels assignment.⁴⁴ Whenever necessary, the performance levels were changed based on the comments and pieces of evidence from the document analysis.

At this point, the results of the Company TRFR performance needed to be presented to the focus group. It would be possible to present the results using the spreadsheet, but as stressed by the core team because, most likely, the communication of the results would be difficult. For this reason, the consolidated results were prototyped into the three distinct visualisations (section 4.3.3), and the positive feedback informed the radar representation as the best format to convey the innovation capability profile shown in Figure 5.7.

⁴³Appendix XI shows the spreadsheet final format, with the graphical representation and entry for inputs.

⁴⁴Evolutionary and performance levels are synonyms. Company TRFR said it was easier to address as performance levels.

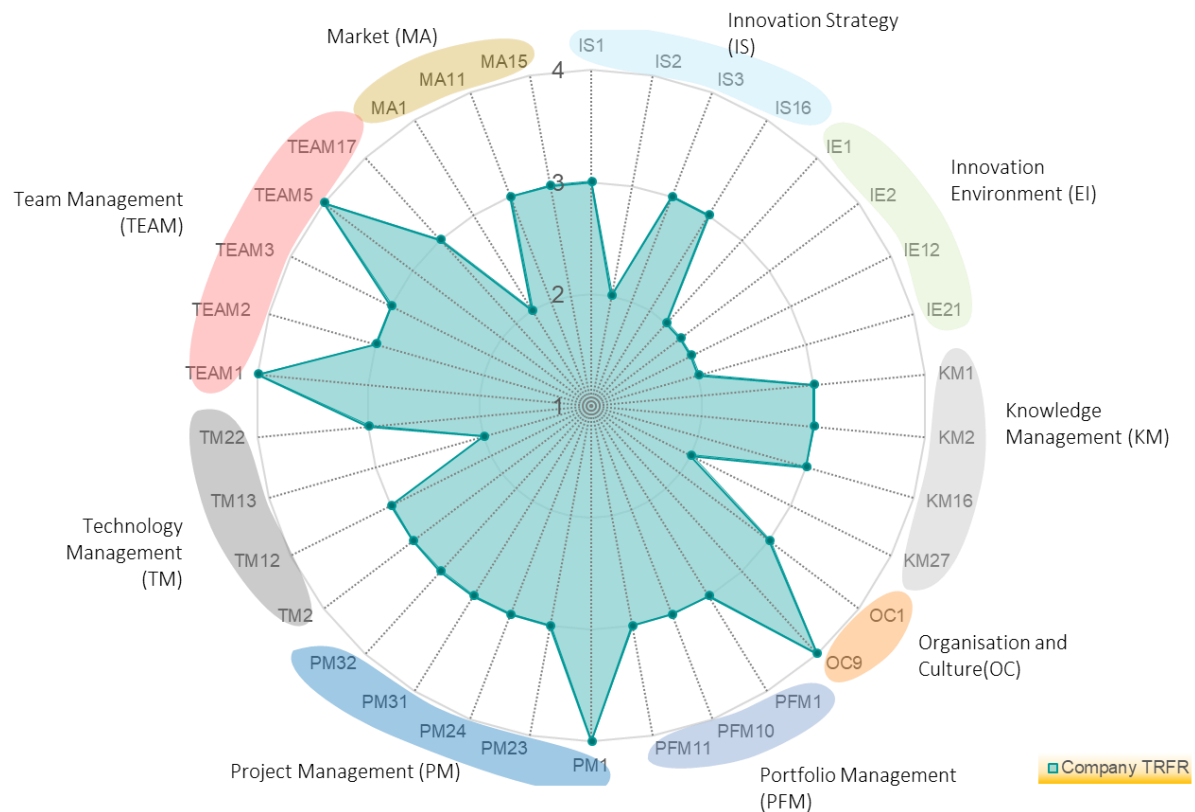


Figure 5.7. Company TRFR innovation capability profile.

Figure 5.7 represents the current innovation capability profile of the Company TRFR, i.e., it indicates which of the four performance levels are being achieved for the 34 PIs (from IS1, IS2, until MA15) according to the data collected from the interviews and the evidence collected from the document analysis. This profile is arranged into successive performance levels from one to four. For instance, rapid assessment indicator [IS1] “Level of awareness of innovation goals”, retrieved via the SLR, presented a performance of 3.6 out of 5, within the limits of performance level 3 ($\text{level } 1 \leq 2.5$; $2.5 < \text{level } 2 < 3.5$; $3.5 \leq \text{level } 3 < 4$; $\text{level } 4 \geq 4$) (Cormican & O’Sullivan, 2004).

An interesting discussion during the focus group workshop was about the titles for the performance levels. Participants expressed that they wanted to know more about the levels with just a glance at their titles. Hence, new titles for 1-4 levels were suggested based on previous well-known studies, e.g., ‘dogs’, ‘low-impact performers’, ‘solid performers’ and ‘high-impact performers’ (see 4.3.3). However, the participants felt that these terms might discourage companies at the lower levels. Therefore, another nomenclature was adopted,

level 1 ‘innovation revealed’; level 2 ‘innovation initiated’; level 3 ‘innovation experienced’; level 4 ‘innovation improved’, applied by other researchers as well, but less frequently.⁴⁵

Further practitioners’ feedback gathered from the workshop referred to the overall profile characterisation of the company. An overall characterisation of the company’s profile should not only be provided but also governed by the lowest performance level identified, meaning that the level should present at least eight measurements to be representative to stimulate process improvement. Following this reasoning, the company was characterised as performance level 2; innovation initiated.

This level highlights that the company has already developed at least one successful innovation in the last ten years, and it is seeking to introduce others; hence, the title ‘innovation initiated’. The company has initiated efforts to manage the innovation process, and innovation has become a priority in the company. Incremental improvements in the main product/technologies are often accompanied by an increase in the operational reliability of the production process, focusing on customer satisfaction. There is greater certainty of revenues so that the critical resources for basic operations are secured, complemented by capital injections or growth-oriented external investments. Initiatives or mechanisms for the collection and analysis of ideas are in operation, linked to a reward system.

5.1.1.4 EVALUATING ACTION

The last step of the AR cycle consists of evaluating the actions implemented and reflecting upon them to identify lessons learned. In this sense, three main points are highlighted here: the identification of the stakeholders, the denomination of the four performance levels and the characterisation of the overall company’s innovation capability profile.

First, the activity of meeting the stakeholders to be interviewed (as designated in the initial procedure) is better structured now. The identification of stakeholders has been supported with tools such as stakeholder maps in other domains, but not in the context of a PF. Nonetheless, following the implemented actions in this company, stakeholder maps will now be part of the PF procedure. Moreover, the guideline to involve stakeholders who might

⁴⁵These titles for performance levels were previously used in conceptual frameworks, where the practices are studied according to the company’s maturity; however, the process performance is not measured (Ramon, 2017). The lack of performance measurement is why this nomenclature was not reviewed in the previous chapters.

have a moderate interest the evaluation process but no strong influence was also seen as positive as to achieve a more accessible way to involve key stakeholders in the application.

Second, the nomenclature of the performance levels improved to ‘innovation revealed’; ‘innovation initiated’; ‘innovation experienced’; and ‘innovation improved’ is an action-oriented result worthy of noting. This insight came from the activities with the focus group and has the potential to address the dissemination and awareness issue for the process of performance measurement in two fronts. First, this change enables a more positive response and engagement from the company using less pejorative (compared to, e.g., level 1 ‘dogs’). Second, these new terms can convey insightful performance information into their titles in a concise way which is useful for communication purposes.

Third, additional practitioners’ feedback gathered from the focus group workshops was that the overall performance level characterising the company’s profile should be provided as well as governed by the lowest performance level identified. These improvements also address the potential to create awareness for the PF application. Other PFs studied in the literature (see section 2.3) do not consider an overall characterisation. However, evidence from practice indicates that several consulting companies use an overall characterisation for their diagnosis on several occasions (Erkens et al., 2014; Junko Kaji et al., 2019).

Finally, encouraging feedback was also received from the participants concerning the innovation capability profile in general. It provides a clear and graphic representation that enables the visualisation of strengths and weaknesses of the company along the nine dimensions. They also corroborated that the profile should begin at level 1 up to level 4, as initially intended, with no suggestion of a performance level 0 nor another top level. Thus, with this positive feedback, the AR enters the next cycle.

5.1.2 DEPLOYMENT OF ACTION PLANS

In this section, the activities performed in the second AR cycle for Company TRFR aimed at deploying action plans to improve performance according to the diagnosis performed are presented. Note that the constructing step was not performed in this AR cycle, as the information for developing the action plans to improve innovation performance was already gathered during the previous cycle (as exposed during section 5.1.1). The next sections present the AR steps: planning action (section 5.1.2.1), implementing action (section 5.1.2.2) and evaluating action (section 5.1.2.3).

5.1.2.1 PLANNING ACTION

Planning action entails making the required arrangements, in Company TRFR, to conduct the steps of the second stage of the initial procedure for the deployment of action plans (as defined in section 4.3.1). Figure 5.8 illustrates the steps of the second stage: 6) identify the where there are needs to be attended; 7) propose action plans to improve performance; 8) prioritise and assign responsibilities, and 9) support performance evaluation over time.

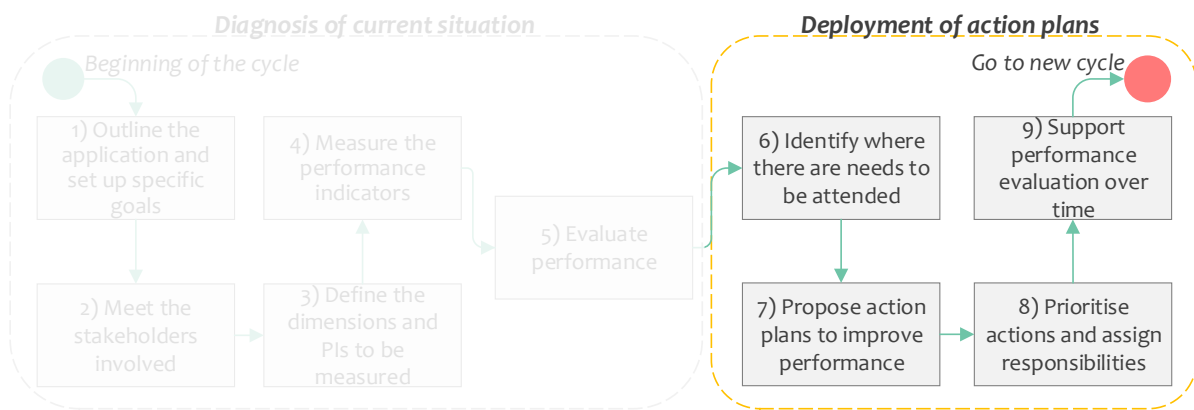


Figure 5.8. Initial procedure of the PF: deployment of action plans.

The efforts of this stage were channelled to the definition of action plans. For this stage, it was decided to follow the same guideline as before that key employees identified at least a moderate level of interest, regardless of their influence should be involved. Thus, the same key employees identified in the stakeholder map in the previous cycle were invited to participate in the focus group conducted in the workshops.

During this planning step, it was observed that different approaches to process improvement might be appropriate for companies depending on their innovation capability profile; those with lower levels would typically require more direction and structured guidance, while those with higher levels would typically have more structure in place to be able to select the dimensions according to their drivers and strategic goals, allowing more freedom. Similar observations can be made by analysing further frameworks in other domains (e.g., ecodesign Pigosso, 2012).

Accordingly, two possible approaches were structured to help with the definition of action plans to improve performance, allowing a degree of flexibility in the definition of the improvement pathway so that it can be aligned with the company's diagnosis:

- Staged approach: recommended for companies with a low-performance level, namely level 1 or 2. It provides a structured way to tackle process improvement based on the implementation of one level at a time, beginning with the gaps located at the lowest level to achieve level 2, and then improving from there.
- Continuous approach: flexible approach recommended only for companies characterised with a higher performance level, i.e., the company has already achieved at least level 2 in all dimensions and is characterised by level 3 or 4. In this case, the company can choose to focus on different dimensions according to its own drivers and strategic goals.

Therefore, the improvement pathway to be followed is driven by the overall performance level characterising the company innovation capability profile in the diagnosis. Either approach should support the preparation of the improvement actions to achieve the desired level.

5.1.2.2 IMPLEMENTING ACTION

The planned actions were implemented throughout several workshops performed with the same 12 key employees from the previous cycle. The staged approach was taken as Company TRFR innovation capability profile indicated that it was performing at level 2. This meant that the target level was determined as the subsequent level of the dimensions in the lowest end of the scale. In this way, the company would have better chances of success if it starts with tackling gaps from the second performance level, before proceeding to the gaps in the third performance level.

Taking the staged approach, the core team identified eight PIs located in the second level (see Figure 5.7 in section 5.1.1.3) in five dimensions – innovation strategy, innovation environment, knowledge management, technology management and market – defined here as the improvement gaps. Then, the core team started to identify suitable innovation practices to help structure actions plans to address these improvement gaps. For this, the team analysed each gap against the compilation of improvement practices (Appendix VII) using the simplified domain mapping matrix relating the performance levels for each indicator with the practices from the literature. This compilation of practices allowed the team to identify the practices from past studies that could be most beneficial for each improvement gap.

For instance, the first gap located in the innovation strategy refers to the indicator [IS2] “Spending reflects the innovation strategy” (Figure 5.7). By consulting the compilation of improvement practices (Appendix VII), the core team selected the practice ‘development of guidelines for the continuity of the innovation strategy’ by (Nilsson & Ritzén, 2014) to ensure innovation is treated as a major component in the company’s strategic planning.

The innovation practices were, at that time, specified into action plans in the format of improvement projects. The projects charters were defined with project goals, description, deliverables, requirements, risks, time and resources. In addition, the PIs database was further consulted to select additional PIs to track the implementation of the projects. Thus, the improvement projects proposed for Company TRFR were summarised as follows:⁴⁶

- Project 1 refers to the innovation strategy gap. Its goal was to build and maintain an innovation strategy ‘alive’ via innovation reports and follow-up meetings (practice P01-IS-IO). PI [IS4] “Frequency of product strategy plan use/update” was suggested to monitor the implementation of this project.
- Project 2 was designed to address the innovation environment gap, openness. It referred to the introduction of a roadmap for mapping external partnerships (P07-IE-Op). The PI [IE7] “External scanning in open innovation initiatives” was selected to monitor this practice implementation.
- Project 3 also refers to the innovation environment but focused on servitisation to incorporate screening for PSS opportunities in the IFE (P10-IE-Ser). To monitor its implementation, the PI of [IE17] “Proficiency in service design” was indicated.
- Project 4 relates to the innovation environment with a sustainability take. The aim was to update the reward system to encourage the ecodesign application (P13-IE-Sus). The PI [IE27] “Number of methods and tools used for sustainability in the innovation process” was indicated to monitor the implementation of this project.
- Project 5 focus on the knowledge management gap proposing the inclusion of tacit knowledge (methodological notes, trade-offs, lessons learned from other areas) into the knowledge repository (P19-KM-R). The [KM14] “Rate of knowledge repository accesses” was in the PI suggested for monitoring the implementation of this project.

⁴⁶Only a redacted and generic improvement project example is presented in Appendix X due to the confidentiality reasons as the content of the projects cannot be published and, therefore, not included in this thesis.

- Project 6 relates to technology management by creating small update cycles of technology plans during the year instead of once a year (P33-TM-P). The PI [TM1] “Constantly thinking of new technology” was indicated for monitoring.
- Project 7 focus on the market dimension aiming to bring commercial and technical areas closer together via a ‘customer day’ (P43-MA-RT). The PI [MA2] “Collection and use of market information” was indicated to manage this practice implementation.

After validating the projects with the key employees in a workshop and providing a compressive report, the projects were prioritised. Mainly because Company TRFR, as any other company, had limited resources and other commitments to follow. For this, an electronic spreadsheet applying the analytical hierarchy process (AHP) was designed so that the company could prioritise the projects. AHP is a decision-making approach that involves decomposing a decision into pairwise comparisons of the criteria and the decisions alternatives (the improvement projects), so the decision-makers can make value judgements that are later aggregated into a ranking of all compared decision alternatives (Saaty, 1990).

The spreadsheet for project prioritisation (Appendix XII) was applied with the following criteria retrieved from the literature (as discussed in section 4.3.4): implementation time; strategic alignment; top management support; resources availability; cost; competitive advantage; legal compliance and return on investment. Interestingly, the focus group was only able to assess the time criterion due to the lack of consensus in evaluating further criteria. As a result, Company TRFR prioritised three projects designated previously as 2, 4 and 7 that are being implemented at the moment. Project management concepts were used to create an implementation roadmap with schedule, work packages, and define project champions.

5.1.2.3 EVALUATING ACTION

The last step of the AR cycle focuses on the evaluation and reflection on the actions implemented. This time, in addition to the results from the second cycle, an overall evaluation performed by the participants from Company TRFR based on the evaluation questionnaire is also discussed. This evaluation was carried out after the final workshop held for the 12 key employees and further people from other areas in the company.

The lessons learned for the second cycle of the AR in Company TRFR related to three main points. First, the empirical development of the two approaches to deal with process improvement, staged and continuous, resulted in the staged approach leading to three

projects being prioritised and implemented. Second, the implementation of the deployment of action plans stage of the PF also allowed the dissemination of performance measurement and improvement concepts among the employees, who started to talk and think about process improvement in a more integrative way. Similarly, the internal communication of the improvement projects also contributed to the dissemination and awareness of this PF application. Third, it was interesting to note that only the implementation time criterion out of the proposed criteria was used to prioritise the projects. In the end, the goal of the prioritisation was to build a 'quick-win' with short-term projects and to avoid losing the momentum of the improvement initiative.

As mentioned previously, this evaluation also refers to the analysis of the PF application considering both cycles. Following the research method adopted in this study (section 3.3), an evaluation questionnaire was sent to all the participants. It was designed to evaluate the participants' perception on the PF utility, consistency, scope, precision, broadness, objectivity, clarity, depth, coherence, clarity, instrumentality, simplicity and forecast (Appendix III). Each of the 12 questions had a four-point scale: (1) "unsatisfactory", (2) "needs improvements"; (3) "satisfactory" and (4) "very satisfactory".⁴⁷ Additional comments from the participants concerning the experience and further feedback were also collected.

The results of the evaluation questionnaire responses are illustrated in Figure 5.9. The figure illustrates the highest, lowest and average scores achieved for each question from the evaluation questionnaire, and the corresponding level of agreement among respondents calculated according to the within-group interrater reliability. Also, Table 5.1 displays the average score ($\mu_{(i)}$), standard deviation ($SD_{(i)}$), and the interrater reliability ($r_{wg(i)}$) for each question. The number of respondents of the questionnaire was seven, which can be considered sufficient for the analysis of the reliability method as it is directed to small groups of respondents (James et al., 1984). It is important to highlight that previous research, such as Caetano and Amaral (2011) and Issa et al. (2015), has also achieved similar numbers of respondents. In addition, note that all seven participants answered each of the 12 questions presented in the evaluation questionnaire. All individual responses for Company TRFR can be found in Appendix XIII.

⁴⁷As explained in Chapter 3 ("Methodology"), this questionnaire applies the criteria used to evaluate frameworks and models already applied in well-established research (Barquet, 2015; Issa et al., 2015; Pigosso et al., 2013).

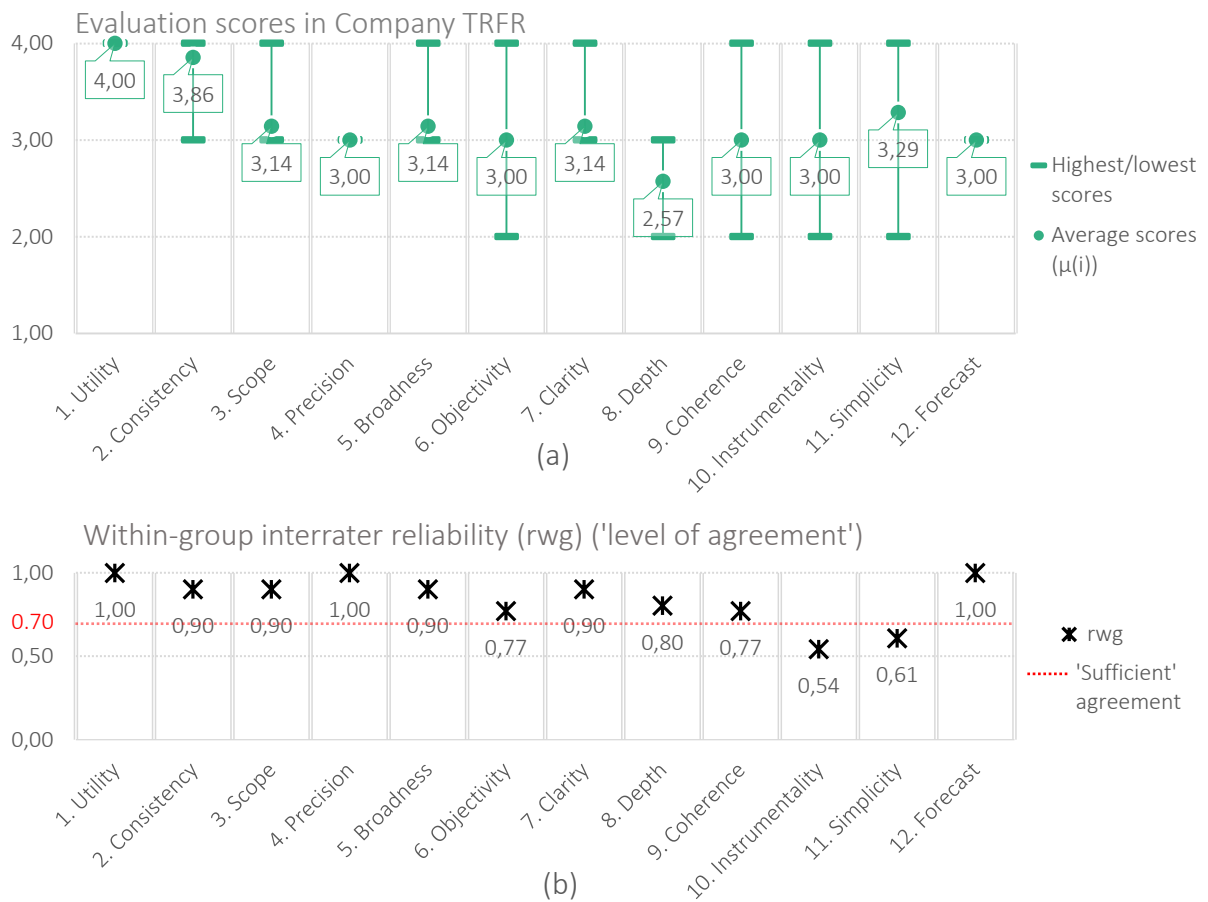


Figure 5.9. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company TRFR.

An overall analysis of the data demonstrates the usefulness of the PF, as sufficient average scores ($\mu_{(1 \rightarrow 7)} = 3.18 > 3.00$) and level of agreement ($r_{wg(1 \rightarrow 7)} > 0.70$)⁴⁸ were achieved for most questions (see Figure 5.9). Note that the users evaluated the utility of the PF (n.1) as (4) “very satisfactory”. In fact, most criteria were evaluated as (3) “satisfactory”; including: consistency of the dimensions; scope of the practices; precision in the innovation profile; applicability in the industry (broadness); objectivity of the diagnosis; coherence between the diagnosis and improvement projects; clarity of results and forecast of next steps.

Further commentaries provided by the company practitioners reinforced the evaluation performed. Participants stated, amongst others, that “*the PF is very interesting and useful*”, “*it contributes to raising awareness among managers and employees from relevant areas to measure the innovation process systematically from time to time*” and “[the PF] *bridges the link between the performance measurement and the identification of improvement paths to be followed, which the company struggled with in the past*”.

⁴⁸As defined in Chapter 3 (“Methodology”), a interrater equal or above 0.70 is considered sufficient agreement according to the literature. In addition, a “satisfactory” score also provides enough evidence of positive feedback from the evaluators.

Table 5.1. Company TRFR evaluation of the PF (n=7).

N.	Questions	$\mu_{(i)}$	$SD_{(i)}$	$r_{wg(i)}$
1	Utility: How do you evaluate the general utility of the PF in supporting companies in the measurement of performance and selection of the most suitable innovation practices to be implemented?	4.00	0.00	1.00
2	Consistency: How do you evaluate the consistency of the nine dimensions of performance used in the PF?	3.86	0.35	0.90
3	Scope: How do you evaluate the PF in relation to the adequacy of the scope of the proposition of the improvement projects?	3.14	0.35	0.90
4	Precision: How do you evaluate the PF in relation to the precision of the innovation capability profile provided?	3.00	0.00	1.00
5	Broadness: How do you evaluate the PF in relation to its applicability in manufacturing companies from different sectors?	3.14	0.35	0.90
6	Objectivity: How do you evaluate the objectivity of the PF in performing the diagnosis of the company and proposing the improvement projects?	3.00	0.53	0.77
7	Clarity: How do you evaluate the PF concerning the clarity in which the results are presented, e.g., the innovation capability profile?	3.14	0.35	0.90
8	Depth: How do you evaluate the PF in relation to the depth of the diagnosis (the innovation capability profile) and the proposition of improvement projects?	2.57	0.49	0.80
9	Coherence: How do you evaluate the coherence of the diagnosis (the innovation capability profile) and the improvement projects proposed in the PF?	3.00	0.53	0.77
10	Instrumentality: How do you evaluate the PF in relation to its instrumentality in the innovation capability profile (e.g., workshop and materials) and the proposition of the innovation practices (project charters)?	3.00	0.76	0.54
11	Simplicity: How do you evaluate the PF in relation to the simplicity of the results presented?	3.29	0.70	0.61
12	Forecast: How do you evaluate the PF in relation to the definition of the next steps to be taken after the proposition of the improvement projects?	3.00	0.00	1.00

In turn, a few evaluations deserve more consideration. The depth evaluation (n.8) presented a low score average (2.57). A possible explanation resides in the desire of some participants for more time in the diagnosis discussion. A solution may be to provide the diagnosis report before the workshop, so the participants are familiar with the results, and time can be better spent. Moreover, both instrumentality (n.10) and simplicity (n.11) criteria presented good scores but insufficient agreement. Indeed, the PF operationalisation requires facilitators with a moderate level of expertise in the subject, which is not uncommon on PFs (cf. Adams et al., 2006; Braz et al., 2011). The resolution could be training materials for facilitators. However, once the PF has been implemented, and its application recurrent, this issue may be resolved naturally with the employees becoming more acquainted with the PF.

In sum, the results of this evaluation can be said to confirm that Company TRFR sees the PF as a valuable tool that supports the measurement and evaluation of innovation performance and further identification of improvement actions thus, indicating the potential to apply the PF in the next AR company.

5.2 COMPANY TRPT

Company TRTP can be defined as a European manufacturer of measuring, testing, navigating and control equipment for railway transport, classified under division 26 of the ISIC classification (United Nations, 2008). This company has a little more than 20 years of experience in the field, with approximately 191 employees and annual revenue between €10M and €50M.⁴⁹

The company has a portfolio of products dedicated to the supply of power, telematics and signalling solutions for railway transportation, which includes subway, road segments, and light rail. The light rail segment, in particular, constitutes their primary market focus at the moment. Also, integrated communication infrastructure solutions for mobile operators and utilities for railways are part of the company's product portfolio but in a minor role.

Company TRPT has already devoted efforts to structuring their innovation process, driven by identified business opportunities to be better positioned in the market for light rail solutions in more demanding markets (e.g., Northern Europe). To achieve this, the company has three primary strategies in place:

- Implementation of best practices in governance and transparency, supported by the development of ethical relationships and an integrated risk management system;
- Increased energy efficiency and reduction of negative environmental impacts by participating in the implementation of circular and low-carbon economies; and,
- Implementation of a proactive human rights policy, promoting equality, integration and personal development among employees, in order to create a safe working environment.

A partnership was established for the PF application, in which the participating company would get guidance for measurement and evaluation of the innovation performance, while the researcher would have the opportunity to apply the PF in practice aiming to its further development and improvement. Thus, the Company TRPT ensured support and commitment for the application, including the provision of the needed information and access to relevant documents and key employees.

⁴⁹Again, due to the non-disclosure agreement signed, the identification of the Company TRPT (**TRansPort**) and certain sensitive information were omitted from this thesis.

5.2.1 DIAGNOSIS OF THE CURRENT SITUATION

The goal of this cycle is to further develop the first stage of the PF in another representative manufacturing company. This first stage consists of the diagnosis aiming to characterise the company's current performance across the performance dimensions. Accordingly, the next sections present the steps performed in the AR cycle: constructing (section 5.2.1.1), planning action (section 5.2.1.2), implementing action (section 5.2.1.3) and evaluating action (section 5.2.1.4).

5.2.1.1 CONSTRUCTING

The goal of the constructing step was to understand how the company performed the innovation process. In the same fashion as the previous company, an initial document analysis was performed to understand how the processes were organised, documented and performed in day-to-day business. Additionally, two knowledgeable employees (the head of technology and an experienced R&D manager) were interviewed to understand how processes were performed and clarify issues that were not clear in the analysed documents.

The interviews were carried out with supporting questionnaire S1 (Appendix VIII), which was already proven to work in the previous application. Again, the comments registered from these interviews were documented in the AR journal and expressed the importance given to the improvement initiatives of existing processes. Moreover, Company TRPT provided access to essential documents, such as annual financial reports, R&D reports, and organograms of roles and responsibilities.

Based on the information gathered from the interviews and the document analysis, it was possible to reconstruct the innovation process to characterise Company TRPT. First, this company is not a big player in the telematics and signalling solutions for light rail but has the ambition to be. To achieve this, Company TRPT presents the characteristics of a prospector company, as defined by Miles & Snow (2003). In this way, to maximise the identification of opportunities and achieve the desired goal, the company has created a business development area dedicated to identifying new market opportunities.

The stimulus that drives the company's innovation process presents characteristics from both market pull and technology push in a more balanced manner than the previous company. For instance, a 4-year strategic plan was structured and approved in 2017 based on the development of new product lines and main functionalities to be implemented by 2021.

The identification of these functionalities derived from the technology roadmapping exercises that captured signals from not only new technologies available in the market (competitors) but also user needs collected from clients in recent years.

Company TRPT has one main distinguishing feature that outlines a variation of the innovation process design from the first company, in particular related to the PD phases. The main difference is that Company TRPT develops substantially more software than the first company, in addition to developing hardware (mostly sensors for crossings and traffic signals). For this, the company applies the concept from the waterfall model⁵⁰ to guide the definition of work during the innovation process phases and support project management of new products for both hardware and software.

The level of formalisation of the innovation process is moderate to high, with the IFE supported by the departments of technology radar and new business development, as illustrated in Figure 5.10. Company TRPT consistently applies technology roadmapping techniques throughout the year (known as ‘T-Plan’) to create market, product and technology roadmaps, following Phaal, Farrukh, & Probert (2006) documented procedures.

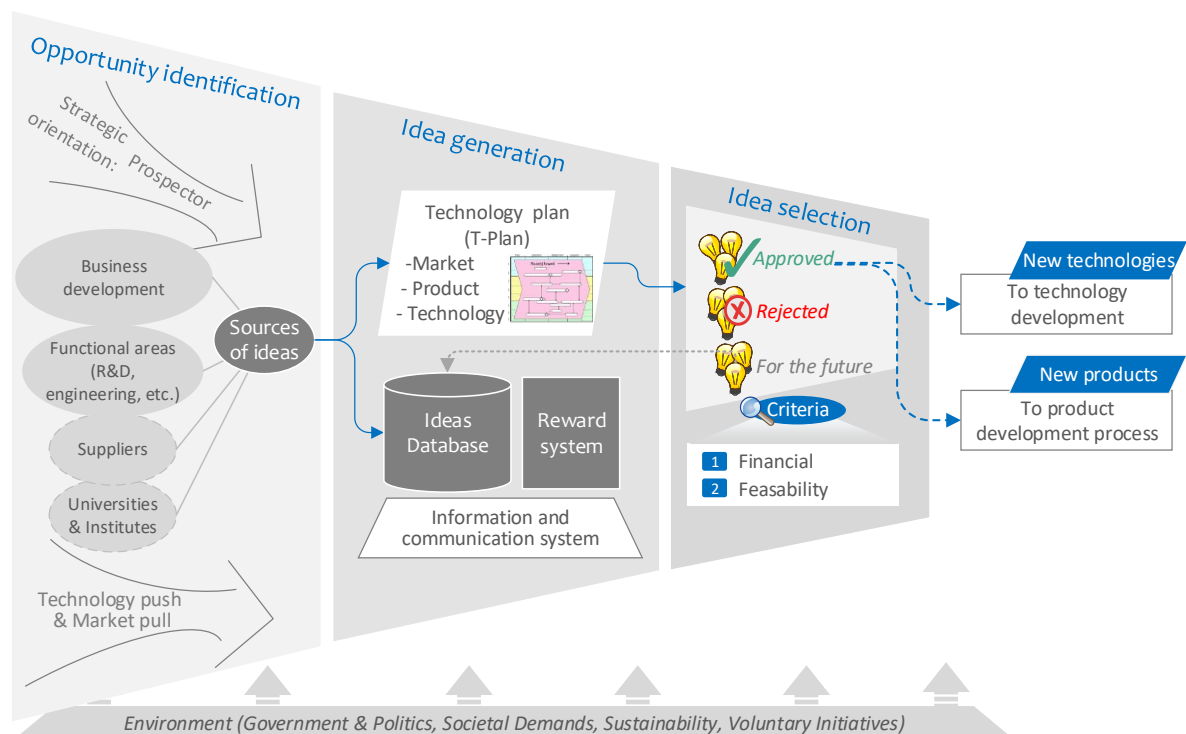


Figure 5.10. Constructing IFE in Company TRPT.

⁵⁰The classical waterfall model is a breakdown of project activities into linear sequential phases that relies on the work of a previous phase being complete before proceeding to the next one. This model is typically applied in project management activities to define tasks and deliverables, and in traditional software development (as opposed to agile management).

New ideas are mostly driven by new business development, technical areas, and to a lesser extent, suppliers and, on very rare occasions, partner universities. Additionally, they have an ideas database in place to collect ideas from distinct departments and a reward system to support the activities of idea generation in the IFE. If an idea requires the development of further technology (usually new types of sensors), resources are allocated for the development of the needed technology.

Figure 5.11 illustrates the technology development, in which R&D project scoping is the first phase of planning. It is followed by a preliminary technical assessment that involves initial testing and analysis and then the proper technical development that can last several months or a year. The outputs of the TD phase would typically involve a technology mature enough for a commercialised product, new production processes or machinery, or more rarely or new idea for a business that, in turn, would feed the roadmapping process.

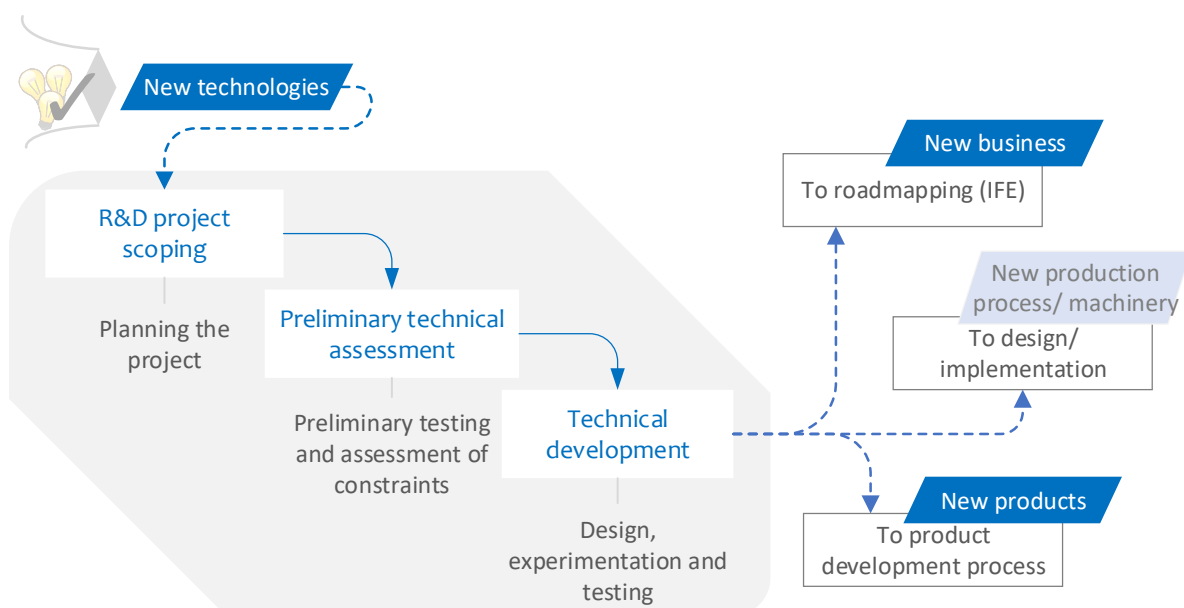


Figure 5.11. Constructing the TD phase in Company TRPT.

The product development phases begin with well-established activities derived from the waterfall model where all the requirements regarding the software/hardware are gathered and analysed (see Figure 5.12). The goal of the analysis is to remove incompleteness and inconsistencies and document the collected requirements. This work can last for several weeks and, eventually leads to design cycles of the solution. The design aims to transform the requirements specified in the documentation into a working concept that is suitable for implementation in either some programming language for the software development and/or

a detailed design suitable for hardware under development. Thus, the software design is translated into coding using suitable programming language, and the hardware is detailed into working prototypes. It is important to note that project management tools are consistently applied to manage an integrated development of both software and hardware whenever required.⁵¹ This is followed by the ‘verification’ activities where exhaustive regulatory testing and checks are performed and documented to verify the functionalities developed.

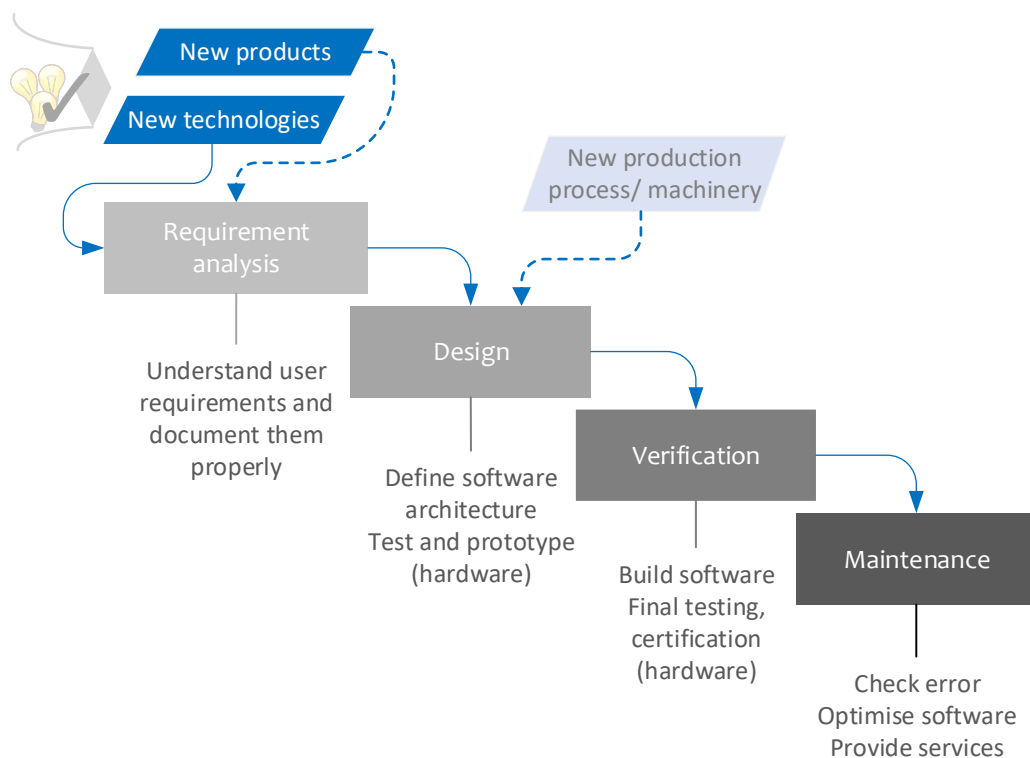


Figure 5.12. Constructing the PD phases (with MAM activities) in Company TRPT.

The MAM phase for Company TRPT presents a twofold nature (designated as ‘maintenance’ in Figure 5.12). One refers to support and assistance for the maintenance of physical sensors and devices for crossings and signalling, while the other focuses on the maintenance of the software developed. The final disposal of the physical products is under customer responsibility, so no EoL activities are carried out. For software, in turn, maintenance is one of the most critical stages of the product life cycle, so the company provides contract services. It may involve corrective maintenance to improve functionalities upon the customer request or even adaptive for transporting the software to a new platform or operating system.

⁵¹Note that not all new product projects have equal parts of hardware components and software development.

5.2.1.2 PLANNING ACTION

The goal of this AR step was to plan how the procedure, already improved from the initial version in the cycle performed at the first company (section 5.1.1), were going to be performed in Company TRPT. The steps from this ‘intermediary’ version of the procedure are illustrated in Figure 5.13: 1) outline the application; 2) set up a core team; 3) define the stakeholders to be interviewed; 4) adapt the questionnaire to the company’s vernacular 5) apply the measurement instruments, and 6) consolidate the diagnosis.

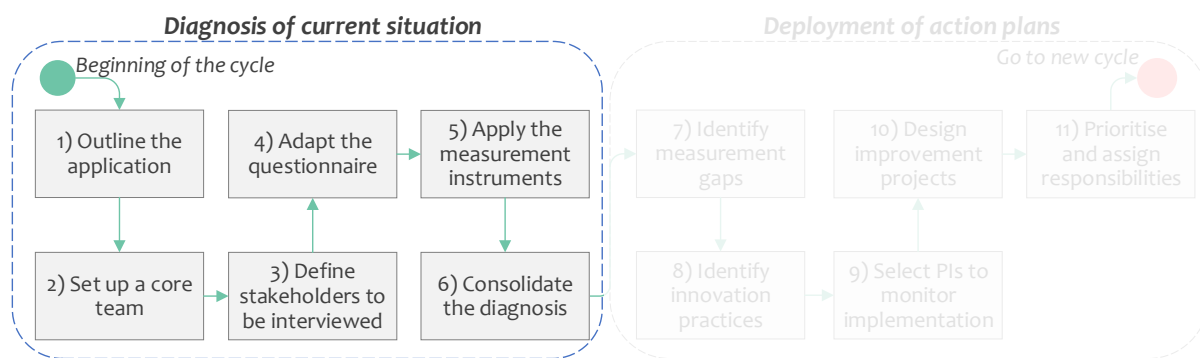


Figure 5.13. ‘Intermediary’ procedure of the PF: diagnosis.

Similarly to the previous company, the action preparation involved planning the interviews and the focus group workshops. One vital part of the planning focused on the outline of the context of the application to the main point of contact in the company, and the formation of a core team to implement the workshops for the focus group – which because of its importance was incorporated into the procedure (step 2). In addition, the preparation involved the adaptation of the vocabulary of the measurement instruments to the terminology used in the company (a step that was also included in the procedure). The general format of the supporting questionnaire S2 can be seen in Appendix IX.

The planning also encompassed the identification of key employees to be interviewed and participate in the focus group. For this, the core team created a stakeholder map to identify key employees (Figure 5.14) in the same fashion as the previous company. The guiding principle used was that the employees presenting at least a moderate level of interest should be involved in the PF application regardless of their influence. Therefore, nine key employees were identified, who were directly related to the innovation process from various areas (such as technology radar, operation support systems, R&D, business development; engineering; tendering; service and project management office (PMO)). These key employees were also

invited to participate in the focus group along with other employees with lower levels of interest in the application of the PF.

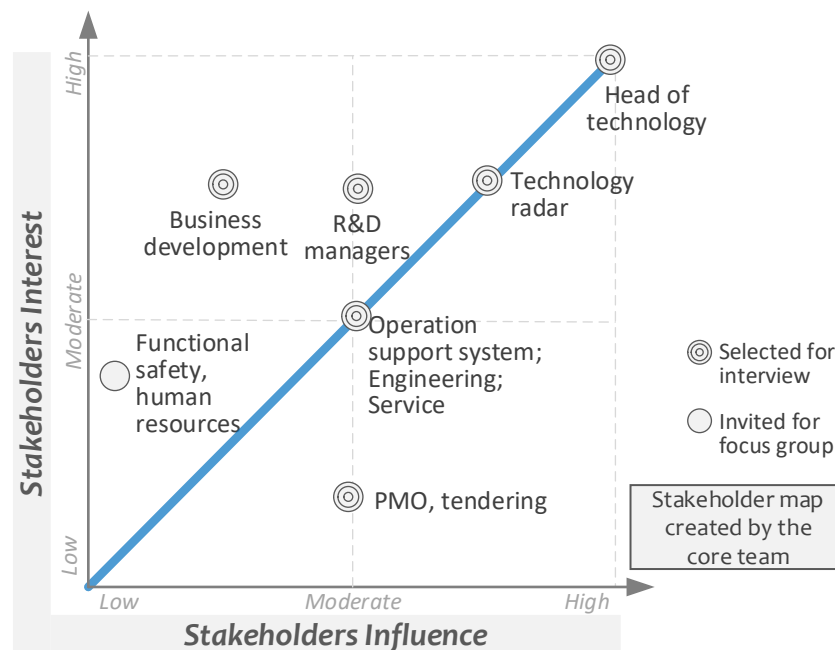


Figure 5.14. Stakeholder map for the PF application in Company TRPT.

One point to note is that although key employees such as PMO and tendering managers were identified as having a low interest, the company indicated that they could contribute to the interviews. Therefore, the core team accommodated this request so that the participants of the company would have shared ownership of the upcoming results and to ensure continuous engagement. Finally, the core team also organised the interview schedule, contacted the people to be interviewed, explained the general context of the project, and prepared the necessary resources.

5.2.1.3 IMPLEMENTING ACTION

The purpose of this step was to put the planning into practice by applying the measurement instruments to create a diagnosis of the innovation process. It required the application of the supporting questionnaire S2, already adapted to the company's vernacular, to measure the rapid assessment PIs and to search for corroborating evidence.

As mentioned before, nine key employees were selected to be interviewed at Company TRPT from different hierarchical levels (head of the department, managers and specialists) and diverse departments associated with the innovation process and related processes. These interviews were designed to be face-to-face interviews encompassing the following:

- a) Introduction to the topic: what is a PF, its relation to process improvement, the context of the application in the company and the goal of the interview;
- b) Application of the structured supporting questionnaire S2 already adapted to the company: in which the interviewee was asked about each rapid assessment indicator and to provide additional comments and evidence to justify the answer; and,
- c) Final remarks: commentaries on the practices that were not asked during the interview and final considerations.

On average, the interviews lasted 80 minutes. The results of the interviews were compiled in a structured spreadsheet (Appendix XI). The answers were analysed against the interviewee's own commentaries, and according to the evidence gathered from the other interviews and the document analysis in order to guarantee coherence and consistency of the performance levels allocated.

The results from the interviews were consolidated into the innovation capability profile for the Company TRPT, as illustrated in Figure 5.15. The profile shows the nine dimensions of performance (from innovation strategy to market) with all the 34 rapid assessment indicators (from IS1, IS2, and so on until MA15) arranged in a radar representation and distinguished into four distinct levels. At this point, with the feedback from the previous cycle in the previous company, TRFR, the characterisation of an overall company performance level is driven by the most expressive of the lowest performance level measured.⁵²

Therefore, the innovation capability profile indicates that Company TRPT is mainly characterised by level 3, with most of the measurements located in this level (precisely 23 metrics), and remaining scores resting in level 2 (3 metrics) and level 4 (8 metrics) (see Figure 5.15). At this level, the company has already identified innovation as an organisational function, with goals formally deployed from corporate strategic planning. In this way, senior management disseminates and reinforces a shared view of the importance of innovation for the organisation. Companies within this level typically present an internal policy oriented to stimulating and coordinating innovation, aligned with the availability of resources. Hence, this

⁵²Considering the number of rapid assessment PIs (n=34), the overall representative performance level needs to present at least eight measurements in order to characterise a company's innovation capability profile.

level of performance is known as ‘innovation experienced’ as the company transforms innovation into a continuous and managed business process.

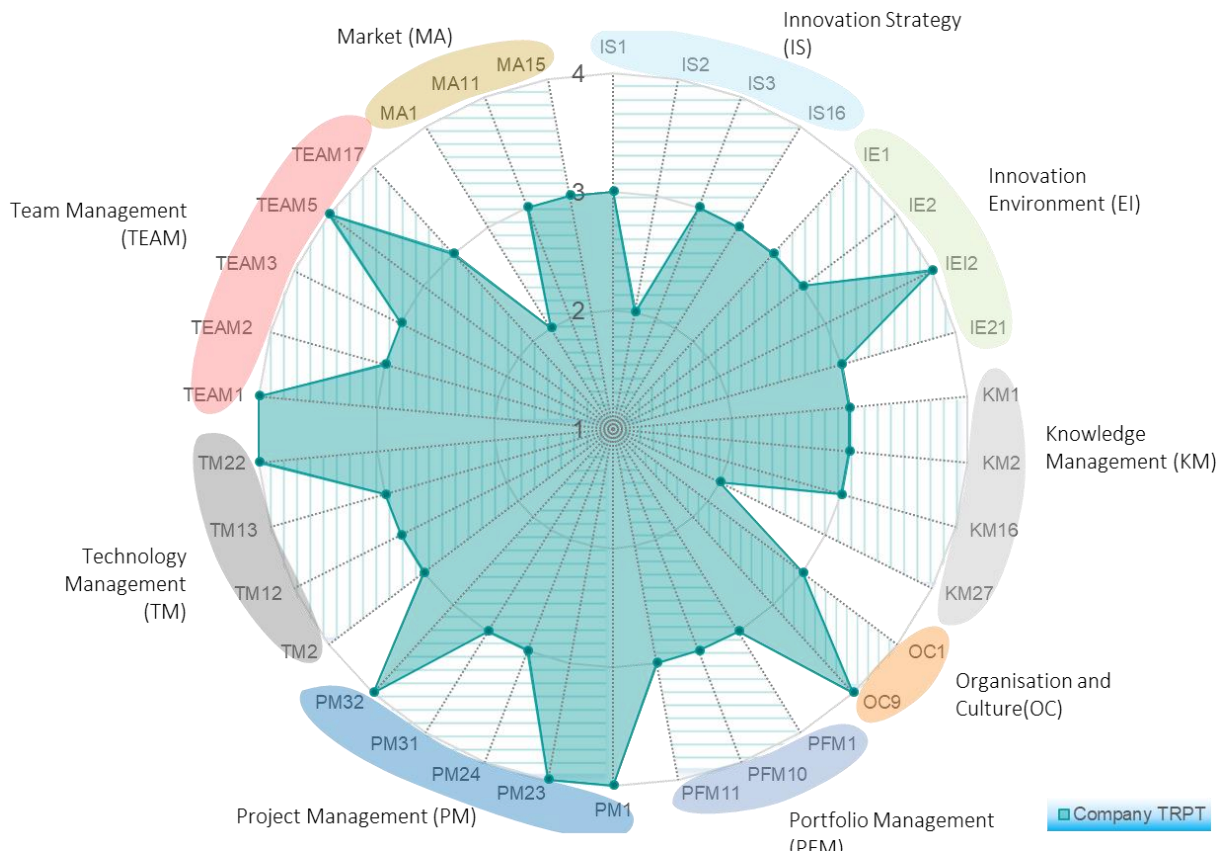


Figure 5.15. Company TRPT innovation capability profile.

Furthermore, innovation activities of level 3 companies are appropriately prioritised, being supported by infrastructure in terms of systems, tools and communication channels. Moreover, companies, like Company TRPT, are seeking to consolidate a portfolio of innovation projects in the mid-term. Processes, departments and activities are already structured to be managed in an integrative manner. Market tools and methods are conducted continuously, supported by established procedures. As a result of those combined efforts, one or more high-performance products are offered to the market.

The workshops for the focus group aiming to validate the results of the diagnosis were run with the 13 participants from the company, including the nine people interviewed. The feedback given reinforced the potential of the innovation capability profile to communicate a comprehensive diagnosis. Additionally, the feedback given indicated that this validation should be seen as a decision-gate to inform either to go ahead with the definition of action plans (which was the case) or to go back and gather more evidence if the profile is not validated.

5.2.1.4 EVALUATING ACTION

The last step of the AR cycle concerns with the evaluation of the actions implemented and further reflection to extract lessons learned. For this cycle, three main lessons can be drawn from action. The first lesson refers to the characterisation of the innovation process. The second relates to the diagnosis and its validation, whereas the third one refers to the visual improvement of the innovation profile.

The characterisation of the company's innovation process was a step performed to construct the current situation concerning the AR and not a step of the PF itself. Nevertheless, the importance of this construction to the PF is noteworthy in the support for understanding to what extent the phases are carried out. For instance, companies with no TD phase (which is not the case for the participating two companies so far) would have an effect in the measurements in the technology dimension, to a degree.⁵³ Thus, this step was introduced into the PF to aid the facilitators in understanding the current situation (e.g., to double-check the values achieved since formalised processes tend to result in higher performance).

The second lesson learned refers to diagnosis validation. Based on the participants' feedback, the validation should be treated as a checkpoint that leads to the next stage of the PF, the deployment of action plans to improve performance. The validation could work as a milestone to increase awareness and dissemination of the improvement projects to come. However, if the diagnosis requires further data collection, then the procedure should indicate more interviews and/or document analysis. To this point, it must be added that the number interviews was considered sufficiently representative as the analysis was based on not only these responses but focus group workshops and document analysis, all backed up by the AR.

The third point relates to the visualisation of the performance progression, the innovation capability profile. The graphic representation was improved based on the practitioners' feedback. The improvements mainly refer to visual cue between the different performance dimensions in the radar representation (see the banded areas in Figure 5.15).

A further discussion was prompted about the relative importance of the dimensions. From the literature, not much is being said about the dimensions' relative importance. Prior studies only specify that all relevant dimensions are necessary to support improvement. With

⁵³Note that the technology management dimension scope is not entirely focused on the development of technology, as companies developing services, for instance, need to monitor the technologies available, being developed or used by competitors.

this in mind, this work takes the position of having almost like a 'default' equal importance. To assign different importance/weight to the dimensions is a feasible feature at this point, but it has a significant shortcoming of some dimensions being undermined and, consequently, overlooked. Therefore, the core team made the conscious decision of not implementing distinct relative importance (weights) to the performance dimensions.

To conclude this cycle, encouraging feedback was given by participants in the workshops about the innovation capability profile (and its improvements) as it indicates the improvement gaps that can benefit the company. In fact, a few managers stated that they had previously identified performance issues in the innovation process that coincided with what the innovation profile was indicating (e.g., market dimension). Moreover, they also stated that according to the methodology being used at the time, they were required to come up with solutions for those issues by themselves; however, this proved to be extremely difficult. Hence, the next section discusses the deployment of action plans.

5.2.2 DEPLOYMENT OF ACTION PLANS

With the results of the diagnosis in hand, the activities performed to define the deployment of action plans were initiated. As explained in the description of the AR cycles in the first company, the 'constructing' step was not performed in this cycle, as the data used for developing action plans to improve innovation performance for Company TRPT was already gathered during the diagnosis cycle (section 5.2.1). Therefore, the next sections describe the results from the steps performed in this AR cycle: planning action (section 5.2.2.1), implementing action (section 5.2.2.2) and evaluating action (section 5.2.2.3).

5.2.2.1 PLANNING ACTION

This step focused on planning the implementation of the procedure to deploy action plans already improved in the cycle performed in Company TRFR, as exposed in section 5.1.2. These steps were, at this point, as follows: 7) identify measurement gaps; 8) identify innovation practices for each improvement gap; 9) select indicators to monitor implementation; 10) design improvement projects, and 11) prioritise improvement projects and assign responsibilities (see Figure 5.16).

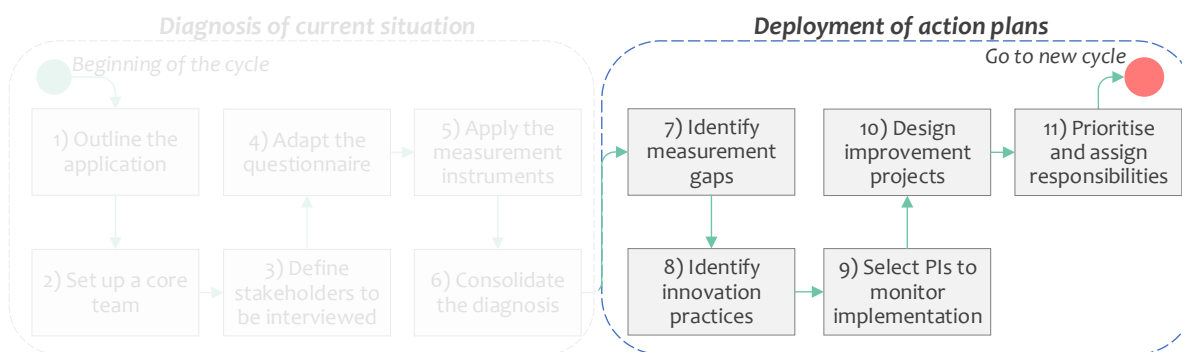


Figure 5.16. 'Intermediary' procedure of the PF: deployment of action plans.

With the validation of the company's innovation capability profile in the diagnosis, the previous participants were invited to take part in the workshops following the same guideline as in the first company. Thus, the participation guideline established was that key employees identified in the stakeholder map with at least a moderate level of interest should be involved in the workshops regardless of their influence.

Learnings from the second cycle in Company TRFR covered the design of two approaches for process improvement depending on a company's current situation. The staged approach is the structured way to identify the improvement gaps, based on the implementation of one level at a time, starting with the gaps from the lowest level. It is recommended for companies a low-performance level, namely performance levels 1 and 2. On the other hand, the continuous approach is a more flexible approach, which is endorsed only for companies that already achieved level 2, and therefore, are characterised as performance levels 3 or 4. In this case, the company can choose to focus on different levels within selected dimensions, according to its own drivers and strategic objectives.

Thus, the improvement path to be followed by a company is indicated by the performance level it presents at the moment of the diagnosis. As mentioned before, either approach (staged or continuous) should enable the identification of gaps that need to be attended. For Company TRPT, because of its characterisation as level 3, the continuous approach was taken. To prepare for the next step, implementation of action, the core team analysed the list of improvement actions retrieved from the literature (shown in Appendix VII) to support the definition of action plans.

5.2.2.2 IMPLEMENTING ACTION

Within two main workshops carried out with the same 13 employees from the previous cycle, the continuous approach was taken as the company's innovation capability profile was characterised as level 3 (see section 5.2.1.3). This approach indicated that the improvement targets could be chosen with the help of the core team. It means that the company, in its current state, could select the dimensions they wished to act upon as they already have a foundation of practices in place.

Based on the continuous approach, the core team identified the possible improvement practices from the compilation of innovation practices (Appendix VII) that already related the performance levels in which these practices could be implemented. This compilation of practices allows the selection of practices that were shown to be beneficial in the SLR. In total, 26 practices were identified covering the nine performance dimensions.

The practices are illustrated in Table 5.2. They were then structured into improvement project (action plans) in the format of project charters. These charters were defined with the project goals, description, deliverables, requirements, risks, time to implement, resources, and additional PIs to monitor their implementation, as performed for the last company. Additionally, practitioners also expressed their interest in knowing examples of previous companies that applied them, which was incorporated into the structure of the improvement projects. A generic example of an improvement project is given in Appendix X.⁵⁴

At this point, it is necessary to differentiate the seven improvement projects indicated for Company TRFR and these 26 suggested here for Company TRPT. The main difference relies on the fact that the seven projects for Company TRFR were in the critical path for process improvement and, therefore, all of them should be implemented (due to the staged approach as company profile was level 2). The issue for the first company was to prioritise the projects to be implemented first, because of constraints of time and resources natural to any company. The case for the second company, on the other hand, is that the 26 practices are possible suggestions from which the company should select the ones they wish to implement, and depending on the number, prioritise as well. Here, Company TRPT does not need to implement all of them because the continuous approach allows flexibility into the company's choices.

⁵⁴Due to the non-disclosure agreement signed with Company TRPT, confidential information contained in the improvement projects cannot be published and was omitted from this document, this only a redacted and generic project is provided.

Table 5.2. List of practices suggested for Company TRPT.

Table 3.2: List of practices suggested for Company 1 (C1).				
ID		Dimension	Sub-dimension	Improvement practice Title
1	P01-IS-IO	Innovation strategy	Strategic orientation	Development of guidelines for the continuity of the innovation strategy
2	P05-IE-Op	Innovation environment	Openness	Lead user method
3	P06-IE-Op			Customer potential of lead users
4	P08-IE-Op			Ideation contest
5	P09-IE-Op		Servitisation	Broadcast search
6	P11-IE-Ser			Networks for enabling PSSs
7	P12-IE-Ser			Simulation of PSS offers
8	P14-IE-Sus		Sustainability	Integration of environmental issues
9	P15-IE-Sus			Coherency of environmental goals
10	P19-KM-R	Knowledge management	Repository	Development of a knowledge repository and management strategies
11	P20-OC-C	Organisation and culture	Structure	‘Skunkworks’ and unofficial projects
12	P21-OC-C		Culture	Fostering intrapreneurship
13	P23-PFM-B	Portfolio management	Balance	Decentralisation of the innovation portfolio management (IPM)
14	P25-PFM-B			Innovation portfolio management connection to other business processes
15	P26-PFM-EvT		Evaluation tools	Hybrid approaches for IPM
16	P27-PFM-EvT			Real options for IPM under high uncertainty environment
17	P29-PM-T	Project management	PM Tools	Life cycle thinking for post-implementation reviews (PIRs)
18	P31-PM-T			Active encouragement of communication zones
19	P30-PM-PE		PM Efficiency	Gates ‘with teeth’
20	P35-TM-P	Technology management	Technology potential	Idea splitters for technology monitoring
21	P34-TM-TO		Technology orientation	Dedicated force for studying artificial intelligence and machine learning
22	P36-TM-R&D		R&D Efficiency	Inter-organisational agreement on performance measurement for IP strategies
23	P39-TEAM-Cr	Team management	Team cross-functionality	Performance measurement introduction to cross-functional training
24	P40-TEAM-St		Team stability	Clearly identifiable project leader for all projects
25	P42-TEAM-St			Creation of shared mental models
26	P43-MA-RT	Market	Research and testing	Development and maintenance of a market monitoring process

To support the selection of the improvement practices, among those 26 suggested, the electronic spreadsheet using the AHP methodology developed previously was applied in one of the workshops. The several criteria already included in the spreadsheet (e.g., implementation time, strategic alignment, top management support, resources availability) were considered for the selection. Because of actions implemented in the first company, the spreadsheet was already set to advise implementation time as the default criterion to prioritise the projects and not select more than four practices at a time.

Therefore, from this pool of projects, the decision to select the projects was mostly driven by implementation time and the criteria used to drive improvement initiatives already used by the company.⁵⁵ Then, portfolio management concepts were applied to create an implementation roadmap with responsibilities assigned to create a schedule and work packages for implementing the following selected practices – project 1 (P01-IS-IO) for the innovation strategy (see Table 5.2); project 10 (P19-KM-R) for knowledge management; project 18 (P31-PM-T) for project management and project 26 (P43-MA-RT) for the market dimension. Lastly, the head of technology was appointed to act as a champion of these selected improvement projects.

5.2.2.3 EVALUATING ACTION

The last step of the AR cycle aims to evaluate and reflect upon the actions implemented as well as the overall evaluation performed by the participants. Thus, at the end of the PF application, the results of the PF application were presented in a final workshop for 10 employees, which most of the interviewees attended. Again, aiming to increase the perception of the employees towards the importance of innovation performance evaluation, a final report was also provided to the participating company.

The lessons of this cycle of the AR in Company TRPT can be summarised into two main points. Firstly, the arrangement of the continuous approach has been proven to be effective, in the sense that the company was able to select the improvement projects based on implementation time and the criteria they apply already for improvement initiatives. In addition, the fact that the company is planning the implementation of the four selected projects also supports the assumption that the continuous approach work (under the conditions of this research). Therefore, the procedure of the PF should maintain the two distinct approaches to process improvement, indicating one or the other depending on the current situation of the company.

Secondly, the introduction of examples of previous companies that applied the suggested practices in the structure of the improvement project charters, initially expressed by the participants, was an interesting action-oriented outcome. It triggered the discussion

⁵⁵The criteria typically applied in Company TRPT were: alignment of projects with the institutional improvement initiative, resource allocation, and their contribution to the construction of a new headquarters dedicated to innovation. The decisions were made based on these criteria, but clearly driven by senior management (internal politics).

about the customisation of these improvement projects. Yet, from consulting the literature, it was not possible to find guidelines on this matter on the studied literature on PFs. Learnings from action in this research focus on the planning of the projects, e.g., if the company uses waterfall or agile to manage their projects, and what that entails in terms of defining the improvement projects (detailed work packages or project backlog) as well as setting up milestones to monitor the implementation of the project with the suggested in-depth PIs.

The evaluation of action also covers the analysis of the results of the AR as a whole, i.e., how satisfied the practitioners (the users) were with the results obtained the PF. Thus, the same evaluation questionnaire used in the previous company was applied to this company. As mentioned before, this questionnaire was designed to evaluate the participants' perception on the PF utility, consistency, scope, precision, broadness, objectivity, clarity, depth, coherence, clarity, instrumentality, simplicity and forecast (Appendix III). Each of the 12 questions had a four-point scale: (1) "unsatisfactory", (2) "needs improvements"; (3) "satisfactory" and (4) "very satisfactory".

In the same fashion as the previous company, the questionnaire was applied in the company after presenting the results of the PF at the evaluation workshop. The results of the analysis of the responses are shown in Figure 5.17. The figure illustrates the highest, lowest and average scores achieved for each question from the evaluation questionnaire, and the corresponding within-group interrater reliability ('level of agreement'). Besides, Table 5.3 also shows with the average score ($\mu_{(i)}$), standard deviation ($SD_{(i)}$), and the corresponding interrater reliability ($r_{wg(i)}$) for each question. The number of respondents for the questionnaire was also seven, which can be considered sufficient for the reliability method analysis as it was developed for small groups assessments (James et al., 1984). Once again, all seven respondents addressed each of the 12 questions from the evaluation questionnaire. At this point, 14 practitioners from the two companies have evaluated the PF so far (see Appendix XIII for the responses in full).

The analysis of the data demonstrates the usefulness of the PF with overall average scores ($\mu_{(1 \rightarrow 7)} = 3.39 > 3.00$) and level of agreement ($r_{wg(1 \rightarrow 7)} > 0.70$)⁵⁶, slightly higher than the previous company. Note that now all criteria were evaluated as at least (3)

⁵⁶As defined in Chapter 3 ("Methodology"), the threshold of 0.70 for the within-group interrater reliability indicates a level of sufficient agreement as informed by the literature. In addition, a "satisfactory" score (3.00) is also sufficient evidence of positive evaluation of the participants (Issa et al., 2015; Pigosso et al., 2013).

“satisfactory”. Additional feedback practitioners also reinforced the evaluation carried out. For instance, the technology coordinator shared a written statement that *“the framework is an extremely interesting tool to obtain a single view the innovation capability of an organisation and then be able to act upon it”*.

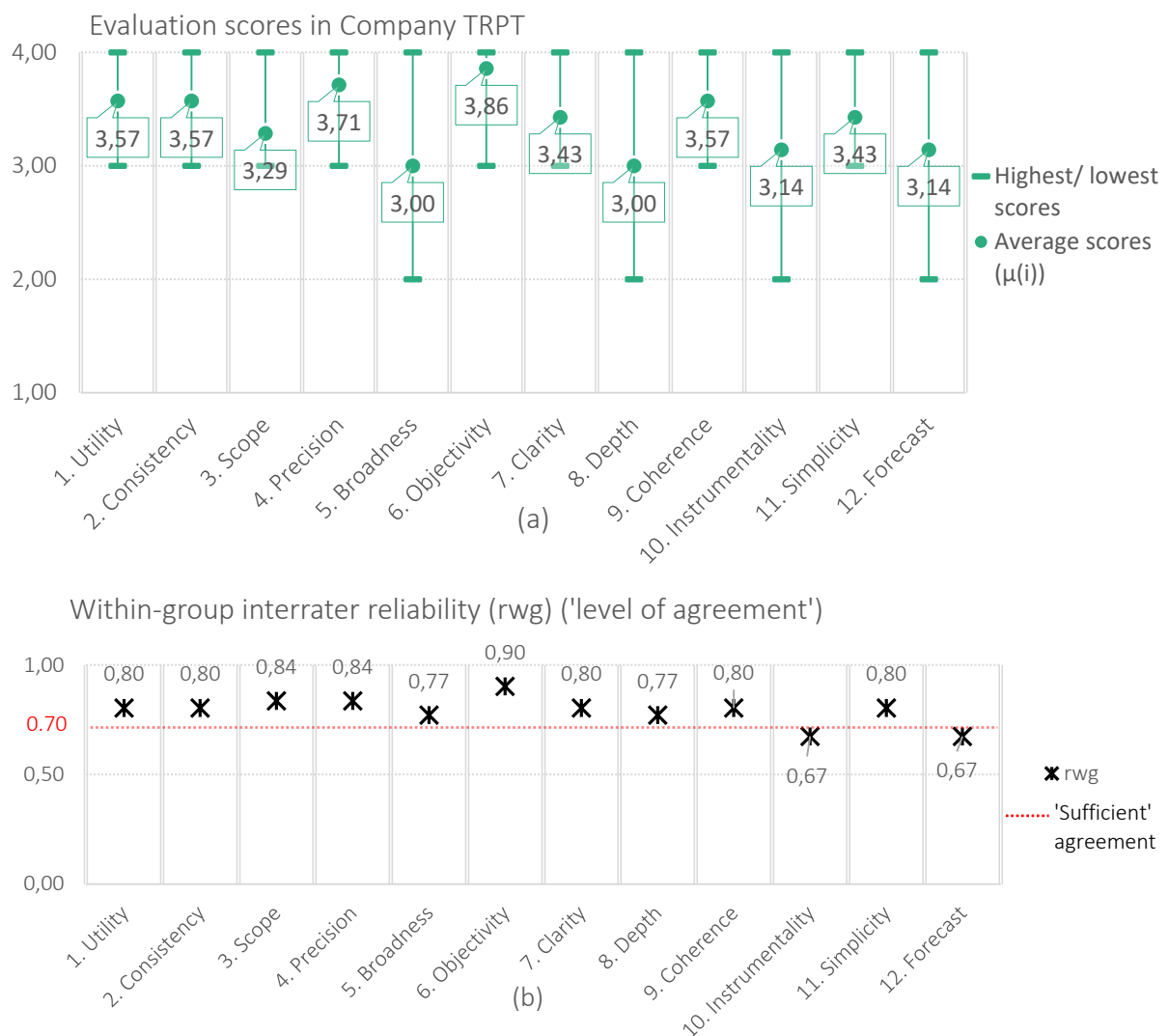


Figure 5.17. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company TRPT.

Nonetheless, there are two evaluation scores that did not reach the required level of agreement of 0.70. The first refers to the evaluation of instrumentality (n.10), a reoccurrence from the previous application, that although was assessed at a 3.14 evaluation score, the agreement level was at 0.67. Once again, this result highlights that the operationalisation of the PF requires facilitators with a moderate level of expertise. Thus, the resolution could rely on further development and use of training materials for facilitators to support the application of the PF in companies.

The second assessment that presented an insufficient level of agreement (0.67) was forecast (n.12), with an average evaluation score of 3.14. The likely explanation is that as the company applied the implementation time criteria and their own criteria to select the projects and assigned responsibilities, the effects of internal power plays may have come into place and slightly blurred the next steps that the company needed to take, and consequently the evaluation. Therefore, a possible way out would be to apply the recommended criteria from the spreadsheet for project prioritisation.

Table 5.3. Company TRPT evaluation of the PF (n=7).

N.	Questions	$\mu_{(i)}$	$SD_{(i)}$	$r_{wg(i)}$
1	Utility: How do you evaluate the general utility of the PF in supporting companies in the measurement of performance and selection of the most suitable innovation practices to be implemented?	3.57	0.49	0.80
2	Consistency: How do you evaluate the consistency of the nine dimensions of performance used in the PF?	3.57	0.49	0.80
3	Scope: How do you evaluate the PF in relation to the adequacy of the scope of the proposition of the improvement projects?	3.29	0.45	0.84
4	Precision: How do you evaluate the PF in relation to the precision of the innovation capability profile provided?	3.71	0.45	0.84
5	Broadness: How do you evaluate the PF in relation to its applicability in manufacturing companies from different sectors?	3.00	0.53	0.77
6	Objectivity: How do you evaluate the objectivity of the PF in performing the diagnosis of the company and proposing the improvement projects?	3.86	0.35	0.90
7	Clarity: How do you evaluate the PF concerning the clarity in which the results are presented, e.g., the innovation capability profile?	3.43	0.49	0.80
8	Depth: How do you evaluate the PF in relation to the depth of the diagnosis (the innovation capability profile) and the proposition of improvement projects?	3.00	0.53	0.77
9	Coherence: How do you evaluate the coherence of the diagnosis (the innovation capability profile) and the improvement projects proposed in the PF?	3.57	0.49	0.80
10	Instrumentality: How do you evaluate the PF in relation to its instrumentality in the innovation capability profile (e.g., workshop and materials) and the proposition of the innovation practices (project charters)?	3.14	0.64	0.67
11	Simplicity: How do you evaluate the PF in relation to the simplicity of the results presented?	3.43	0.49	0.80
12	Forecast: How do you evaluate the PF in relation to the definition of the next steps to be taken after the proposition of the improvement projects?	3.14	0.64	0.67

In conclusion, this evaluation performed in the second participating company also corroborates that the PF can support the measurement and evaluation of innovation performance in Company TRPT, including the further identification of improvement actions, which substantiates the proposition advocated in this thesis.

5.3 KEY LEARNINGS

This section summarises the key learnings from the AR performed sequentially in Company TRFR and then Company TRTP. Hence, these learnings refer to the improvements incorporated into the PF elements during the empirical development, discussed in section 5.3.1. This discussion is followed by the presentation of the consolidated version of the PF in its final version in section 5.3.2.

5.3.1 FRAMEWORK IMPROVEMENTS DURING THE ACTION RESEARCH

The improvements implemented in the PF during the AR are mostly related to the supporting elements as they are actionable. In this sense, the improvements in the database elements are addressed within the supporting element in which they are used. In either case, these improvements are exemplified next, with the description of what was defined at the time of the conceptual development, followed by what was done in the empirical development in the narrative of events, first in Company TRFR and then in Company TRPT.

Table 5.4 begins by presenting the improvements in the PF procedure, which relates to the introduction of the stakeholder map to identify key employees, the characterisation of the innovation process, the validation of the diagnosis, the two approaches to address process improvement, and the criteria to support prioritisation of improvement projects:

Table 5.4. Improvements in the PF procedure.

Description of the improvement	Narrative of events		
	Conceptual development	Empirical development	
		Company TRFR	Company TRPT
The identification of key employees now relies on a formal step with the creation of a stakeholder map, which, despite being a simple tool, was not applied in the context of a PF before. It is easier to involve stakeholders, who have a moderate interest but no strong influence.	A step was foreseen but with no further support, e.g., stakeholder map (discussion on section 4.3.1).	New step first suggested and introduced in the PF (sections 5.1.1.2, 5.1.1.4).	The step was replicated with positive feedback (sections 5.2.1.2, 5.2.1.4).
The characterisation of the company's innovation process was initially an AR step. However, because of its contribution to the PF application, for instance, as a double-check of the values achieved since formalised process activities tend to result in higher performance, it was incorporated into the procedure.	Not addressed.	AR step performed to understand the company context (sections 5.1.1.1, 5.1.1.4).	New step formally introduced into the PF (sections 5.2.1.1, 5.2.1.4).

EMPIRICAL DEVELOPMENT

Table 5.4. Improvements in the PF procedure (continued).

Description of the improvement	Narrative of events		
	Conceptual development	Empirical development	
		Company TRFR	Company TRPT
A validation step that leads to the second stage of the PF was introduced as a milestone to verify the decision to go ahead with the definition of action plans and generate awareness among employees or go back and gather more evidence if the profile is not validated.	An initial verification point to validate the findings was planned (section 4.3.1).	Validation performed informally (sections 5.1.1.3, 5.1.1.4).	New step formally introduced into the PF (sections 5.2.1.3, 5.2.1.4).
The proposition of the two distinct approaches, staged and continuous, has guided the companies in the improvement of the process. This PF feature is a novelty, as such an approach has never been proposed for PF focused on the innovation process before.	Not addressed.	New step first suggested and introduced in the PF (sections 5.1.2.1, 5.1.2.2, 5.1.2.3).	The step was replicated with positive feedback (sections 5.2.2.1, 5.2.2.2, 5.2.2.3).
The several criteria were included in the PF to help prioritise or select improvement projects to support the balance of projects.	An initial step to prioritise was defined (section 4.3.1).	Criteria were included in the step (sections 5.1.2.2, 5.1.2.3).	The step was replicated with positive feedback (sections 5.2.2.2, 5.2.2.3).

Secondly, the key learnings introduced into the PF during the AR concerning facilitation relate to the formation of a core team to lead the PF application and the support of a spreadsheet for prioritisation of the improvement projects, as illustrated in Table 5.5:

Table 5.5. Improvements in the PF facilitation.

Description of the improvement	Narrative of events		
	Conceptual development	Empirical development	
		Company TRFR	Company TRPT
The conception of a formal step to set up a core team for leading the procedure ensured that the PF application is supported throughout the measurement process.	The facilitation role was defined (section 4.3.2).	Core team created informally (sections 5.1.1.2, 5.1.1.4).	New step formally introduced into the PF (sections 5.2.1.2, 5.2.1.4).
A spreadsheet for prioritising improvement projects applying the AHP methodology was developed to support the facilitator's role in the companies.	Not addressed.	The support was first introduced in the PF (sections 5.1.2.2, 5.1.2.3).	The support further improved with more feedback (sections 5.2.2.2, 5.2.2.3).

Thirdly, Table 5.6 presents the improvements related to the visualisation of performance progression in the PF, which refer to the developments in the terminology of the performance levels, the innovation capability profile and its representation:

EMPIRICAL DEVELOPMENT

Table 5.6. Improvements in the PF visualisation of performance progression.

Description of the improvement	Narrative of events		
	Conceptual development	Empirical development	
		Company TRFR	Company TRPT
New terminology for the performance levels ('innovation revealed'; 'innovation initiated'; 'innovation experienced'; and 'innovation improved') was introduced to facilitate the communication of the diagnosis performed.	The terminology used was only based on levels 1 to 4 (section 4.3.3).	The terminology was improved with the new complements (sections 5.1.1.3, 5.1.1.4).	The terminology was replicated with positive feedback (sections 5.2.1.3, 5.2.1.4).
The overall characterisation of the company's profile is now defined by the most representative lower level identified. Although other PFs do not provide an overall characterisation, this novelty has been said to help disseminate the diagnosis.	Not addressed.	The overall characterisation was introduced in the PF (sections 5.1.1.3, 5.1.1.4).	It was applied with positive feedback (sections 5.2.1.3, 5.2.1.4).
The graphic representation of the innovation capability profile is improved based on the practitioners' feedback and the introduction of visual cues of the distinct dimensions.	A provisional radar profile was defined to display the four levels (section 4.3.3).	The radar representation was applied with positive feedback (section 5.1.1.4).	The radar representation was improved (section 5.2.1.4).

Finally, Table 5.7 presents the improvements in the PF related to the support for actions plans, with the changes related to the introduction of examples of past companies in the improvement project charters and the customisation of improvement projects:

Table 5.7. Improvements in the PF support for improvement actions.

Description of the improvement	Narrative of events		
	Conceptual development	Empirical development	
		Company TRFR	Company TRPT
Examples from previous companies applying the recommended practices as well as further PIs to monitor implementation were introduced in the improvement project charters.	Not addressed.	The structuring of projects charters was introduced with positive feedback (sections 5.1.2.2, 5.1.2.3).	The projects were further improved with examples of past companies (sections 5.2.2.2, 5.2.2.3).
The customisation of improvement projects yielded learnings, e.g., the definition of detailed work packages depending on the PM model in the company and the use of implementation time as a default criterion to create a 'quick win' and build momentum.	Not addressed.	Customisation considerations were performed informally (section 5.1.2.3).	Incremental changes were implemented in the PF (section 5.2.2.3).

These improvements demonstrate that the PF was substantially improved in several instances during the empirical development, the AR conducted in the two manufacturing companies. The ultimate output of the AR was the consolidated version of the PF, which presented next in its final version.

5.3.2 CONSOLIDATED VERSION OF THE FRAMEWORK

This section presents the consolidated and final version of the PF, after the results and action-oriented improvements performed during the AR cycles at Company TRFR and Company TRPT. Thus, the resulting PF follows a step-by-step procedure of data collection, feedback and analysis focused on two primary purposes:

- 1) To measure the current performance of the company across a range of performance dimensions in a diagnosis structure in stage I, and
- 2) To evaluate and interpret performance to identify opportunities and define actions of improvement in stage II.

The flow of the procedure of the PF is described linearly for clarity in the next pages; however, it should be noted that the steps were applied in AR cycles, as explained in the previous sections.

Stage I: Diagnosis of the current situation

The aim of stage I is to assess the current state of the company's related to the innovation process across the nine performance dimensions. This diagnosis can be accomplished through the eight steps outlined in Figure 5.18.

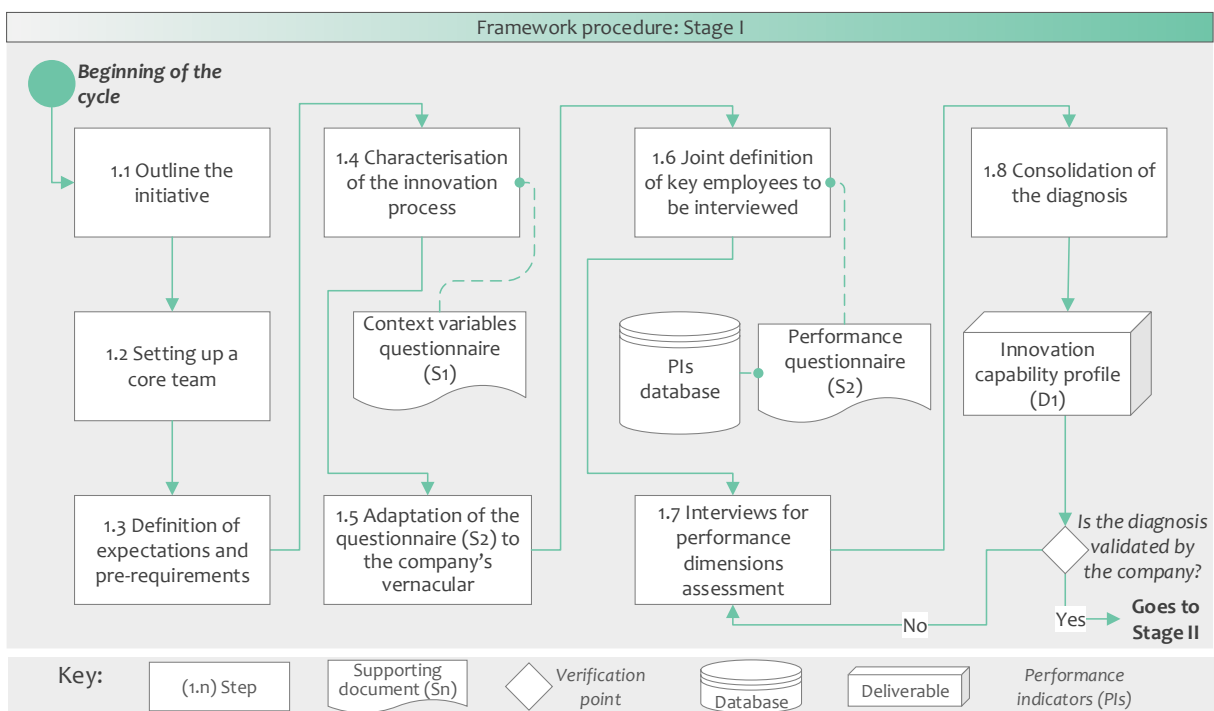


Figure 5.18. Stage I: Diagnosis of the current situation.

Step 1.1 – Outline the initiative: the main objective of this step is to pitch the initiative to the top management to gain support and help secure traction for the following steps. One or more facilitators should take the lead on this step, ensuring that the head(s) of departments/areas are on board.

Step 1.2 – Setting up a core team: the purpose of this step is to set up a core team within the company, who will be tasked with leading the implementation of the PF. Ideally, this team will be composed up to four members and made up some should have experience in diagnosis initiatives before (in other domains, for example).

Step 1.3 – Definition of expectations and pre-requirements: this step aims to build a mutual understanding of the goals as well as to identify any prerequisites. For instance, this PF has a focus on the development and analysis of the performance and, therefore, the development of software is not within the scope. Additionally, it should be clear from the outset that this PF also enables benchmarking for top-performing companies' performance.

Step 1.4 – Characterisation of the innovation process: this step aims to identify the phases of the innovation process performed by the company, even when not highly formalised, or only with process architecture in place. It includes a document analysis of reference models, roles and responsibilities, product documentation and reports. Key employees are also interviewed using a semi-structured supporting questionnaire S1 to understand the day-to-day processes and the contextual variables of the innovation process and clarify issues of the analysed documents (shown in Appendix VIII).

Step 1.5 – Adaptation of the questionnaire to the company's vernacular: this step aims to adapt the supporting questionnaire S2 (Appendix IX), developed for this study based on the rapid assessment PIs retrieved via the systematic review of the literature, to the company's vernacular to ensure that the questions will be effectively understood and that the answers will be reliable.

Step 1.6 – Joint definition of key employees to be interviewed: in this step, the core team identifies key employees to be interviewed (ideally 6 – 25),⁵⁷ prioritising a variety of employees from different areas and hierarchical levels to ensure a broad overview on how the innovation process is conducted in the company. Past applications involved people from areas, such as

⁵⁷Although little practical guidance is available for defining sample sizes of interviews, Guest et al. (2006) and Morse (2000) indicate that six can be sufficient to capture meaningful results and achieve theoretical saturation (with a maximum of 25).

technology development, R&D, product engineering, process engineering, business development, and technology radar. The core team is responsible for scheduling the interviews, contacting the employees to be interviewed and providing the necessary resources (space, etc.).

Step 1.7 – Interviews for performance dimensions assessment: this step aims to measure the performance of each indicator, according to the perception of key employees jointly selected with the company in the previous step. The methodology consists of face-to-face interviews with the selected employees using a structured questionnaire (supporting questionnaire S2 – Appendix IX) adapted to the company's vocabulary. The interviews are designed to last around 70-90 minutes, encompassing:

- a) Introduction to the topic: what is a PF, its relation to process improvement, the context the application in the company and the objective of the interview;
- b) Application of the structured supporting questionnaire S2 adapted to the company: in which the interviewee is asked to measure each indicator and to provide additional comments and evidence to justify the answer;
- c) Final remarks: commentaries on the practices that were not asked during the interview and final considerations.

Step 1.8 – Consolidation of the diagnosis: finally, the performance levels are assigned and analysed with the evidence provided to validate the answers given by the interviewees and to ensure coherence and consistency (supported by the spreadsheet for profile construction shown in Appendix XI). With the performance levels assigned, the company's innovation capability profile is designed, using the radar representation (e.g., Figure 5.15) and presented to the larger group to be validated. The validation results into two possible outcomes: go ahead to the next stage or go back and gather more evidence with the interviews if the profile is not validated (see the PF procedure illustrated in Figure 5.18).

Stage II: Deployment of action plans

Once the profile of the company's innovation capability has been validated, stage II can begin. The goal of this stage is to support the definition of action plans to improve performance. For this, the PF indicates six steps to identify the most suitable innovation practices to prompt improvement action plans based on the identification of gaps between current and desired

performance within the dimensions where there are needs to be attended. The procedure is illustrated in Figure 5.19.

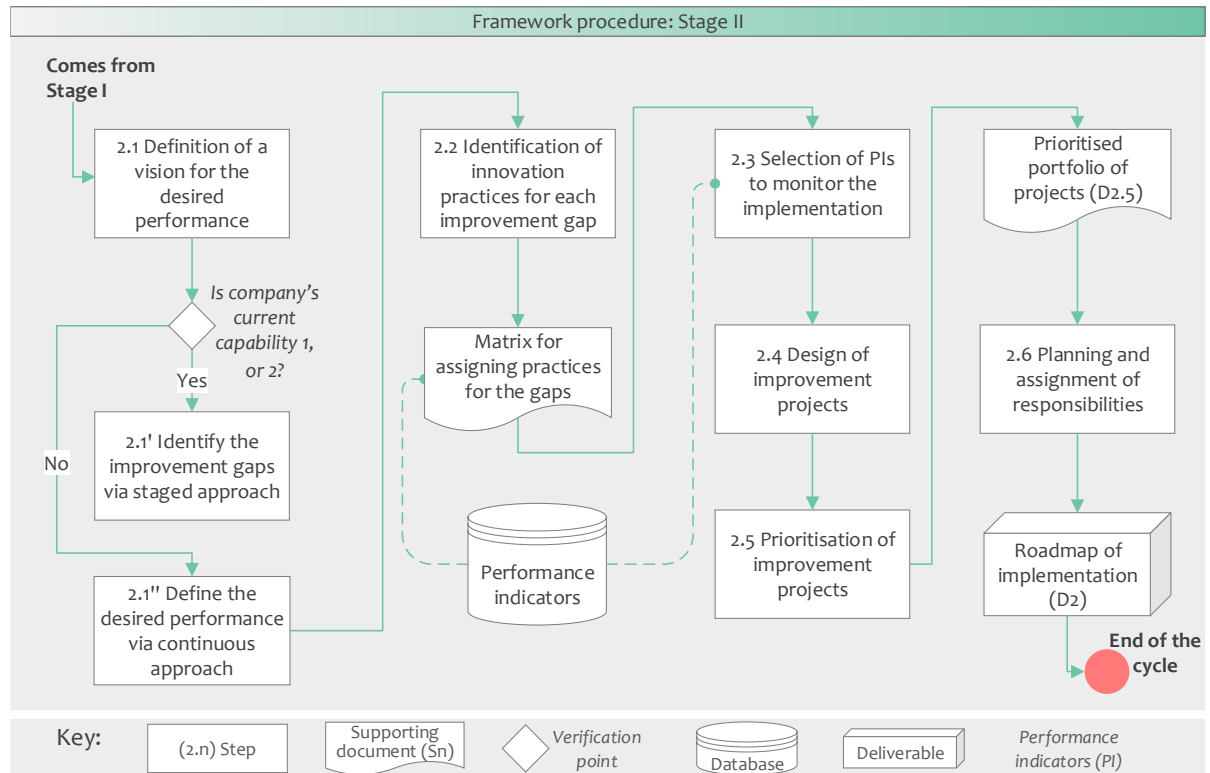


Figure 5.19. Stage II: Deployment of action plans.

Step 2.1 – Definition of the vision for the desired performance: this step begins with the preparation of the target level of performance based on a gap analysis. The PF allows a degree of flexibility in the vision definition so that it can be aligned with the company's diagnosis. There are two possible approaches to structure action plans:

- **Staged approach:** is an orderly way to define the vision for companies with a low-performance level (namely levels 1 and 2). It is based on the implementation of one level at a time, targeting the gaps located at the lowest level, and moving up.
- **Continuous approach:** is a more flexible approach recommended only for companies characterised with a higher performance level, i.e., companies with all performance level 2 achieved, and profile characterised by performance levels 3 or 4. In this case, the company can choose to focus on different levels related to one or several performance dimensions according to its own internal drivers and strategic objectives.

Thus, the pathway to improvement to be followed is based on the current innovation capability profile of the company. The staged approach is suitable for companies which have a

low-performance level. In contrast, the continuous approach is recommended when the company has a relatively moderate performance, already presenting a significant effort to structure and manage the innovation process (see the characterisation of the levels in Appendix VI).

Step 2.2 – Identification of suitable innovation practices for each improvement gap within the dimensions: this step identifies suitable innovation practices to help define actions plans to address the improvement gaps identified by either approach, staged or continuous. Each gap is analysed with the help of a simplified domain mapping matrix relating the performance levels for each indicator with innovation practices from the literature (see Appendix VII). It allows the core team to select the most beneficial innovation practices to attend the needs (the improvement gap) previously identified.

Step 2.3 – Selection of indicators to monitor the implementation: to track the implementation of the action plans, the PIs database (Appendix V) is further consulted to select additional indicators to monitor the implementation.

Step 2.4 – Design of improvement projects for the innovation practices: in this step, the innovation practices identified are specified into improvement projects (the action plans).⁵⁸ For each improvement gap, examples of innovation practices from the literature were used to define the improvement projects with goals, description, deliverables, requirements, risks, implementation time and necessary resources (a generic example is given in Appendix X).

Step 2.5 – Prioritisation of improvement projects: the projects should then be prioritised. The company can use the electronic spreadsheet applying the AHP (Appendix XII) to prioritise (for companies characterised as levels 1 or 2) or select and then prioritise the projects (for companies characterised as levels 3 or 4). One or more prioritisation criteria can be used in the prioritisation spreadsheet according to the stakeholders' preference among: implementation time, strategic alignment, top management support, resources availability, cost, competitive advantage, legal compliance and return on investment; with implementation time as the default criterion.

Step 2.6 – Planning and assignment of responsibilities: the PF allows the company to adopt its usual practices for planning the improvement projects' implementation. At this point,

⁵⁸Once the action plans are specified into project charters with the definition of goals, project description, main deliverables, requirements, risks, implementation time and necessary resources (as presented in the example, shown in Appendix X), they are called improvement projects.

portfolio management concepts can be used to create an implementation roadmap with the selected improvement projects. The company should determine the schedule, work packages, project champions, and teams involved, according to the project management practices already adopted in the company (for example, traditional PM or agile management). The PF does not intend to establish and define how a company should implement the improvement projects, since each company should carry out these implementation activities using its best and current practices.

Furthermore, during the implementation of the improvement practices, special care should be taken concerning people change management, as people are the gatekeepers of change. People change management is the cornerstone of successful improvement projects and an area that must be focused on throughout the entire implementation of the project (Jeston & Nelis, 2006). It may include considerations about resistance to change, leadership roles, change planning, change communication, employees' motivation and staff training. Having a core team to lead the implementation of the PF in the company already facilitates the discussion and consideration of people change management, as the team would have an overview of the conduction of the PF procedure and the people involved.

As a final point, the total duration of the application of the PF will depend on a set of variables, such as top management support, resources available in the company, resistance and the characteristics of the improvement projects selected. It is indispensable, in the short and mid-term horizon of the implementation of the prioritised improvement projects, the use of the PIs suggested to monitor implementation to measure the results of the improvement projects. In addition, in a longer timeframe, it is also important to finally measure KPIs such as the number of new products launched in the last three years, sales and revenue of new products to measure the final results of the improvement cycles.⁵⁹ In this work, it is foreseen that the measurement of this type of lagging KPIs should take place after two improvement cycles (i.e., two applications of the PF covering both stages I and II) so management can have an overview of the final outcomes and assess accordingly.

⁵⁹Due to confidentiality reasons, the values for this type of lagging indicators (sales, revenue and return on investment of new product launched) for Company TRFR and Company TRPT are not shared in this thesis.

6 THEORY VALIDATION

In this chapter, the application of the final version of the PF into a case study for theory-testing is discussed, which corresponds to stage 4 of the research method. The domain in which the PF is applied in the case study follows the same guidelines previously established: an SME classified under category C (manufacturing) of the ISIC classification (United Nations, 2008), with a minimum level of formalisation and a commitment to innovation (that can be indicated by either the presence of innovation goals or resources destined to new projects).

The case study is conducted according to the procedure established in the consolidated version of the PF (as described in section 5.3.2) to perform the diagnosis of the current situation and the deployment of action plans. The results of the application are discussed in section 6.1.1, followed by its evaluation in section 6.1.2. Then, section 6.2 presents the overall assessment of the PF, considering both AR and case study results. Finally, section 6.3 analyses the theoretical contributions of the proposed PF against existing PFs. Figure 6.1, below, indicates the section in which the results of the corresponding research activities are discussed.

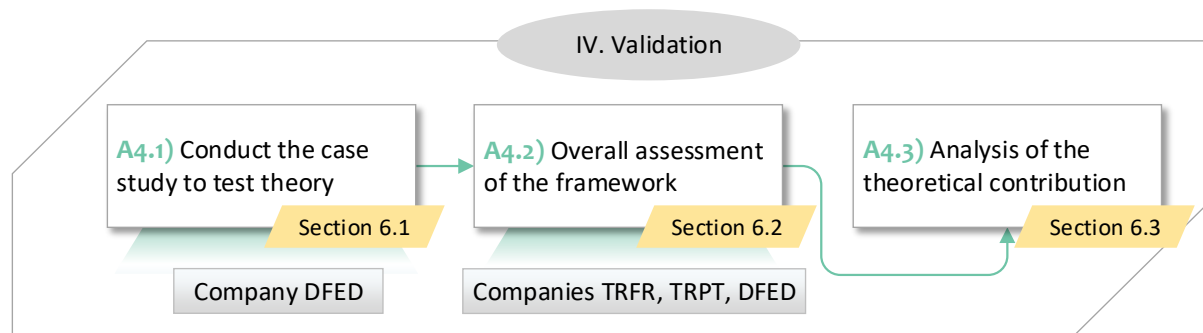


Figure 6.1. Location of the results for stage 4 of the research method.

6.1 CASE STUDY FOR THEORY TESTING

Company DFED is a European diet feeder machinery manufacturer that can be classified under division 28 of the ISIC classification (United Nations, 2008). The company has more than 40 years of experience in farming solutions, with approximately 165 employees and annual revenue between €25M and €35M.⁶⁰

⁶⁰This document does not include a set of further information about the case study Company DFED (Diet FEeDers) to protect the identity of the company.

The company's portfolio consists of two main product lines of livestock-feeding machinery developed for the dairy industry, that present six to eight possible variations, some of which can include an interface to support data analysis for feed management. Because of its 40 years of experience and internal culture, Company DFED has a strong reliance on their engineering capability to ensure the efficiency and durability of their products, hence, the long product life cycles (20-35 years). The company also follows the lean manufacturing methodology to plan and control their production and applies remanufacturing strategies. One of the company's primary strategic goals is to build customer loyalty for the long-term through reliable products. This is the main motivation for the company to participate in this research.

6.1.1 APPLICATION

Next, the results of the eight steps for performing the diagnosis of the current innovation capability profile are presented, according to the procedure defined in section 5.3.2.

Stage I: Diagnosis of the current situation

Step 1.1 – Outline the initiative: in this step, the researcher presented the findings of the AR conducted in the two previous companies and their testimonials to the heads of innovation and operation in the company of the case study that, in turn, confirmed the interest in participating in the research.

Step 1.2 – Setting up a core team: the core team was created with two researchers and the head of innovation to lead the application of the PF in the company, enabling access to key employees for data gathering and interviews.

Step 1.3 – Definition of expectations and pre-requirements: the purpose of this step was to establish a mutual understanding of the expected results as well as to identify any prerequisites. For this, a discussion about the scope of the results of the PF application was held by both parties, emphasising the importance of the diagnosis and the following improvement projects and the fact that the development of software was out of the scope.

Step 1.4 – Characterisation of the innovation process: this step identified the innovation process phases carried out in the company. It was based on a semi-structured interview of two key employees using the questionnaire S1 (Appendix VIII) to understand the day-to-day processes and the contextual variables of the innovation process, e.g., level of formalisation, main drivers, closed/open innovation paradigm, and surrounding environment.

As previously mentioned, the company aims to build long-term customer loyalty. For this, the company employs ‘defender’ strategies. This means that the company works hard to defend its market, with incremental changes along the way to remain competitive in the form of cost savings and gains in the efficiency of the products offered. Meanwhile, the company has occasionally introduced new-to-the-company features (e.g., carbon footprint certified products, digital controlling interfaces add-ons). The stimulus that drives the company’s innovation process emerges mostly internally, from technology push efforts, with a minor force exerted by market pull activities. For instance, new customer needs are captured only if the service personnel or sales bring that information back to the company in an informal and *ad-hoc* mode.

New ideas are mostly driven by technical areas and sales. The company maintains lists of ideas in the head of innovation local computer that, from time to time, are screened for further development by an innovation committee composed of senior management members. Evidence from the interviews indicate that the company’s main driver for selecting the ideas is based on financial analysis, mostly cost savings and implementation cost, and the efficiency improvement. Furthermore, the company had a reward system based on the cost savings figures or efficiency improvements of the ideas; however, it is no longer in use. Figure 6.2 illustrates these characteristics of Company DFED.

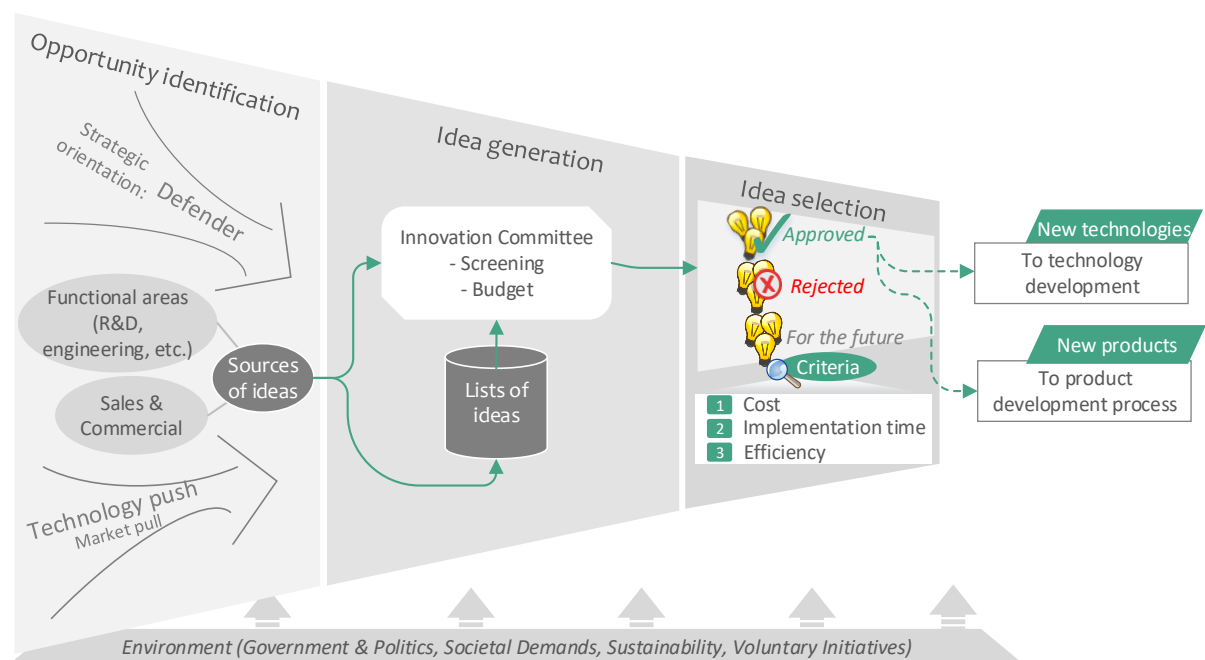


Figure 6.2. Characterisation of the IFE in Company DFED.

With the selection of a prospective project by the innovation committee, a budget is decided and allocated to provide resources and plan the project. If this idea demands further investigation into new technology, preliminary work starts with initial simulations and modelling that can lead to product development with more information in time. Once the analysis demonstrates the feasibility of the concept, the project can grow into a detailed and lengthy investigation that may result in a new technology incorporated into a product or the production process (Figure 6.3).

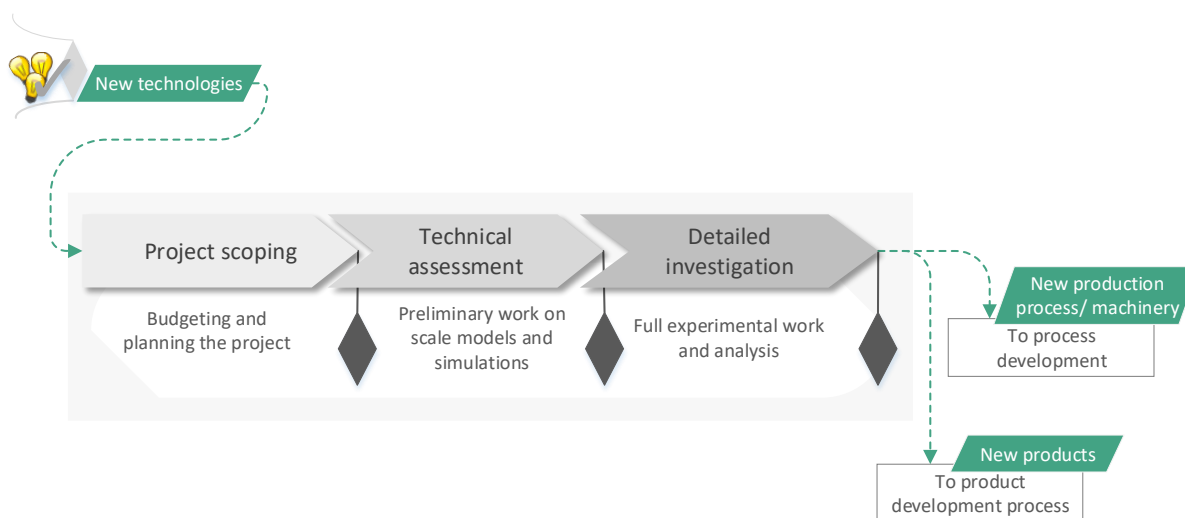


Figure 6.3. Characterisation of the TD phase in Company DFED.

The PD begins with the development team detailing the concept coming either from the IFE or TD phase into the conceptual design. The company follows a stage-gate process, as illustrated in Figure 6.4, with a moderate level of formalisation. As more information arrives and decisions are made, a detailed design emerges. As the company adopts lean manufacturing for its production method, production starts only with orders coming from the sales/commercial area. With the weekly planning of these orders, the production line starts to assemble the ordered products culminating in the final tests and quality checks. Products are then tested, and once certified, they are ready for delivery.

The company also applies EoL principles, in terms of collecting used diet feeders to remanufacture and then resell – almost 40% of all sales come from remanufactured machines. Once these used machines are in the main plant, their parts and components are inspected and tested. Appropriate measures are then taken for the parts and components so that the production process for these machines can begin. These machines are inspected and certified in the same way as the new ones, aiming for the same performance.

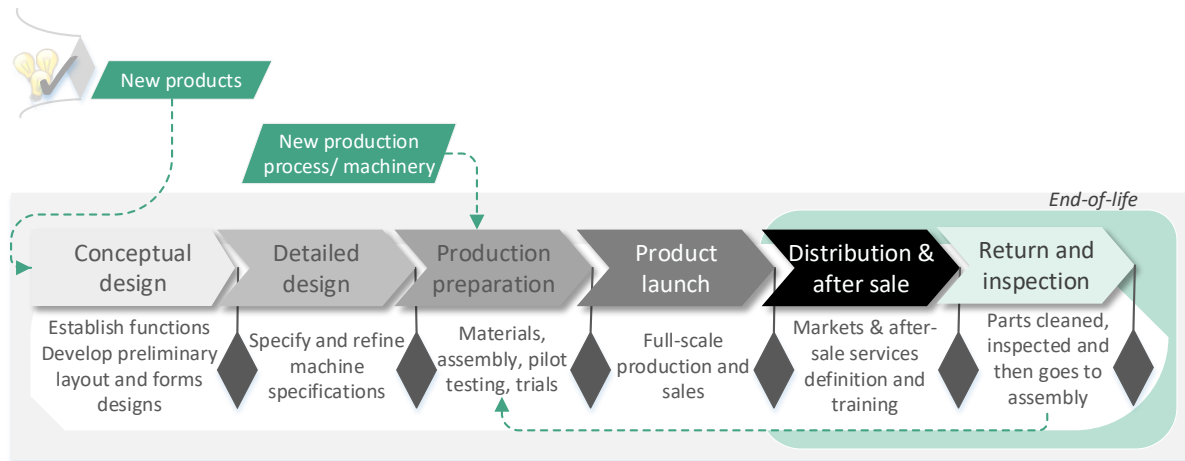


Figure 6.4. Characterisation of the PD and EoL phase in Company DFED.

The products are then shipped through international and national distribution channels, and the after-sales protocols are put in place in dealerships to train salespeople. They also have a customer relationship management (CRM) software to collect general satisfaction feedback from the customers, and gather some demographics, especially to profile repeated customers. Nonetheless, at the moment, there is no current procedure or formalisation in the company to put to use the captured feedback or other types of data to retro-feed new information into the innovation process.

Step 1.5 – Adaptation of the questionnaire to the company’s vernacular: the characterisation of the innovation process in the previous step informed the necessary adaptations of performance supporting questionnaire S2 (see the generic format provided in Appendix IX) to the company’s vernacular to ensure the employees’ understanding during the interviews to be held in the next step.

Step 1.6 – Joint definition of key employees to be interviewed: in this step, the key employees to be interviewed were identified from various areas and hierarchical levels to ensure a broad overview of the company’s performance dimensions. Based on a stakeholder map's construction, the key stakeholders with at least a moderate interest in the process were identified (Figure 6.5). Thus, the identified key employees were from R&D, sales and commercial, finance, operations, servicing, and front-end application area. It is important to note that although the front-end application area presented a lower level of interest, it was suggested by the company, and to ensure continuous engagement of the company; it was included. The core team organised the schedule for the interviews and contacted the employees to be interviewed.

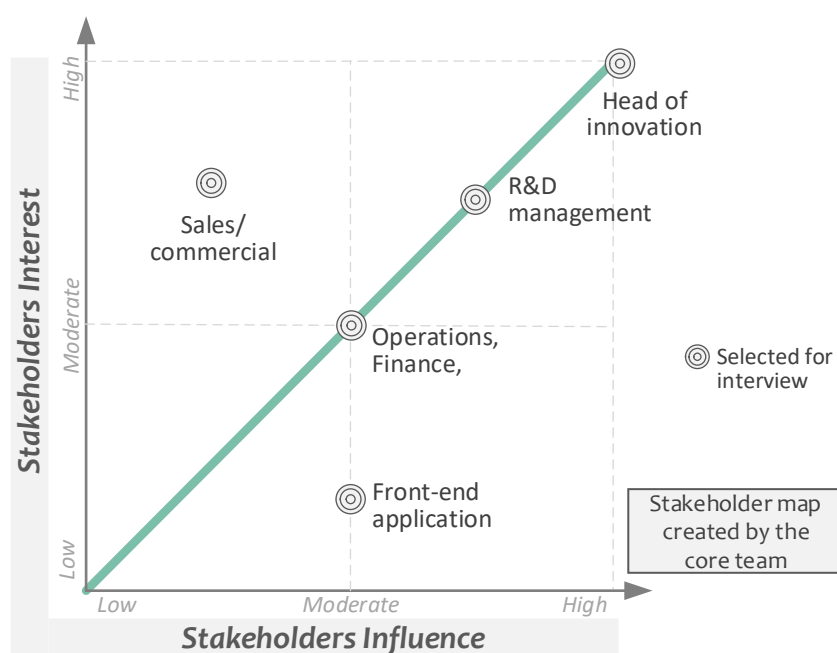


Figure 6.5. Stakeholder map for the PF application in Company DFED.

Step 1.7 – Interviews for performance dimensions assessment: the goal of this step was to collect relevant data to measure the rapid assessment PIs, according to the inputs of key-employees jointly selected with the company in the previous step with the help of the stakeholder map. Accordingly, six key employees were interviewed remotely using a structured questionnaire (supporting questionnaire S2 – Appendix IX) adapted to the company’s vocabulary. The interviews lasted approximately 81 minutes.

Step 1.8 – Consolidation of the diagnosis: based on the evidence collected from the interviews, the performance levels were assigned, as illustrated in Figure 6.6. The innovation capability profile indicates that Company DFED is mainly characterised by level 1 with 9 measurements at this level, and remaining measurements located at level 2 (20 metrics) and level 3 (5 metrics).⁶¹

It was observed that the company strives, through its distribution channels, to maintain its revenues from the commercialisation of its two main product lines. There are limited resources, so, in financial terms, the focus is on obtaining those necessary to maintain the main (or most profitable) outcomes to the market. Thus, the company is oriented to its internal environment and daily operations, paying little to the external environment in terms of prospecting potential partners or building cooperation networks to open innovation.

⁶¹Remember that the level of a company is defined by the lowest level with at least eight measurements, since there are 34 the rapid assessment PIs covering the four levels.

Innovating is not a priority, but interest on the topic has been awakened due to competitors' analysis, even though managers do not have a completely clear understanding of what innovation implies for the company. For this reason, the level characterising this company is level 1, which is called 'innovation revealed', insofar as it is perceived ('revealed') as an alternative ('salvation') for the company's long-term survival, even if management only knows they should do something about it.

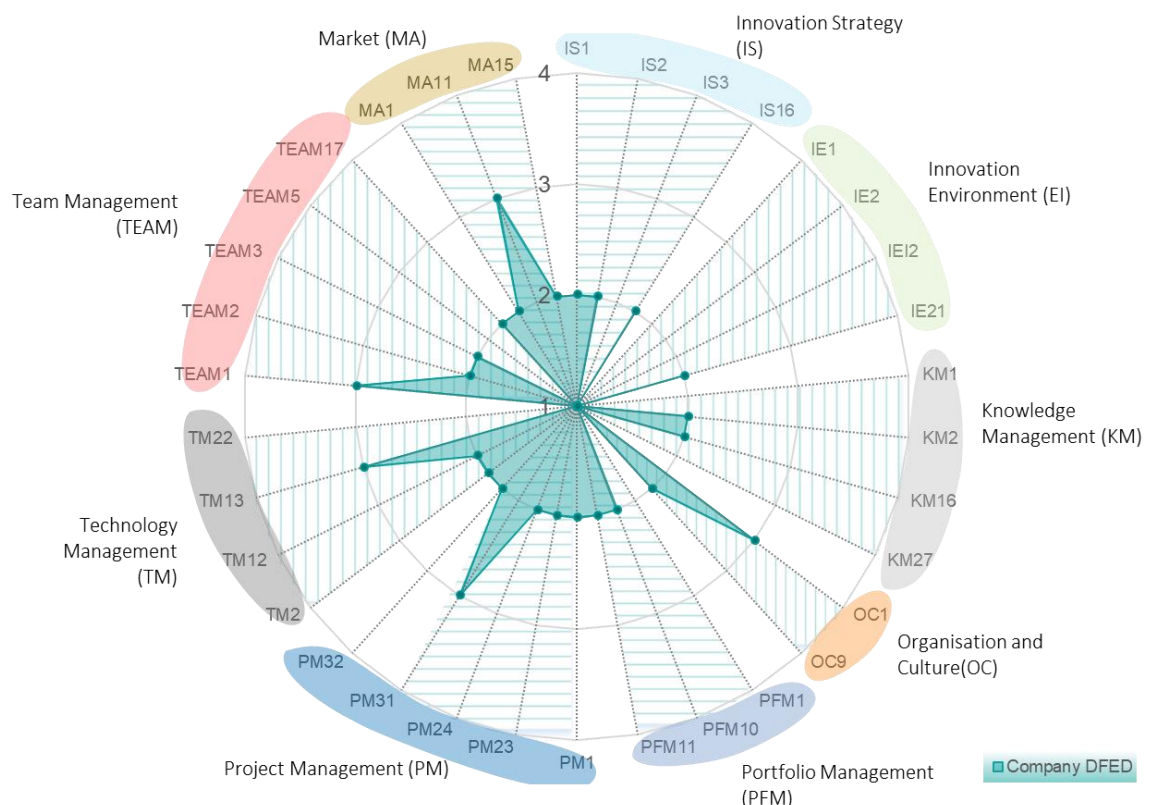


Figure 6.6. Company DFED innovation capability profile.

Thus, when sporadic projects with incremental new-to-the-company changes are executed, they are focused on the short-term, and their implementation is *ad hoc*, without proper prospecting activities and support tools, making it harder to maintain an inflow of new product projects for the mid-term and long-term horizons. Eventually, as a way of expanding and diversifying revenues, there are sparse efforts to develop new solutions for customers. However, these initiatives are not always understood and managed as innovation efforts.

Stage II: Deployment of action plans

Based on the diagnosis and the innovation capability profile, the six steps for the deployment of action plans were put to practice, beginning with the definition of the desired performance.

Step 2.1 – Definition of the vision for the desired performance: in this step, the pathway to improvement is determined by the company's level resulting in either the staged or the continuous approach. Because of its characterisation as level 1, the staged approach was the one to be followed. This meant that the desired performance was informed by the dimensions with gaps at level 1 (see the characterisation of the levels in Appendix VI). Therefore, the dimensions presenting the opportunities to improve were the following: innovation strategy, innovation environment, knowledge management, technology management and team management (see Figure 6.6).

Step 2.2 – Identification of suitable innovation practices within the dimensions: based on the staged approach, the core team identified the possible improvement practices from the compilation of innovation practices (Appendix VII) for levelling up the company to performance level 2 in the dimensions mentioned in the previous step. In total, seven innovation practices were identified, summarised as follows:

Table 6.1. List of practices suggested for Company DFED.

	Code	Dimension	Sub-dimension	Improvement practice title
1	P03-IS-IO	Innovation strategy	Strategic orientation	Delphi method for innovation planning
2	P07-IE-Op	Innovation environment	Openness	Roadmapping for partnerships
3	P10-IE-Ser		Servitisation	Screen for product-service systems (PSS)
4	P16-KM-IdM	Knowledge management	Idea management	Idea management system
5	P24-PFM-B	Portfolio management	Balance	Innovation portfolio management
6	P37-TM-R&D	Technology management	R&D intensity	In-house R&D monitoring
7	P41-TEAM-St		Team stability	"Ambidextrous teams"

Step 2.3 – Selection of indicators to monitor the implementation: for each of those innovation practices, additional in-depth PIs from the database (Appendix V) were selected to monitor the implementation. For example, the indicator [IS4] "Frequency of product strategy plan use/update" was selected to help track the implementation of the practice Delphi method for innovation planning (P03-IS-IO). The same procedure was performed for each of the innovation practices selected.

Step 2.4 – Design of improvement projects for the innovation practices: the innovation practices identified in the previous steps can be specified into improvement projects in this step. These improvement projects specifications follow the example presented in Appendix X, with goals, description, deliverables, requirements, risks, time and resources.

Step 2.5 – Prioritisation of improvement projects: with the seven projects, the next step was to provide support in the prioritisation. As previously mentioned, an electronic spreadsheet applying the AHP was designed to help with the prioritisation. It includes several sample criteria, such as implementation time, strategic alignment, and availability of resources, amongst others, which one or several criteria can be selected.

Step 2.6 – Planning and assignment of responsibilities: based on the discussion in the case study, there is an inclination in the direction of project 1, “Delphi method for innovation planning”, and project 2, “Roadmapping for partnerships”. From this point, the company was responsible for defining the schedule, work packages, project champions, and teams involved.

6.1.2 EVALUATION

The evaluation of the PF in the case study follows the same procedure established for the AR with the application of the evaluation questionnaire (Appendix III) in Company DFED. As aforementioned, the questionnaire evaluates the users’ perception of the PF utility, consistency, scope, precision, broadness, objectivity, clarity, depth, coherence, clarity, instrumentality, simplicity and forecast. It presents a four-point scale, as follows: (1) “unsatisfactory”, (2) “needs improvements”; (3) “satisfactory” and (4) “very satisfactory”.

The responses’ results are shown in Figure 6.7, which illustrates the highest, lowest and average scores for each question and the corresponding within-group interrater reliability (‘level of agreement’). Additionally, Table 6.2 also displays the average score ($\mu_{(i)}$), standard deviation ($SD_{(i)}$), and the corresponding interrater reliability ($r_{wg(i)}$) achieved for each question. In the case of Company DFED, the number of respondents for the questionnaire was four, which can be considered sufficient to analyse the reliability method and the evaluation of the PF. Furthermore, all the questions were answered by each of the evaluators. The complete view on the responses can be found in Appendix XIII.

The analysis of the data obtained in the questionnaire demonstrates the usefulness of the PF, as all the criteria were evaluated as at least (3) “satisfactory” ($\mu_{(1 \rightarrow 4)} = 3.38 > 3.00$), with a sufficient level of agreement on all questions ($r_{wg(1 \rightarrow 4)} > 0.70$).⁶² In this sense, none of the evaluation criteria was assessed as “needs improvement” or “unsatisfactory” by any of

⁶²Remember that, as defined in Chapter 3 (“Methodology”), the threshold of 0.70 for the within-group interrater reliability provides a level of sufficient agreement according to the literature and a “satisfactory” score is also sufficient evidence of a positive evaluation of the respondents (Issa et al., 2015; Pigosso et al., 2013).

THEORY VALIDATION

the respondents. Also, the evaluation scores achieved were very similar to the second AR company, but now with a sufficient level of agreement for all responses. This evaluation demonstrates that the PF provided the expected results for Company DFED, and it can support manufacturing companies in the measurement of performance and definition of action plans to improve performance.

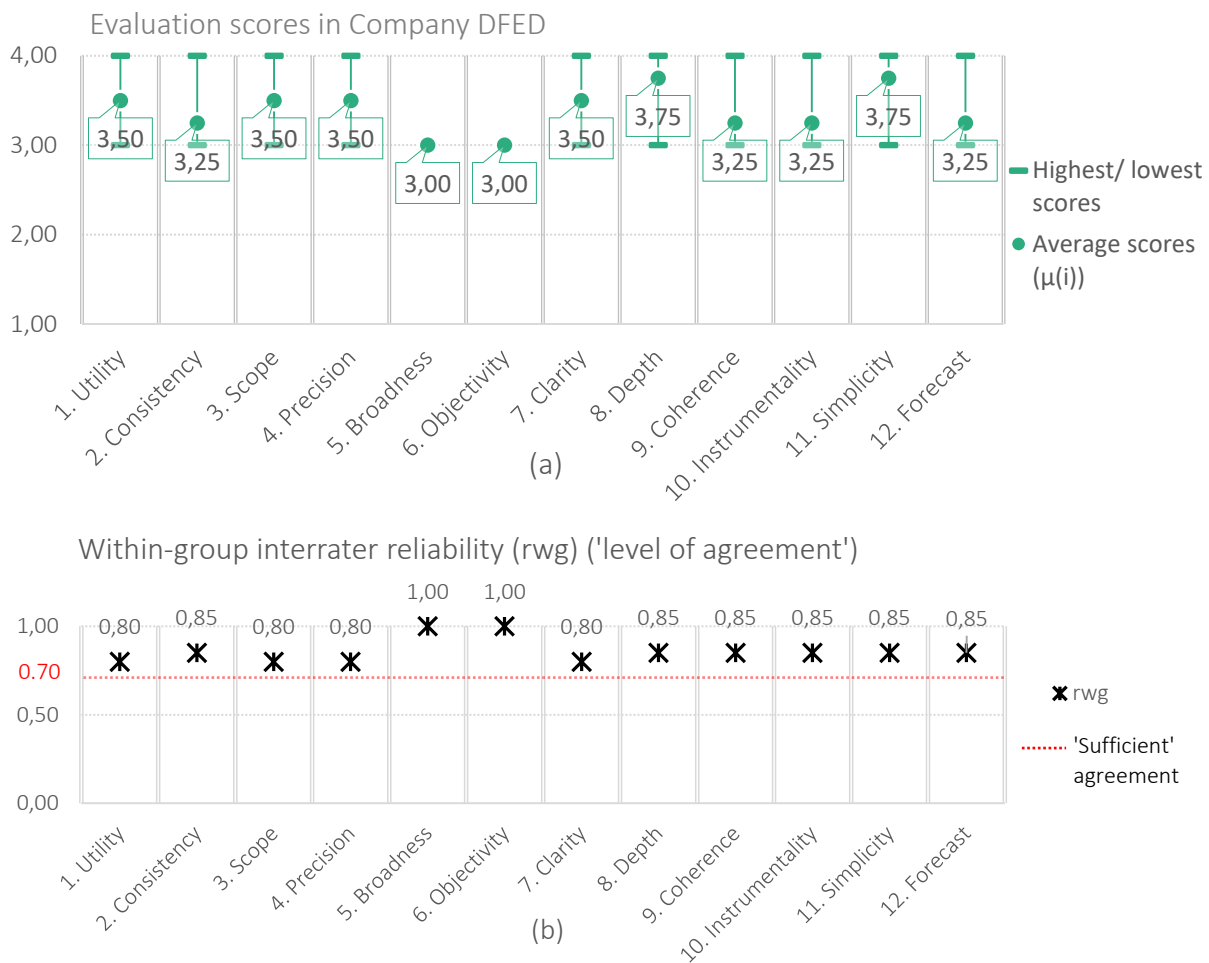


Figure 6.7. Graphs illustrating the evaluation scores (a) and level of agreement (b) in Company DFED.

Further commentaries by practitioners also corroborate the evaluation carried out in Company DFED. For instance, a senior management employee shared in the questionnaire: *"I believe the analysis captured a true reflection of where we are as an organisation in regard to our innovation capability. It raised relevant questions in areas that we can act upon"* while another complemented with *"I very impressed with the level of detail of the results and feel it was a good representation of where innovation is at within the company"* and *"a lot of work has gone into the framework, and as a company, I think we can benefit greatly if we take some of the detail on board"*.

On the other hand, for the first time, one of the evaluators stated that a higher level was expected on a specific dimension, innovation environment, particularly openness because of previous cooperation. Analysing the PIs related to openness in the innovation capability profile, although there was a previous external collaboration, it was with suppliers of component parts. Besides, at the moment, there is not an indication of current partnerships or collaboration with external parties or planning of future ones. Moreover, a suggestion from Company DFED is to incorporate the consideration of financial constraints. Physical and financial resources are considered in the organisation and culture dimension (see Appendix V), but future research can deepen in a study of financial constraints as a lever of the PF, for example.

Table 6.2. Company DFED evaluation of the PF (n=4).

N.	Questions	$\mu_{(i)}$	$SD_{(i)}$	$r_{wg(i)}$
1	Utility: How do you evaluate the general utility of the PF in supporting companies in the measurement of performance and selection of the most suitable innovation practices to be implemented?	3.50	0.50	0.80
2	Consistency: How do you evaluate the consistency of the nine dimensions of performance used in the PF?	3.25	0.43	0.85
3	Scope: How do you evaluate the PF in relation to the adequacy of the scope of the proposition of the improvement projects?	3.50	0.50	0.80
4	Precision: How do you evaluate the PF in relation to the precision of the innovation capability profile provided?	3.50	0.50	0.84
5	Broadness: How do you evaluate the PF in relation to its applicability in manufacturing companies from different sectors?	3.00	0.00	1.00
6	Objectivity: How do you evaluate the objectivity of the PF in performing the diagnosis of the company and proposing the improvement projects?	3.00	0.00	1.00
7	Clarity: How do you evaluate the PF concerning the clarity in which the results are presented, e.g., the innovation capability profile?	3.50	0.50	0.80
8	Depth: How do you evaluate the PF in relation to the depth of the diagnosis (the innovation capability profile) and the proposition of improvement projects?	3.75	0.43	0.85
9	Coherence: How do you evaluate the coherence of the diagnosis (the innovation capability profile) and the improvement projects proposed in the PF?	3.25	0.43	0.85
10	Instrumentality: How do you evaluate the PF in relation to its instrumentality in the innovation capability profile (e.g., workshop and materials) and the proposition of the innovation practices (project charters)?	3.25	0.43	0.85
11	Simplicity: How do you evaluate the PF in relation to the simplicity of the results presented?	3.75	0.43	0.80
12	Forecast: How do you evaluate the PF in relation to the definition of the next steps to be taken after the proposition of the improvement projects?	3.25	0.43	0.80

In summary, this evaluation performed in the case study company also corroborates the results achieved in the AR companies, indicating that the PF can support the measurement and evaluation of innovation performance, including the identification of improvement actions, which substantiates the proposition advocated in this thesis.

6.2 OVERALL ASSESSMENT OF THE FRAMEWORK

A management tool, such as a PF proposed in this research, needs to be legitimised by its users to have value to practice in the OM research field. It can only be truly evaluated in the intended situation, in practice and as many instances as possible. To generalise results from both the AR and the case study is not possible, but they can be used to enhance the validity of the theory developed (Dul & Hak, 2008), as the main purpose of this study is not to generalise but to increase understanding. For case-oriented research, the validity of the theory developed depends on its applicability, usability and usefulness.

As explained in section 3.5.2 of Chapter 3 (“Methodology”), applicability refers to the conditions of the study given by the context in which the new tool is to be used (Blessing & Chakrabarti, 2009). Poor contextual conditions and lack of clear procedures and support can make a subsequent data analysis especially difficult. To overcome this, the research employed the Eisenhardt and Graebner (2007) strategy for selecting the industry partners, taking into consideration sectorial and contextual particularities. Additionally, the choice of first conducting AR in two companies to improve the theory was vital to leverage the experience of practitioners and their involvement and then a case study in another company builds upon an effective strategy to test the improved managerial tool (Barquet, 2015; Pigosso, 2012).

At this point, it must be highlighted that although the participating companies are characterised as SMEs, they are all medium-sized companies. Small and medium-sized companies alike may have an advantage in the management of innovation processes as they can be more flexible and adaptable to changing market needs than large companies (Alegre et al., 2013; Hudson Smith & Smith, 2007). Thus, small companies also have flat structures, fewer management layers, and less bureaucratic structures than large companies (even medium). Considering this, the PF has the potential to be applicable for relatively small companies, at least for the ones that are approaching medium companies in scale. In addition, the conceptual definition of the database was developed considering the previous application of PIs into SMEs, and associated with insights from the empirical development, especially the procedure, which includes the search for evidence to corroborate the measurements in the diagnosis, will likely facilitate the PF application into small companies.

In contrast, small companies may face the challenge of information deficits with missing details about innovation policy and technical information due to the lack of capital and

resources (Becheikh et al., 2006). This can be aggravated in smaller firms, such as micro-enterprises,⁶³ in which case, the facilitator will have to look for the differences in which they implement the management practices and adapt the PF. Nonetheless, the way the diagnosis of the current situation is constructed, the performance level 1 of the PIs can work as a checklist of practices that the company can concentrate its efforts to implement, one dimension at a time. Furthermore, one of the drivers for the managers/directors of young small and micro companies is to see what the competitors are doing in terms of structuring their innovation process so that they can establish suitable practices (Rantala & Ukko, 2018). Some companies will even benchmark best practices from other company sizes. Thus, the PF can help managers in this ongoing endeavour.

The applicability discussion should also cover large companies. This type of company is more likely to invest in innovation since it can allocate more resources than SMEs (Becheikh et al., 2006). They have a typically greater portfolio with diversified products, most likely developed in distinct BUs, including different countries. Hence, within this context, the application of the PF can be broken down into the two stages of the PF. The diagnosis stage should be applied to each unit responsible for the development of new products, except in the case when a BU only manufactures the products designed by the headquarters, so both parts should be considered jointly. Then, the stage II, deployment of action plans, should involve a cross-functional team from all relevant BUs to analyse the complementarities and synergies among the action plans to propose which ones should be aggregated to be implemented at the institutional level and which ones should be executed at the local level.

A final consideration of the PF applicability concerns innovation ecosystems. These ecosystems refer to networks of distinct stakeholders, mostly companies, universities, research institutions and government bodies that come together to share strategic resources and knowledge in the context of open innovation (Hall, 2010). Although one of the dimensions does acknowledge and measures openness as a sub-dimension of the innovation environment, because in the context AR did it did not emerge, the PF was not applied nor improved in this scenario. However, if the occasion arrives, the PF has the potential to be applied in the different manufacturing companies (including separate BUs) that compose the system using

⁶³SMEs are further subdivided into micro enterprises (fewer than 10 employees), small enterprises (10 to 49 employees), medium-sized enterprises (50 to 249 employees) (OECD, 2017).

the same facilitation, possibly, so that once the innovation capability profiles are ready, they can be compared (by overlapping them). In addition to the innovation practices, the ecosystem may be able to compile and share their own practices as a community of practice. Such an application needs further research, so more considerations are made in future research discussion (section 7.2).

After discussing applicability, the assessment discussion around usability, which in this context, relates to the extent to which the developed tool can be applied by specified users to achieve the defined goals (Blessing & Chakrabarti, 2009). Following the reasoning of well-established research for developing PFs (e.g., Chiesa et al., 1996) as explained in section 3.5.2 of Chapter 3 (“Methodology”), the usability is defined as the achievement of the measurement of the innovation performance and definition of action plans. It also depends on the design decision of developing a stand-alone or a supported tool (with facilitators). This study opted for the latter design. The results show that the two AR companies corroborated by the case study indicated that the PF can be used, supported by facilitation, without major difficulty to measure innovation performance and with tangible results with the definition of action plans (including several of them being implemented).

The third and final point about the PF assessment relates to its usefulness. It refers to the managerial tool’s ability to realise the expected impact defined by measurable success criteria (Blessing & Chakrabarti, 2009). For this, this work applied an evaluation questionnaire in the companies in which the PF was implemented. The evaluation questionnaire results for Company TRFR were already discussed in section 5.1.2.3, Company TRPT in section 5.2.2.3 and Company DFED in section 6.1.2, but further qualitative analysis can underline relevant insights. Since the first two evaluations of the PF were performed within the scope of the AR, which presents a unique cyclical nature of implementing changes, a qualitative comparison can be made to observe whether there was an increase in the evaluation as the final AR version is an improved version of the PF,⁶⁴ and it would be expected to have a higher evaluation. Secondly, another interesting comparison is to analyse whether the evaluation performed in the case study maintains a similar evaluation (or improves) of the AR companies (as the PF resulting from the second company is the final and the same one applied in the case study).

⁶⁴Remember that there are three versions of the PF developed: the conceptual version, the ‘intermediary’ version after the first AR company, and the consolidated and final version achieved after the second AR company, which the one was applied in the case study.

The comparison of the evaluations is illustrated in Figure 6.8, considering the average scores⁶⁵ achieved in each company against the criteria. First, it is possible to observe an increase in the scores of 9 out of 12 criteria in the AR companies, indicating a perceived improvement in the PF proposal and a positive contribution of the AR to the research. In addition, even though three decreases can be observed in utility (n.1), consistency (n.2) and broadness (n.5); they are not too high as the Company TRPT average scores are still above ‘satisfactory’ (level 3). Note that the evaluations were made by practitioners from two independent companies, and therefore, these considerations are purely non-statistical, and reservations must be made in the evaluations of these average scores.

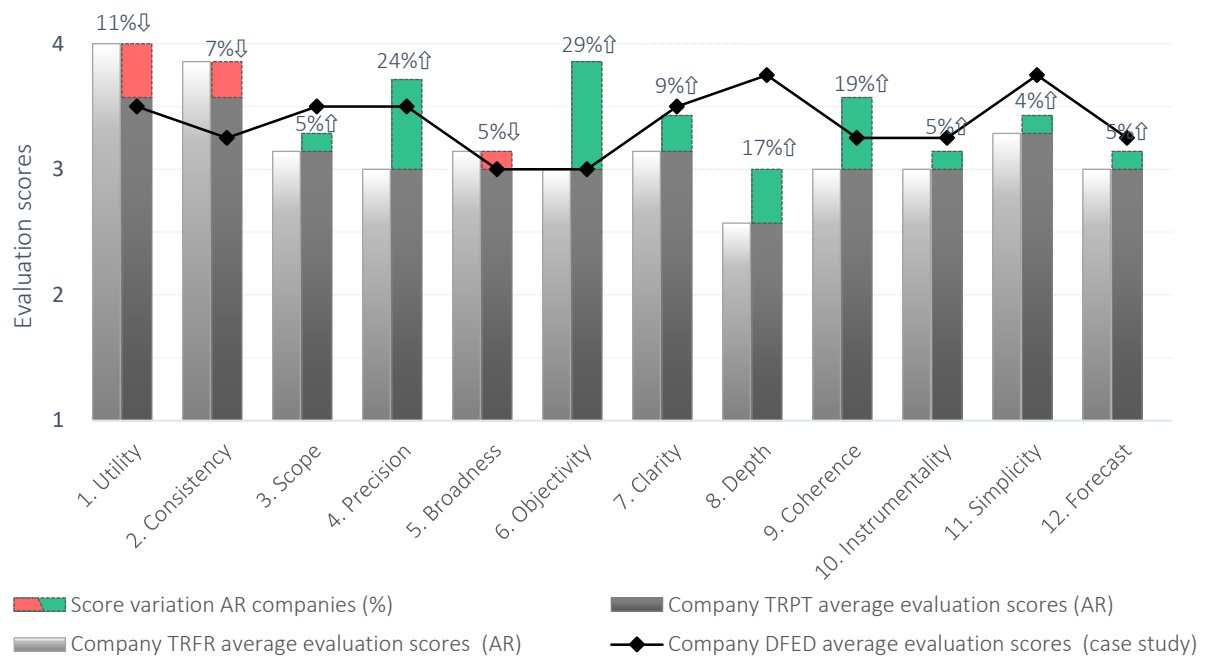


Figure 6.8. Comparison of the evaluation in companies TRFR, TRPT and DFED (n=18).

Furthermore, the line illustrated in Figure 6.8 represents the evaluation of the PF in the case study. It is possible to observe that the evaluation scores were maintained at similar levels or improved for seven criteria, showing a congruent qualitative evaluation in both companies TRPT and DFED. Despite the decreases in the evaluation of utility (n.1), consistency (n.2), precision (n.4), objectivity (n.6) and coherence (n.9), they still maintained the ‘satisfactory’ evaluation above level 3. To conclude, the evaluation results performed at the three participating companies provide reasonable evidence that the PF has value to practice.

⁶⁵Remember that the response scale of the questionnaire is (1) “unsatisfactory”, (2) “needs improvements”; (3) “satisfactory” and (4) “very satisfactory”. See the evaluation questionnaire in Appendix III.

6.3 ANALYSIS OF THEORETICAL CONTRIBUTION

After discussing the PF assessment to demonstrate its value to practice, the discussion now addresses its value to academia. For this, a specific literature review indicated the criteria used for comparing PFs in previous academic studies. These criteria enable the identification of distinguishing and common features of proposed PFs. They can relate to either database or supporting elements, as follows:

- Provide a diagnosis or an audit of the current state of the company (Medori & Steeple, 2000; Neely et al., 2002);
- Present a comprehensive set of performance dimensions (Adams et al., 2006; Markham & Lee, 2013);
- Offer a listing state-of-art PIs and steps to facilitate their use (Medori & Steeple, 2000; Neely et al., 2002);
- Support companies in their market pull and/or technology push strategies (Atuahene-Gima, 2005; Brattström et al., 2018);
- Provide a step-by-step procedure to apply the framework (Medori & Steeple, 2000; Neely et al., 2002; Niven, 2006), and
- Enable the deployment of strategy into actions plans (Kaplan & Norton, 1992; Niven, 2006).

Table 6.3 presents a summary of the analysis depicting the mentioned criteria and the existing PFs (first discussed in Chapter 2 “Literature review”). For instance, from the existing PFs, only a few perform diagnosis (or audit) (e.g., Chiesa et al., 1996, 2009; Werner & Souder, 1997). Nevertheless, Pigosso et al. (2013) show that managers are more willing to implement action plans when a diagnosis is provided. This study also shared this finding, as one of the evaluation questionnaire comments was that *“the framework is an extremely interesting tool to obtain an integrated view that shows in a single diagnosis the innovation capability of an organisation and then the organisation is able to act upon it”*. Thus, innovation managers can use the diagnosis steps as a roadmap for supporting their improvement initiatives.

Most PFs present performance dimensions, as discussed in Chapter 2 “Literature review”. While most PFs do present some dimensions, they do not cover all the ones demonstrated to be relevant in previous literature. For example, Crossan & Apaydin (2010) PF provides seven dimensions, the largest found in the literature; however, relevant dimensions

to the current innovation landscape like innovation environment is missing. In contrast, the developed PF in this thesis provides an integrative overview incorporating the nine dimensions most commonly demonstrated in the literature, which enables managers not only to get an overall picture but also to focus on particular dimensions of interest.

Table 6.3. Comparison of existing PFs and the proposed PF.

Criteria PFs	Diagnosis/ audit	Performance dimensions	State-of- art PIs	Market pull & technology push	Step-by- step procedure	Action plans
(W. B. Brown & Gobeli, 1992)	✗	✓	✓	✗	✓	✓
(Chiesa et al., 1996)	✓	✓	✓	✓	✓	✗
(Werner & Souder, 1997)	✓	✓	✗	✗	✓	✗
(C. H. Loch & Tapper, 2002)	✗	✓	✓	✗	✗	✗
(Kahn et al., 2006)	✗	✓	✓	✓	✗	✗
(Berg et al., 2009)	✗	✓	✗	✗	✗	✗
(Chiesa et al., 2009)	✓	✓	✓	✗	✓	✗
(Crossan & Apaydin, 2010)	✗	✓	✓	✓	✗	✗
(Lakiza et al., 2018)	✗	✗	✓	✓	✓	✓
Proposed framework	✓	✓	✓	✓	✓	✓

Several authors also argue that it is indispensable for a PF to present a list of indicators (Medori & Steeple, 2000; Neely et al., 2002). However, not all PFs provide examples of PIs, let alone compiling a comprehensive list of them. Even though many other studies may specify PIs, as discussed in Chapter 2 (“Literature review”), the proposed PF is the only one with an extensive compilation of 259 PIs and the systematisation of 34 rapid assessment PIs, a novelty in the context of PFs for the innovation process. In addition, the database of PIs also enables management to spend less time in the pursuit of PIs and more on the analysis and improvement side. If necessary, steps are also provided to enable more PIs from the database to be applied to monitor the improvement projects implementation.

PFs should also be designed to support the company in the market pull and/or technology push strategies. Existing PFs that address the two strategies, meaning that the framework measure whether the company captures market insights, as well as technology-

based inventions, are Kahn et al. (2006), Chiesa et al. (1996) and Crossan and Apaydin, (2010). The PF, in its conceptual form, also allowed the measurement of the market pull strategies in the market and technology push in the technology management dimension. Yet, the three participating companies presented more emphasis on the technology-push, meaning that the PF was further developed in this direction.

Providing a procedure to support the PF application is a requirement typically related to practice, but also acknowledged by several researchers (Medori & Steeple, 2000; Neely et al., 2002; Niven, 2006). Nevertheless, only the PFs proposed by Chiesa et al. (1996) and more recently by Lakiza et al. (2018) explicitly present a procedure; while others implicitly demonstrate it through case studies (e.g., W. B. Brown & Gobeli, 1992; Chiesa et al., 2009; Werner & Souder, 1997) as discussed in Chapter 2 ("Literature review"). On the other hand, the proposed PF clearly provides a step-by-step procedure for the PF with facilitation support.

Considering the criterion of deployment of action plans (Kaplan & Norton, 1992; Niven, 2006), only the PFs proposed by Brown & Gobeli (1992) and Lakiza et al., (2018) provide guidance. In addition, even though they discuss improvement actions, they do not provide explicit support for the identification of gaps and the subsequent development of improvement actions. In this sense, the new PF developed in this work contributes to research with a new way to systematically identify the current gaps of the company across relevant performance dimensions and deploy action plans to tackle them. The PF even provides even further examples of past actions applied by companies reported in the literature.

To summarise, when compared with previous PFs, the novelty of this research lies in the fact that the new and updated PF consolidates distinct elements from the literature but combined in a new and actionable way for SMEs in the manufacturing sector. Thus, this exploratory study allowed the researcher to substantiate the conceptual PF from the literature with practical issues from practice, which leads to a new and updated approach for the PF.

Finally, it is important to stress this research's scope was delimited to the manufacturing sector. First, the conceptual development reflected the manufacturing industry dimensions and PIs (they feature 81% of the SLR selected papers, see section 4.2). Then, the empirical development was drawn in the scope of manufacturing companies in the AR (Chapter 5) and the case study (section 6.1). Accordingly, service sector application needs to be further studied.

7 CONCLUSIONS AND FINAL REMARKS

This chapter presents the conclusions and final remarks of the research demonstrated in this thesis. It is divided into two sections, one discussing the results and research objectives achieved (section 7.1) and the other presenting future work (section 7.2).

7.1 RESULTS AND RESEARCH OBJECTIVES

PFs are important to companies as the central tools for process management. In the management of the innovation process, it is no different. Strategy implementation, performance evaluation, decision making, and process improvement can be implemented with the support of a PF. However, despite the many contributions of prior work, there is an open call for more research (Dzallas & Blind, 2018). New PFs are needed to provide an integrative overview of relevant dimensions of innovation performance with state-of-the-art PIs. New PF studies should also consider their application in SMEs. Furthermore, the use of PFs needs to shift from solely performance measurement to evaluation of whether there are needs to be addressed and to making information available for the development of action plans. These concerns were evidenced by the need of companies TRFR, TRPT, and DFED for a PF that could support them in innovation measurement and management.

In order to overcome these barriers, this work presents a PF that allows managers to have a diagnosis across a comprehensive set of dimensions and define improvement actions accordingly. For this, first, the technology and innovation management and managerial accounting bodies of literature were studied, mainly to define the innovation process phases and their characteristics as well as the necessary elements that form a PF, achieving the two initial specific objectives outlined in section 1.2. Then, the PF was developed in the context of the hypothetic-deductive approach, combining conceptual and empirical developments. The conceptual version of the PF was developed based on a systematic review of the literature to define the database and supporting elements. This review indicated the existence of nine dimensions, 259 PIs (of which 34 can be considered rapid assessment) and further supporting elements (e.g., the support for action plans), achieving the specific objective stated as “systematic map the existing elements from the theoretical domain theory, with special attention to performance indicators” (section 1.2). These dimensions and PIs are presented in the literature in a somewhat fragmented manner and not systematised to facilitate use.

The conceptual version was then empirically developed via AR conducted at two SMEs manufacturing companies (TRFR and TRPT), which had a formalised innovation process and aimed to improve innovation performance. The contributions from the practice gathered during the AR enabled PF improvement, especially the supporting elements. The steps for building a diagnosis of the current state of the company with an innovation capability were refined and, a graphical representation with four distinct levels was detailed, for example. Besides enabling a broad understanding of the current situation of the company, the PF turns in the direction of improving the awareness of the involved employees, including an opportunity for further reflections on the topic. Similarly, the presentation of the results in focus groups and the discussion of the improvement projects together with the key employees at the organisations is a positive evaluation of the PF application. As a result of the AR, the final version of the PF was consolidated, fulfilling the specific objective described as “structure a procedure and further elements of the PF, including its construction, validation and respective evaluation by the users in the participating companies” (see section 1.2).

Subsequently, a case study for theory-testing was carried out at Company DFED, which brought richness to understanding how the application of the PF is done in practice. The proposition advocated in this research that the PF can support the measurement of innovation performance and definition of improvement actions to be applied by a company was confirmed by the evaluation of the PF performed in the company. All the success criteria defined for the PF evaluation questionnaire with 18 practitioners’ responses were assessed as satisfactory by Company DFED and previous companies (TRFR, TRPT), along with positive considerations on applicability, usability and usefulness. To gather more evidence on the confirmation of the proposition and establish generalisations of the PF; however, replication of the case studies must be performed in future research.

The PF proposed can be considered a management innovation. In this sense, the use of the PF has the potential to help companies in the:

- 1) Diagnosis of the innovation capability of the company, with the identification of improvement opportunities and the development of action plans. This benefit is confirmed by the satisfactory results achieved in the PF evaluation and corroborated by the practitioner’s testimonials expressing that the support received in addressing improvement opportunities was missing in the firm before this study (e.g., TRFR).

- 2) Continuous improvement towards better innovation performance based on the proposed PF. This support is demonstrated through the positive results from the evaluation questionnaire and the fact that one of the companies have committed resources to implement the prioritised improvement projects.
- 3) Establishment of a common language and a shared vision across the company. The users' positive feedback indicates the PF contribution to raising awareness among the managers, which enable the establishment of a common language in the company.

In addition, the main academic contributions of the present research can be summarised as follows, based on the analysis of theoretical contribution:

- 1) Identification and systematisation of existing PIs and dimensions. Hence, this research can help researchers who may need a swift identification of relevant PIs and dimensions.
- 2) Identification and illustration of a novel innovation capability profile before proceeding to the selection of PIs and identification of improvement projects.
- 3) Proposition of a procedure to apply a PF to deploy action plans based on continuous improvement and action-oriented results in the manufacturing industry.
- 4) Establishment of a broader understanding of innovation measurement, related to the PF necessary elements and their real-life application into manufacturing companies.

The conclusion is that the PF successfully achieved the objective of this research, which was to support medium-sized manufacturing companies in measuring their performance, diagnosing their innovation capability profile, and then selecting the most suitable innovation practices to be implemented into the innovation process, according to companies' strategic objectives and drivers.

Nevertheless, this study has limitations in the same way as similar research developing a managerial tool for the first time (e.g., Pigosso et al., 2013). The PF has been validated only in three manufacturing SMEs, with more emphasis on technology-push, where the research took place. Thus, it needs to be validated in distinct manufacturing companies to be generalisable. The merit of the work for this case is that the description of the study can serve as a start as the elements of this proposal are comprehensive in terms of a procedure to apply the PF. Second, innovation research does not stand still, and new approaches can be proposed. Thus, the PF needs to be updated with new PIs and innovation practices from time to time.

7.2 FUTURE RESEARCH

As a consequence of the limitations of the developed PF and the increased understanding of the researcher on the topic, a set of possible directions of future work are presented here in questions to be explored in upcoming research, as follows:

- Is it possible to discern patterns and propose a typology of similar profiles within the diagnosis of the current situation of companies, e.g., groups of ‘proactive’, ‘reactive’, ‘passive’, when applying the PF with all dimensions, or a subset, to a larger number of companies?
- How to compare the innovation capability profile of different companies – is it possible to inform recommendations based on the conclusions and insights for policymakers (e.g., complements to the European innovation scorecard)?
- How might the PF function as an online tool in the context of companies enabling more remote work for parts of their staff? Are the results the same as for face-to-face interactions?
- How long does each improvement cycle of the PF take for the practices to be fully implemented and operational? What are the barriers and enablers to the total duration?
- The experience in the field indicates a certain degree of expertise required for the facilitator role. Is there a subset of PIs on specific dimensions that may not require expertise to be analysed? Is it possible to create a self-diagnosis in those cases?
- What is the role of big data once a more extensive base of case studies is achieved? Could big data also play a role in identifying further indicators to feed the PF (e.g., service performance data for the innovation environment)?
- How to keep the PF up to date considering the increasing proposition and development of innovation practices?
- How to support the use of PF the context of innovation ecosystems (a network of companies and other entities)? What are the changes to be made in the supporting elements of the PF?
- Which are the organisational barriers that must be overcome to implement innovation practices selected in the PF? How to tackle within the PF scope?

- How to ensure that a company with a high-performance level on the innovation process will develop higher innovative performance products?
- How can the PF better support companies in successfully passing the audits of standards (e.g., ISO 56002:2019, and equivalents NP4457)? Could a new certification similar to the ISO be proposed in an innovation ecosystem?
- What other diagnosis tools, beyond interviews and document analysis, could be used to identify the performance levels of the indicators? Are there more suitable tools depending on the current profile of the company?
- What adjustments or adaptations are required in the PF in order to be applied to service-oriented companies (with market-pull strategies)?
- What adjustments are required in the PF in order to be applied to micro and small companies?
- On the other hand, what adjustments are required in the PF in order to be applied to large companies?
- How to support companies in the application of the PF but in the context of eco-innovation? What are the changes to be made in the database elements?
- What is the landscape of the performance level of the companies in specific geographical regions? Are there significant differences to be identified in the distinct divisions of the manufacturing sector?
- Is it possible to apply the PF in companies with a low innovation process formalisation? What adjustments would need to be done?
- What are the critical success factors for the introduction of action plans implementation in manufacturing companies?
- How to support companies in the customisation of the innovation practices selected to be implemented? How to best collect a portfolio of lessons learned of past implementations?
- How to spread the application of the PF across the supply chain? How to deploy the application of the PF among suppliers?
- How can the PF incorporate financial constraints as a managerial lever that hinders/enables innovation?

REFERENCES

- Abbey, A., & Dickson, J. W. (1983). R&D Work climate and innovation in semiconductors. *The Academy of Management Journal*, 26(2), 362–368. Retrieved from <http://www.jstor.org/stable/255984>
- Acur, N., Kandemir, D., & Boer, H. (2012). Strategic alignment and new product development: Drivers and performance effects. *Journal of Product Innovation Management*, 29(2), 304–318. <https://doi.org/10.1111/j.1540-5885.2011.00897.x>
- Adams, R., Bessant, J., & Phelps, R. (2006). Innovation management measurement: a review. *International Journal of Management Reviews*, 8(1), 21–47. <https://doi.org/10.1111/j.1468-2370.2006.00119.x>
- Adriaanse, L. S., & Rensleigh, C. (2013). Web of Science, Scopus and Google Scholar: a content comprehensiveness comparison. *The Electronic Library*, 31(6), 727–744. <https://doi.org/10.1108/EL-12-2011-0174>
- Agostini, L., & Nosella, A. (2017). Enhancing radical innovation performance through intellectual capital components. *Journal of Intellectual Capital*, 18(4), 789–806. <https://doi.org/10.1108/JIC-10-2016-0103>
- Ahlström, P. (2016). The research process. In C. Karlsson (Ed.), *Research Methods for Operations Management* (2nd ed., pp. 46–78). New York: Routledge.
- Akroush, M. N., & Awwad, A. S. (2018). Enablers of NPD financial performance: The roles of NPD capabilities improvement, NPD knowledge sharing and NPD internal learning. *International Journal of Quality & Reliability Management*, 35(1), 163–186. <https://doi.org/10.1108/IJQRM-08-2016-0122>
- Alegre, J., Lapiedra, R., & Chiva, R. (2006). A measurement scale for product innovation performance. *European Journal of Innovation Management*, 9(4), 333–346. <https://doi.org/10.1108/14601060610707812>
- Alegre, J., Sengupta, K., & Lapiedra, R. (2013). Knowledge management and innovation performance in a high-tech SMEs industry. *International Small Business Journal*, 31(4), 454–470. <https://doi.org/10.1177/0266242611417472>
- Alfian, G., Rhee, J., & Yoon, B. (2014). A simulation tool for prioritizing product-service system (PSS) models in a carsharing service. *Computers and Industrial Engineering*, 70(1), 59–73. <https://doi.org/10.1016/j.cie.2014.01.007>
- Amabile, T. M., Conti, R., Coon, H., Lazenby, J., & Herron, M. (1996). Assessing the work environment for creativity. *The Academy of Management Journal*, 39(5), 1154–1184. <https://doi.org/10.2307/256995>
- Amaral, D. C., & Rozenfeld, H. (2007). Integrating new product development process references with maturity and change management models. *International Conference on Engineering Design, ICED'07*, (August), 1–12. Paris.
- Amigo, C. (2013). Modelos de referência para o processo de desenvolvimento de produtos: novas possibilidade de representação. University of São Paulo.
- Amores-Salvadó, J., Martin-de Castro, G., & Navas-López, J. E. (2015). The importance of the

REFERENCES

- complementarity between environmental management systems and environmental innovation capabilities: A firm level approach to environmental and business performance benefits. *Technological Forecasting & Social Change*, 96, 288–297. <https://doi.org/https://doi.org/10.1016/j.techfore.2015.04.004>
- Anderson, A. M. (2008). A framework for NPD management: Doing the right things, doing them right, and measuring the results. *Trends in Food Science and Technology*, 19(11), 553–561. <https://doi.org/10.1016/j.tifs.2008.01.015>
- Anderson, N., & West, M. (1996). The team climate inventory: Development of the TCI and its applications in teambuilding for innovativeness. *European Journal of Work and Organizational Psychology*, 5(1), 53–66. <https://doi.org/10.1080/13594329608414840>
- Ardito, L., Messeni Petruzzelli, A., & Albino, V. (2015). From technological inventions to new products: A systematic review and research agenda of the main enabling factors. *European Management Review*, 12(3), 113–147. <https://doi.org/10.1111/emre.12047>
- Attadia, L. C. D. L., Canevarolo, M. E., & Martins, R. A. (2003). Balanced Scorecard: Uma análise crítica. *XXIII Encontro Nacional de Engenharia de Produção ENEGEP*, 1–8. Outo Preto.
- Atuahene-Gima, K. (1995). An exploratory analysis of the impact of market orientation on new product performance a contingency approach. *Journal of Product Innovation Management*, 12(4), 275–293. [https://doi.org/10.1016/0737-6782\(95\)00027-Q](https://doi.org/10.1016/0737-6782(95)00027-Q)
- Atuahene-Gima, K. (2005). Resolving the capability—rigidity paradox in new product innovation. *Journal of Marketing*, 69(4), 61–83. <https://doi.org/10.1509/jmkg.2005.69.4.61>
- Azzone, G., & Noci, G. (1998). Identifying effective PMSs for the deployment of “green” manufacturing strategies. *International Journal of Operations & Production Management*, 18(4), 308–335. <https://doi.org/10.1108/01443579810199711>
- Bach, J. (1994). The Immaturity of CMM. *The American Programmer*, (September).
- Baines, T., & Lightfoot, H. W. (2013). Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services. *International Journal of Operations & Production Management*, 34(1), 2–35. <https://doi.org/10.1108/IJOPM-02-2012-0086>
- Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., ... Wilson, H. (2007). State-of-the-art in product-service systems. *Journal of Engineering Manufacture*, 221(10), 1543–1552. <https://doi.org/10.1243/09544054JEM858>
- Bantel, K. A., & Jackson, S. E. (1989). Top management and innovation in banking: does the composition of the top management make a difference. *Strategic Management Journal*, 10(Special Issue), 107–124. <https://doi.org/10.1002/smj.4250100709>
- Barczak, G., & Kahn, K. B. (2012). Identifying new product development best practice. *Business Horizons*, 55(3), 293–305. <https://doi.org/10.1016/j.bushor.2012.01.006>
- Barczak, G., Kahn, K. B., & Moss, R. (2006). An exploratory investigation of NPD practices in nonprofit organizations. *Journal of Product Innovation Management*, 23(6), 512–527. <https://doi.org/10.1111/j.1540-5885.2006.00221.x>
- Barquet, A. P. (2015). *Creation of product-service systems (PSS) proposals in the fuzzy front-*

REFERENCES

- end. University of São Paulo.
- Barquet, A. P., Seidel, J., Buchert, T., Galeitzke, M., Neugebauer, S., Oertwig, N., ... Seliger, G. (2016). Sustainable product Service systems - From concept creation to the detailing of a business model for a bicycle sharing system in berlin. *Procedia CIRP* 40, 524–529. <https://doi.org/10.1016/j.procir.2016.01.127>
- Bassani, C., Lazzarotti, V., Manzini, R., Pellegrini, L., & Santomauro, S. (2010). Measuring performance in R&NPD: The case of Whitehead Alenia Sistemi Subacquei – a Finmeccanica company. *European Journal of Innovation Management*, 13(4), 481–506. <https://doi.org/10.1108/14601061011086302>
- Becheikh, N., Landry, R., & Amara, N. (2006). Lessons from innovation empirical studies in the manufacturing sector: A systematic review of the literature from 1993–2003. *Technovation*, 26, 644–664. <https://doi.org/10.1016/j.technovation.2005.06.016>
- Belderbos, R., Carree, M., & Lokshin, B. (2004). Cooperative R&D and firm performance. *Research Policy*, 33(10), 1477–1492. <https://doi.org/10.1016/j.respol.2004.07.003>
- Berg, P., Pihlajamaa, J., Poskela, J., Lempiälä, T., Haner, U., & Mabogunje, A. (2008). Measurement of the innovation front end: Viewpoint of process, social environment and physical environment. *PICMET 2008 Proceedings*, 1112–1120. <https://doi.org/10.1109/PICMET.2008.4599721>
- Berg, P., Pihlajamaa, J., Poskela, J., Lempiälä, T., Haner, U., & Mabogunje, A. (2009). Balanced innovation front end measurement: Discontinuous innovation approach. *PICMET 2009 Proceedings*, 746–753. <https://doi.org/10.1109/PICMET.2009.5262065>
- Beringer, C., Jonas, D., & Kock, A. (2013). Behavior of internal stakeholders in project portfolio management and its impact on success. *International Journal of Project Management*, 31, 830–846. <https://doi.org/10.1016/j.ijproman.2012.11.006>
- Bertrand, J. W. M., & Fransoo, J. C. (2016). Modelling and simulation. In C. Karlsson (Ed.), *Research Methods for Operations Management* (2nd ed., Vol. 19). <https://doi.org/10.4324/9781315671420>
- Biberoglu, E., & Haddad, H. (2002). A survey of industrial experiences with CMM and the teaching of CMM practices. *Journal of Computing Sciences in Colleges*, 18, 143–152.
- Biolchini, J., Mian, P. G., Candida, A., & Natali, C. (2005). Systematic review in software engineering. In *Systems Engineering and Computer Science Department*.
- Birchall, D. W., & Tovstiga, G. (2006). Innovation performance measurement: Expert vs. practitioner views. *PICMET 2006 Proceedings*, 870–883. <https://doi.org/10.1109/PICMET.2006.296620>
- Birkinshaw, J., Hamel, G., & Mol, M. J. (2008). Management innovation. *Academy of Management Review*, 33(4), 825–845. <https://doi.org/10.5465/amr.2008.34421969>
- Bissola, R., Imperatori, B., & Colonel, R. T. (2014). Enhancing the creative performance of new product teams: An organizational configurational approach. *Journal of Product Innovation Management*, 31(2), 375–391. <https://doi.org/10.1111/jpim.12101>
- Bititci, U., Garengo, P., Dörfler, V., & Nudurupati, S. (2012). Performance measurement: Challenges for tomorrow. *International Journal of Management Reviews*, 14(3), 305–327.

REFERENCES

- <https://doi.org/10.1111/j.1468-2370.2011.00318.x>
- Björklund, M., Martinsen, U., & Abrahamsson, M. (2012). Performance measurements in the greening of supply chains. *Supply Chain Management: An International Journal*, 17(1), 29–39. <https://doi.org/10.1108/13598541211212186>
- Blessing, L. T. M., & Chakrabarti, A. (2009). *DRM, a Design Research Methodology* (1st Ed.). London: Springer.
- Boeddrich, H. J. (2004). Ideas in the workplace: A new approach towards organizing the fuzzy front end of the innovation process. *Creativity and Innovation Management*, 13(4), 274–285. <https://doi.org/10.1111/j.0963-1690.2004.00316.x>
- Boly, V., Morel, L., Assielou, N. G., & Camargo, M. (2014). Evaluating innovative processes in french firms: Methodological proposition for firm innovation capacity evaluation. *Research Policy*, 43(3), 608–622. <https://doi.org/10.1016/j.respol.2013.09.005>
- Bose, R. (2004). Knowledge management metrics. *Industrial Management & Data Systems*, 104(6), 457–468. <https://doi.org/10.1108/02635570410543771>
- Boudreau, M. C., Gefen, D., & Straub, D. W. (2001). Validation in information systems research: A state-of-the-art assessment. *MIS Quarterly: Management Information Systems*, 25(1), 1–16. <https://doi.org/10.2307/3250956>
- Bourne, M., Mills, J., Wilcox, M., Neely, A., & Platts, K. (2000). Designing, implementing and updating performance measurement systems. *International Journal of Operations & Production Management*, 20(7), 754–771. <https://doi.org/10.1108/01443570010330739>
- Bourne, M., Neely, A., Mills, J., & Platts, K. (2003). Implementing performance measurement systems: A literature review. *International Journal of Business Performance Management*, 5(1), 1–24.
- Bourne, M., Neely, A., Platts, K., & Mills, J. (2002). The success and failure of performance measurement initiatives: perceptions of participating managers. *International Journal of Operations & Production Management*, 22(11), 1288–1310. <https://doi.org/10.1108/01443570210450329>
- Brattström, A., Frishammar, J., Richtnér, A., & Dane, P. (2018). Can innovation be measured? A framework of how measurement of innovation engages attention in firms. *Journal of Engineering and Technology Management*, 48(April 2017), 64–75. <https://doi.org/10.1016/j.jengtecman.2018.04.003>
- Braz, R. G. F., Scavarda, L. F., & Martins, R. A. (2011). Reviewing and improving performance measurement systems: An action research. *International Journal of Production Economics*, 133(2), 751–760. <https://doi.org/10.1016/j.ijpe.2011.06.003>
- Brem, A., & Voigt, K.-I. (2009). Integration of market pull and technology push in the corporate front end and innovation management — Insights from the German software industry. *Technovation*, 29, 351–367. <https://doi.org/10.1016/j.technovation.2008.06.003>
- Brereton, P., Kitchenham, B. A., Budgen, D., Turner, M., & Khalil, M. (2007). Lessons from applying the systematic literature review process within the software engineering domain. *Journal of Systems and Software*, 80(4), 571–583. <https://doi.org/10.1016/j.jss.2006.07.009>

REFERENCES

- Brignall, T. J., Fitzgerald, L., Johnston, R., & Silvestro, R. (1991). Performance measurement in service businesses. *Management Accounting*, 69(10), 34.
- Brown, T., & Rowe, P. G. (2008). Design thinking. *Harvard Business Review*, 86(6), 252. <https://doi.org/10.5437/08956308X5503003>
- Brown, W. B., & Gobeli, D. (1992). Observations on the measurement of R&D productivity: A case study. *IEEE Transactions on Engineering Management*, 39(4), 325–331. <https://doi.org/10.1109/17.165414>
- Buganza, T., & Verganti, R. (2006). Life-cycle flexibility: How to measure and improve the innovative capability in turbulent environments. *Journal of Product Innovation Management*, 23(5), 393–407. <https://doi.org/10.1111/j.1540-5885.2006.00212.x>
- Burger, T., Ganz, W., Pezzotta, G., Rapaccini, M., & Saccani, N. (2013). Service development for product services: A maturity model and a field research. *Service Industries Journal*, 33(3–4), 300–319. <https://doi.org/10.1080/02642069.2013.747513>
- Caetano, M., & Amaral, D. C. (2011). Roadmapping for technology push and partnership: A contribution for open innovation environments. *Technovation*, 31(7), 320–335. <https://doi.org/10.1016/j.technovation.2011.01.005>
- Cagan, J., & Vogel, C. M. (2008). *Creating breakthrough products: Innovation from product planning to program approval*. New Jersey: FT Prentice Hall.
- Cagnin, C. H., Loveridge, D., & Butler, J. (2005). Business sustainability maturity model. *2005 CRR Conference*, 1–15.
- Carbonell, P., & Rodriguez Escudero, A. I. (2016). The effects of decentralization in strategy-making and national culture on NPD portfolio planning. *Journal of Product Innovation Management*, 33, 101–116. <https://doi.org/10.1111/jpim.12356>
- Cedergren, S., Wall, A., & Norström, C. (2010). Evaluation of performance in a product development context. *Business Horizons*, 53(4), 359–369. <https://doi.org/10.1016/j.bushor.2010.03.001>
- Chang, S., & Ahn, J. (2005). Product and process knowledge in the performance-oriented knowledge management approach. *Journal of Knowledge Management*, 9(4), 114–132. <https://doi.org/10.1108/13673270510610378>
- Chen, Y., Ren, H., Bao, Z., Liu, G., & Ma, H. (2013). Performance evaluation method and algorithm of knowledge management for product innovation design. *International Journal of Online and Biomedical Engineering (IJOE)*, 9(2), 59–62. <https://doi.org/10.3991/ijoe.v9iS2.2604>
- Chesbrough, H. W. (2006). *Open innovation: Researching a new paradigm* (1st ed.). Oxford University Press.
- Chiesa, V., Coughlan, P., & Voss, C. A. (1996). Development of a technical innovation audit. *Journal of Product Innovation Management*, 13, 105–136. [https://doi.org/10.1016/0737-6782\(95\)00109-3](https://doi.org/10.1016/0737-6782(95)00109-3)
- Chiesa, V., Frattini, F., Lazzarotti, V., & Manzini, R. (2004). Measuring performance in new product development projects: a case in the aerospace industry. *Project Management Journal*, 7(3), 47–67. <https://doi.org/10.1002/pmj>

REFERENCES

- Chiesa, V., Frattini, F., Lazzarotti, V., & Manzini, R. (2009). Performance measurement in R&D: Exploring the interplay between measurement objectives, dimensions of performance and contextual factors. *R&D Management*, 39(5), 488–519. <https://doi.org/10.1111/j.1467-9310.2009.00554.x>
- Chiesa, V., & Masella, C. (1996). Searching for an effective measure of R&D performance. *Management Decision*, 34(7), 49–57.
- Chirumalla, K., Bertoni, A., Parida, A., Johansson, C., & Bertoni, M. (2013). Performance measurement framework for product-service systems development: A balanced scorecard approach. *International Journal of Technology Intelligence and Planning*, 9(2), 146. <https://doi.org/10.1504/IJTIP.2013.058135>
- Cho, E., & Lee, M. (2005). An exploratory study on contingency factors affecting R&D performance measurement. *International Journal of Manpower*, 26(6), 502–512. <https://doi.org/https://doi.org/10.1108/01437720510625421>
- Chrissis, M. B., Konrad, M., & Shrum, S. (2003). *CMMI: Guidelines for Process Integration and Product Development* (1st ed.). Addison-Wesley.
- Chung, C. C., Chao, L. C., Chen, C. H., & Lou, S. J. (2016). A balanced scorecard of sustainable management in the Taiwanese bicycle industry: Development of performance indicators and importance analysis. *Sustainability*, 8(6). <https://doi.org/10.3390/su8060518>
- Comoglio, C., & Botta, S. (2012). The use of indicators and the role of environmental management systems for environmental performances improvement: A survey on ISO 14001 certified companies in the automotive sector. *Journal of Cleaner Production*, 20(1), 92–102. <https://doi.org/10.1016/j.jclepro.2011.08.022>
- Cooper, R. G. (2001). *Winning at new products: accelerating the process from idea to launch* (3rd ed.). New York: Basic Books.
- Cooper, R. G. (2006). Managing technology development projects. *Research-Technology Management*, 49(Nov/Dec), 23–31. <https://doi.org/10.1109/EMR.2007.329141>
- Cooper, R. G. (2008). What leading companies are doing to re-invent their NPD processes. *PDMA Visions Magazine*, (September), 6–10. Retrieved from http://www.stage-gate.com/resources_stage-gate_wp34.php
- Cooper, R. G., & Edgett, S. J. (2008). Maximizing productivity in product innovation. *Research-Technology Management*, 51(2), 1–16. <https://doi.org/10.1080/08956308.2008.11657495>
- Cooper, R. G., & Edgett, S. J. (2012). Best practices in the idea-to-launch process and its governance. *Research-Technology Management*, 55(2), 43–54. <https://doi.org/10.5437/08956308X5502022>
- Cooper, R. G., & Edgett, S. J. (2014a). *Benchmarking best practices performance results and the role of senior management*.
- Cooper, R. G., & Edgett, S. J. (2014b). Portfolio management for new products: Picking the winners. In *Product Innovation Best Practices Series*.
- Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (1999). New product portfolio management: Practices and performance. *Journal of Product Innovation Management*, Vol. 16, pp. 333–

REFERENCES

351. <https://doi.org/10.1111/1540-5885.1640333>
- Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (2000). New problems, new solutions: Making portfolio management more effective. *Research-Technology Management*, 43(2), 18–33.
- Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (2004). Benchmarking best NPD practices I: culture, climate, teams, and senior management's. *Research-Technology Management*, 47(3), 50–59. <https://doi.org/10.1080/08956308.2004.11671606>
- Cooper, R. G., & Kleinschmidt, E. J. (1986). An investigation into the new product process: Steps, deficiencies, and impact. *The Journal of Product Innovation Management*, 3(2), 71–85. [https://doi.org/10.1016/0737-6782\(86\)90030-5](https://doi.org/10.1016/0737-6782(86)90030-5)
- Cooper, R. G., & Kleinschmidt, E. J. (1995). Benchmarking the firm's critical success factors in new product development. *Journal of Product Innovation Management*, 12(5), 374–391. [https://doi.org/10.1016/0737-6782\(95\)00059-3](https://doi.org/10.1016/0737-6782(95)00059-3)
- Cooper, R. G., & Kleinschmidt, E. J. (2007). Winning businesses in product development: The critical success factors. *Research-Technology Management*, May-June, 1–15. <https://doi.org/10.1080/08956308.2007.11657441>
- Cordero, R. (1990). The measurement of innovation performance in the firm: An overview. *Research Policy*, 19(2), 185–192. [https://doi.org/10.1016/0048-7333\(90\)90048-B](https://doi.org/10.1016/0048-7333(90)90048-B)
- Cormican, K., & O'Sullivan, D. (2004). Auditing best practice for effective product innovation management. *Technovation*, 24(10), 819–829. [https://doi.org/10.1016/S0166-4972\(03\)00013-0](https://doi.org/10.1016/S0166-4972(03)00013-0)
- Costa, J. M. H. da. (2010). *Método de diagnóstico e identificação de oportunidades de melhoria do processo de desenvolvimento de produtos utilizando um padrão de recorrência de efeitos indesejados*. University of São Paulo.
- Costa, J. M. H. da, Oehmen, J., Rebentisch, E., & Nightingale, D. (2014). Toward a better comprehension of lean metrics for research and product development management. *R&D Management*, 44(4), 370–383. <https://doi.org/10.1111/radm.12074>
- COTEC, & Deloitte. (2018). Innovation scoring. Retrieved March 20, 2020, from <https://www.innovationscoring.pt/>
- Coughlan, P., & Coughlan, D. (2002). Action research for operations management. *International Journal of Operations & Production Management*, 22(2), 220–240. <https://doi.org/10.1108/01443570210417515>
- Covin, J. G., & Slevin, D. P. (1989). Strategic management of small firms in hostile and benign environments. *Strategic Management Journal*, 10(1), 75–87. <https://doi.org/10.1002/smj.4250100107>
- Crawford, C. M. (1985). *New product evaluation: system, not an act* (No. Working Paper No. 427).
- Crawford, C. M., & Di Benedetto, C. A. (2011). *New Products Management* (10th ed.). New York: McGraw-Hill Irwin.
- Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of Management Studies*, 47(6), 1154–1191. <https://doi.org/10.1111/j.1467-6486.2009.00880.x>

REFERENCES

- Cunha, V. P. (2011). *Análise da gestão de ideias de produtos para apoiar o planejamento da inovação*. University of São Paulo.
- Czuchry, A. J., & Yasin, M. M. (2001). Enhancing global competitiveness of small and mid-sized firms: a rapid assessment methodology approach. *Advances in Competitiveness Research*, 9(1), 87–99.
- Damanpour, F. (1991). Organizational innovation: A meta-analysis of effects of determinants and moderators. *Academy of Management Journal*, 34(3), 555–590. <https://doi.org/10.2307/256406>
- Dayan, M., & Di Benedetto, C. A. (2009). Antecedents and consequences of teamwork quality in new product development projects: An empirical investigation. *European Journal of Innovation Management*, 12(1), 129–155. <https://doi.org/10.1108/14601060910928201>
- De Benedetto, L., & Klemeš, J. (2009). The environmental performance strategy map: An integrated LCA approach to support the strategic decision-making process. *Journal of Cleaner Production*, 17(10), 900–906. <https://doi.org/10.1016/j.jclepro.2009.02.012>
- de Brentani, U., Kleinschmidt, E. J., & Salomo, S. (2010). Success in global new product development: Impact of strategy and the behavioral environment of the firm. *Journal of Product Innovation Management*, 27(2), 143–160. <https://doi.org/10.1111/j.1540-5885.2010.00707.x>
- de Bruin, T., Freeze, R., Kaulkarni, U., & Rosemann, M. (2005). Understanding the main phases of developing a maturity assessment model. *ACIS 2005 Proceedings.*, 109. <https://doi.org/http://aisel.aisnet.org/acis2005/109>
- de Castro Rodrigues, K. F., Nappi, V., & Rozenfeld, H. (2014). A proposal to support the value proposition in product oriented service business model of product service systems. *Procedia CIRP*, 16, 211–216. <https://doi.org/10.1016/j.procir.2014.02.009>
- Detzen, N., Verbeeten, F. H. M., Gamm, N., & Möller, K. (2018). Formal controls and team adaptability in new product development projects. *Management Decision*, 56(7), 1541–1558. <https://doi.org/10.1108/MD-07-2017-0692>
- Dewangan, V., & Godse, M. (2014). Towards a holistic enterprise innovation performance measurement system. *Technovation*, 34(9), 536–545. <https://doi.org/10.1016/j.technovation.2014.04.002>
- Driva, H., Pawar, K. ., & Menon, U. (2000). Measuring product development performance in manufacturing organisations. *International Journal of Production Economics*, 63(2), 147–159. [https://doi.org/10.1016/S0925-5273\(99\)00007-9](https://doi.org/10.1016/S0925-5273(99)00007-9)
- Driva, Helen, Pawar, K. S., & Menon, U. (2001). Performance evaluation of new product development from a company perspective. *Integrated Manufacturing Systems*, 12(5), 368–378. <https://doi.org/10.1108/EUM0000000005714>
- Du, S., Yalcinkaya, G., & Bstieler, L. (2016). Sustainability, social media driven open innovation, and new product development performance. *Journal of Product Innovation Management*, 33, 55–71. <https://doi.org/10.1111/jpim.12334>
- Dubiel, A., Durmusoglu, S. S., & Gloeckner, S. (2016). Firm characteristics and NPD program success: The significant influence of global discovery management. *Journal of Product Innovation Management*, 33(S1), 86–100. <https://doi.org/10.1111/jpim.12330>

REFERENCES

- Dul, J., & Hak, T. (2008). *Case study methodology in business research* (1st ed.). Oxford: Else.
- Dzialis, M., & Blind, K. (2018). Innovation indicators throughout the innovation process: An extensive literature analysis. *Technovation*, (February 2017), 1–27. <https://doi.org/10.1016/j.technovation.2018.05.005>
- Ebersberger, B., & Herstad, S. J. (2011). Product innovation and the complementarities of external interfaces. *European Management Review*, 8(3), 117–135. <https://doi.org/10.1111/j.1740-4762.2011.01014.x>
- Edgett, S., & Snow, K. (1996). Benchmarking measures of customer satisfaction, quality and performance for new financial service products. *Journal of Services Marketing*, 10(6), 6–17.
- Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, 50(1), 25–32. <https://doi.org/10.5465/AMJ.2007.24160888>
- Eldred, E. W., & Mcgrath, M. E. (1997). Commercializing new technology — I. *Research Technology Management*, 40(1), 41–47. <https://doi.org/10.1080/08956308.1997.11671102>
- Eling, K., Griffin, A., & Langerak, F. (2016). Consistency matters in formally selecting incremental and radical new product ideas for advancement. *Journal of Product Innovation Management*, 33(S1), 20–33. <https://doi.org/10.1111/jpim.12320>
- Enkel, E., Bell, J., & Hogenkamp, H. (2011). Open innovation maturity framework. *International Journal of Innovation Management*, 15(06), 1161–1189. <https://doi.org/10.1142/S1363919611003696>
- Erkens, M., Wosch, S., Piller, F., & Lüttgens, D. Measuring open innovation: A toolkit for successful innovation teams. , 6 Performance by EY 12–23 (2014).
- EU. (2016). *Innovation performance compared: How innovative is your country?* Brussels, Belgium.
- Farris, J. A., Van Aken, E. M., Letens, G., Ellis, K. P., & Boyland, J. (2007). A structured approach for assessing the effectiveness of engineering design tools in new product development. *Engineering Management Journal*, 19(2), 31–39. <https://doi.org/10.1080/10429247.2007.11431729>
- Folan, P., & Browne, J. (2005). A review of performance measurement: Towards performance management. *Computers in Industry*, 56(7), 663–680. <https://doi.org/10.1016/j.compind.2005.03.001>
- Franco-Santos, M., Kennerley, M., Micheli, P., Martizez, V., Mason, S., Marr, B., ... Neely, A. (2007). Towards a definition of a business performance measurement system. *International Journal of Operations & Production Management*, 27(8), 784–801. <https://doi.org/10.1108/01443570710763778>
- Funk, M., Rozinat, A., & Alves De Medeiros, A. K. (2009). Improving product usage monitoring and analysis with semantic concepts. *UNISCON 2009*, 109–121.
- Gallego-Álvarez, I., Manuel Prado-Lorenzo, J., & García-Sánchez, I. (2011). Corporate social responsibility and innovation: a resource-based theory. *Management Decision*, 49(10),

REFERENCES

- 1709–1727. <https://doi.org/10.1108/00251741111183843>
- García-Zamora, E., González-Benito, óscar, & Muñoz-Gallego, P. A. (2013). Organizational and environmental factors as moderators of the relationship between multidimensional innovation and performance. *Innovation: Management, Policy and Practice*, 15(2), 224–244. <https://doi.org/10.5172/impp.2013.15.2.224>
- Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *The Journal of Product Innovation Management*, 19, 110–132.
- Geisler, E. (1995). An integrated cost-performance model of research and development evaluation. *Omega*, 23(3), 281–294. [https://doi.org/10.1016/0305-0483\(95\)00006-A](https://doi.org/10.1016/0305-0483(95)00006-A)
- Geissdoerfer, M., Bocken, N. M. P., & Hultink, E. J. (2016). Design thinking to enhance the sustainable business modelling process – A workshop based on a value mapping process. *Journal of Cleaner Production*, 135, 1218–1232. <https://doi.org/10.1016/j.jclepro.2016.07.020>
- Gerlach, S., & Brem, A. (2017). Idea management revisited: A review of the literature and guide for implementation. *International Journal of Innovation Studies*, 1(2), 144–161. <https://doi.org/10.1016/j.ijis.2017.10.004>
- Gill, J., & Johnson, P. (2002). *Research methods for managers* (Third Edit). Kent: SAGE Publications Ltd.
- Gillon, A. C. (2018). *The Nature of Contemporary Organization Development* (1st ed.). Routledge.
- Globerson, S. (1985). Issues in developing a performance criteria system for an organization. *International Journal of Production Research*, 23(4), 639–646. <https://doi.org/10.1080/00207548508904734>
- Gonzalez, R. V. D., & Martins, M. F. (2017). Knowledge management process: A theoretical-conceptual research. *Gestão & Produção*, 24(2), 248–265. <https://doi.org/10.1590/0104-530x0893-15>
- Griffin, A., & Page, A. L. (1993). An interim report on measuring product development success and failure. *Journal of Product Innovation Management*, Vol. 10, pp. 291–308.
- Guelere Filho, A., Pigosso, D. C. A., & Rozenfeld, H. (2009). Remanufacturing on a framework for product life-cycle management (PLM) in the context of product-service systems (PSS). *CIRP IPS2 Conference 2009 Industrial Product-Service Systems*.
- Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods*, 18(1), 59–82. <https://doi.org/10.1177/1525822X05279903>
- Guimarães, J. C. F. de, Severo, E. A., Dorion, E. C. H., Coallier, F., & Olea, P. M. (2016). The use of organisational resources for product innovation and organisational performance: A survey of the Brazilian furniture industry. *International Journal of Production Economics*, 180, 135–147. <https://doi.org/10.1016/j.ijpe.2016.07.018>
- Gulledge, T., & Chavusholu, T. (2008). Automating the construction of supply chain key performance indicators. *Industrial Management & Data Systems*, 108(6), 750–774.

REFERENCES

- <https://doi.org/10.1108/02635570810883996>
- Gurtner, S., & Reinhardt, R. (2016). Ambidextrous idea generation-antecedents and outcomes. *Journal of Product Innovation Management*, 33(S1), 34–54. <https://doi.org/10.1111/jpim.12353>
- Hald, K. S., & Mouritsen, J. (2018). The evolution of performance measurement systems in a supply chain: A longitudinal case study on the role of interorganisational factors. *International Journal of Production Economics*, 205, 256–271. <https://doi.org/10.1016/j.ijpe.2018.09.021>
- Hall, B. H. (2010). Open innovation & intellectual property rights: The two-edged sword. *Japan Spotlight*, (January), 1–5. <https://doi.org/10.1038/nbt1205-1485>
- Hall, D. L., & Nauda, A. (1990). An interactive approach for selecting IR&D projects. *IEEE Transactions on Engineering Management*, 37(2), 126–133. <https://doi.org/10.1109/17.53715>
- Hall, J., & Wagner, M. (2012). Integrating sustainability into firms' processes: Performance effects and the moderating role of business models and innovation. *Business Strategy and the Environment*, 21(3), 183–196. <https://doi.org/10.1002/bse.728>
- Hammer, M. (2007). The Process Audit. *Harvard Business Review*, 85(4), 111–123.
- Haner, U.-E. (2005). Spaces for creativity and innovation in two established organizations. *Creativity and Innovation Management*, 14(3), 288–298. <https://doi.org/10.1111/j.1476-8691.2005.00347.x>
- Hanson, J. D., Melnyk, S. a., & Calantone, R. a. (2011). Defining and measuring alignment in performance management. *International Journal of Operations & Production Management*, 31(10), 1089–1114. <https://doi.org/10.1108/01443571111172444>
- Hart, S., Hultink, E. J., Tzokas, N., & Commandeur, H. R. (2003). Industrial companies' evaluation criteria in new product development gates. *Journal of Product Innovation Management*, 20, 22–36. <https://doi.org/10.1111/1540-5885.201003>
- Healy, B., Ledwith, A., & O'Dwyer, M. (2014). Perceptions of product advantage, NPD and organisational performance. *Journal of Small Business and Enterprise Development*, 21(1), 49–68. <https://doi.org/10.1108/JSBED-05-2013-0078>
- Hegde, V., & Konakanchi, K. (2011). Case study - Post market product monitoring system. *2011 Proceedings - Annual Reliability and Maintainability Symposium*, 1–4.
- Henttonen, K., Ojanen, V., & Puumalainen, K. (2016). Searching for appropriate performance measures for innovation and development projects. *R&D Management*, 46(5), 914–927. <https://doi.org/10.1111/radm.12178>
- Herbsleb, J. D., & Goldenson, D. R. (1996). Systematic survey of CMM experience and results. *Proceedings - International Conference on Software Engineering*, 323–330. <https://doi.org/10.1109/ICSE.1996.493427>
- Hertenstein, J. H., & Platt, M. B. (2000). Performance measures and management control in new product development. *Accounting Horizons*, 14(3), 303–323.
- Howell, J. M., & Shea, C. M. (2006). Effects of champion behavior, team potency, and external communication activities on predicting team performance. *Group and Organization*

REFERENCES

- Management*, 31(2), 180–211. <https://doi.org/10.1177/1059601104273067>
- Howell, J. M., Shea, C. M., & Higgins, C. A. (2005). Champions of product innovations: Defining, developing, and validating a measure of champion behavior. *Journal of Business Venturing*, 20(5), 641–661. <https://doi.org/10.1016/j.jbusvent.2004.06.001>
- Hudson Smith, M., & Smith, D. (2007). Implementing strategically aligned performance measurement in small firms. *International Journal of Production Economics*, 106(2), 393–408. <https://doi.org/10.1016/j.ijpe.2006.07.011>
- Hung, K. P., & Chou, C. (2013). The impact of open innovation on firm performance: The moderating effects of internal R&D and environmental turbulence. *Technovation*, 33(10–11), 368–380. <https://doi.org/10.1016/j.technovation.2013.06.006>
- Inauen, M., & Andrea Schenker-Wicki. (2011). The impact of outside-in open innovation on innovation performance. *European Journal of Marketing*, 14(4), 496–520. <https://doi.org/10.1108/EL-01-2014-0022>
- Issa, I. I., Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2015). Leading product-related environmental performance indicators: A selection guide and database. *Journal of Cleaner Production*, 108, 321–330. <https://doi.org/10.1016/j.jclepro.2015.06.088>
- Ivanov, C.-I., & Avasilcăi, S. (2014). Measuring the performance of innovation processes: A Balanced Scorecard perspective. *Procedia - Social and Behavioral Sciences*, 109, 1190–1193. <https://doi.org/10.1016/j.sbspro.2013.12.610>
- Iversen, J., Nielsen, P. A., & Norbjerg, J. (1999). Situated assessment of problems in software development. *ACM SIGMIS Database*, 30(2), 66–81. <https://doi.org/10.1145/383371.383376>
- James, L. R., Demaree, R. G., & Wolf, G. (1984). Estimating within-group interrater reliability with and without response bias. *Journal of Applied Psychology*, 69(1), 85–98. <https://doi.org/10.1037/0021-9010.69.1.85>
- Jassawalla, A. R., & Sashittal, H. C. (1999). Building collaborative cross-functional new product teams. *Academy of Management Executive*, 13(3), 50–63. <https://doi.org/https://doi.org/10.5465/ame.1999.2210314>
- Jayaram, J., & Narasimhan, R. (2007). The influence of new product development competitive capabilities on project performance. *IEEE Transactions on Engineering Management*, 54(2), 241–256. <https://doi.org/10.1109/TEM.2007.893992>
- Jeston, J., & Nelis, J. (2006). *Business process management: Practical guidelines to successful implementations*. Oxford: Butterworth-Heinemann.
- Junko Kaji, Hurley, B., Gangopadhyay, N., Bhat, R., & Khan, A. (2019). Deloitte Insights: Global Human Capital Trends 2019. In *Deloitte University Press*.
- Kahn, K. B., Barczak, G., & Moss, R. (2006). Perspective: Establishing an NPD best practices framework. *Journal of Product Innovation Management*, 23(2), 106–116. <https://doi.org/10.1111/j.1540-5885.2006.00186.x>
- Kahn, K. B., Barczak, G., Nicholas, J., Ledwith, A., & Perks, H. (2012). An examination of new product development best practice. *Journal of Product Innovation Management*, 29(2), 180–192. <https://doi.org/10.1111/j.1540-5885.2011.00888.x>

REFERENCES

- Kankanhalli, A., & Tan, B. C. Y. (2005). Knowledge management metrics: A review and directions for future research. *International Journal of Knowledge Management (IJKM)*, 1(2), 20–32. <https://doi.org/10.4018/jkm.2005040103>
- Kaplan, R. S., & Norton, D. P. (1992). The Balanced Scorecard – Measures that drive performance. *Harvard Business Review*, (January–February), 71–79. <https://doi.org/10.1017/CBO9781107415324.004>
- Kaplan, R. S., & Norton, D. P. (2007). Using the balanced scorecard as a strategic management system. *Harvard Business Review*, (July–August). <https://doi.org/10.1108/10878570410699825>
- Karlsson, C. (2016). Research in operations management. In C. Karlsson (Ed.), *Research Methods for Operations Management* (Second Edi). New York: Routledge.
- Keller, R. T. (1986). Predictors of the performance of project groups in R&D. *The Academy of Management Journal*, 29(4), 715–726.
- Keller, R. T. (2001). Cross-functional project groups in research and new product development: Diversity, communications, job stress, and outcomes. *The Academy of Management Journal*, 44(3), 547–555.
- Kennerley, M., & Neely, A. (2002). A framework of the factors affecting the evolution of performance measurement systems. *International Journal of Operations & Production Management*, 22(11), 1222–1245. <https://doi.org/10.1108/01443570210450293>
- Kerssens-van Drongelen, I. C., & Bilderbeek, J. (1999). R&D performance measurement: More than choosing a set of metrics. *R and D Management*, 29(1), 35–46. <https://doi.org/10.1111/1467-9310.00115>
- Kerssens-van Drongelen, I. C., & Cook, A. (1997). Design principles for the development of measurement systems for research and development processes. *R&D Management*, 27(4), 345–357. <https://doi.org/10.1111/1467-9310.00070>
- Kerssens-van Drongelen, I. C., Nixon, B., & Pearson, A. (2000). Performance measurement in industrial R&D. *International Journal of Management Reviews*, 2(2), 111–143. <https://doi.org/10.1111/1468-2370.00034>
- Kessler, E. H., & Chakrabarti, A. K. (1996). Innovation speed: A conceptual model of context, antecedents, and outcomes. *The Academy of Management Review*, 21(4), 1143–1191.
- Kester, L., Hultink, E. J., & Griffin, A. (2014). An empirical investigation of the antecedents and outcomes of NPD portfolio success. *Journal of Product Innovation Management*, 31(6), 1199–1213. <https://doi.org/10.1111/jpim.12183>
- Khurana, A., & Rosenthal, S. R. (1997). Integrating the fuzzy front end of new product development. *Sloan Management Review*, (Winter).
- Killen, C. P., & Hunt, R. A. (2013). Robust project portfolio management: Capability evolution and maturity. *International Journal of Managing Projects in Business*, 6(1), 131–151. <https://doi.org/10.1108/17538370810883819>
- Killen, C. P., Hunt, R. A., & Kleinschmidt, E. J. (2008). Project portfolio management for product innovation. *International Journal of Quality & Reliability Management*, 25(1), 24–38. <https://doi.org/10.1108/02656710810843559>

REFERENCES

- Kivimäki, M., Lämsäsalmi, H., Elovainio, M., Heikkilä, A., Lindström, K., Harisalo, R., ... Puolimatka, L. (2000). Communication as a determinant of organizational innovation. *R&D Management*, 30(1), 33–42. <https://doi.org/10.1111/1467-9310.00155>
- Kleinknecht, A. (1987). Measuring R&D in small firms: How much are we missing? *The Journal of Industrial Economics*, 36(2), 253–256.
- Klimkó, G. (2001). Knowledge management and maturity models: Building common understanding. *Second European Conference on Knowledge Management*.
- Koen, P., Ajamian, G., Burkart, R., Clamen, A., Davidson, J., D'Amore, R., ... Wagner, K. (2001). Providing clarity and a common language to the “fuzzy front end.” *Research-Technology Management*, 44(2), 46–55. <https://doi.org/10.1080/08956308.2001.11671418>
- Kohlegger, M., Maier, R., & Thalmann, S. (2009). Understanding maturity models results of a structured content analysis. *Proceedings of IKNOW '09 and ISEMANTICS '09*, (September), 51–61. <https://doi.org/hdl:10419/44444> [Handle]
- Kress, G. L., & Schar, M. (2012). Applied teamology: The impact of cognitive style diversity on problem reframing and product redesign within design teams. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research: Understanding innovation* (p. 302). https://doi.org/DOI.10.1007/978-3-642-31991-4_8
- Kühnen, M., & Hahn, R. (2017). Indicators in social life cycle assessment: A review of frameworks, theories, and empirical experience. *Journal of Industrial Ecology*, 21(6), 1547–1565. <https://doi.org/10.1111/jiec.12663>
- Lakiza, V., & Deschamps, I. (2019). How to develop an impactful action research program: Insights and lessons from a case study. *Technology Innovation Management Review*, 9(5), 34–43. <https://doi.org/10.22215/timreview/1239>
- Lakiza, V., Deschamps, I., & Cameron, W. B. (2018). How to develop innovation KPIs in an execution-oriented company. *Technology Innovation Management Review*, 8(7), 14–31. <https://doi.org/http://doi.org/10.22215/timreview/1168>
- Lau, H. C. W., Hui, I. K., Chan, F. T. S., & Wong, C. W. Y. (2002). Monitoring the supply of products in a supply chain environment: A fuzzy neural approach. *The Fourth International Conference on Electronic Business (ICEB2004)*, 1162–1166. Beijing.
- Lazzarotti, V., Manzini, R., & Mari, L. (2011). A model for R&D performance measurement. *International Journal of Production Economics*, 134(1), 212–223. <https://doi.org/10.1016/j.ijpe.2011.06.018>
- Lee, H., & Markham, S. K. (2016). PDMA Comparative performance assessment study (CPAS): Methods and future research directions. *Journal of Product Innovation Management*, 33(S1), 3–19. <https://doi.org/10.1111/jpim.12358>
- Leten, B., Belderbos, R., & Looy, B. Van. (2007). Technological diversification, coherence, and performance of firms. *Journal of Product Innovation Management*, 24, 567–579.
- Lettice, F., Roth, N., & Forstenlechner, I. (2006). Measuring knowledge in the new product development process. *International Journal of Productivity and Performance Management*, 55(3/4), 217–241. <https://doi.org/10.1108/17410400610653200>
- Leydesdorff, L., Carley, S., & Rafols, I. (2013). Global maps of science based on the new Web-

REFERENCES

- of-Science categories. *Scientometrics*, 94(2), 589–593. <https://doi.org/10.1007/s11192-012-0784-8>
- Lilien, G. L., Morrison, P. D., Searls, K., Sonnack, M., & Hippel, E. Von. (2002). Performance assessment of the lead user idea-generation process for new product development. *Journal of the Academy of Marketing Science*, 48(July 2014), 1042–1059. <https://doi.org/https://doi.org/10.1287/mnsc.48.8.1042.171>
- Lim, C. H., Kim, K. J., Hong, Y. S., & Park, K. (2012). PSS Board: A structured tool for product-service system process visualization. *Journal of Cleaner Production*, 37, 42–53. <https://doi.org/10.1016/j.jclepro.2012.06.006>
- Linton, J. D., & Thongpapanl, N. (Tek). (2004). Perspective: Ranking the technology innovation management journals. *Journal of Product Innovation Management*, (21), 123–139.
- Loch, C. H., & Tapper, U. A. S. (2002). Implementing a strategy-driven performance measurement system for an applied research group. *Journal of Product Innovation Management*, 19(3), 185–198. [https://doi.org/10.1016/S0737-6782\(02\)00136-4](https://doi.org/10.1016/S0737-6782(02)00136-4)
- Loch, C., Stein, L., & Terwiesch, C. (1996). Measuring development performance in the electronics industry. *Electronics Industry*, 6782(95), 3–20.
- Lopez-Valeiras, E., Gonzalez-Sanchez, M. B., & Gomez-Conde, J. (2016). The effects of the interactive use of management control systems on process and organizational innovation. *Review of Managerial Science*, 10(3), 487–510. <https://doi.org/10.1007/s11846-015-0165-9>
- Lovallo, D., & Sibony, O. (2010). The case for behavioral strategy. *McKinsey Quarterly*, (30–34).
- Maestrini, V., Luzzini, D., Shani, A. B., & Canterino, F. (2016). The action research cycle reloaded: Conducting action research across buyer-supplier relationships. *Journal of Purchasing and Supply Management*, 22(4), 289–298. <https://doi.org/10.1016/j.pursup.2016.06.002>
- Maier, A. M., Moultrie, J., & Clarkson, P. J. (2012). Assessing organizational capabilities: Reviewing and guiding the development of maturity grids. *IEEE Transactions on Engineering Management*, 59(1), 138–159. Retrieved from https://www.wiso-net.de/document/ECON__687937566
- Manzini, E., & Vezzoli, C. (2003). A strategic design approach to develop sustainable product service systems: Examples taken from the “environmentally friendly innovation” Italian prize. *Journal of Cleaner Production*, 11(8 SPEC.), 851–857. [https://doi.org/10.1016/S0959-6526\(02\)00153-1](https://doi.org/10.1016/S0959-6526(02)00153-1)
- Maravelakis, E., Bilalis, N., Antoniadis, A., Jones, K. A., & Moustakis, V. (2006). Measuring and benchmarking the innovativeness of SMEs: A three-dimensional fuzzy logic approach. *Production Planning and Control*, 17(3), 283–292. <https://doi.org/10.1080/09537280500285532>
- Markham, S. K., & Lee, H. (2013). Product development and management association’s 2012 comparative performance assessment study. *Journal of Product Innovation Management*, 30(3), 408–429. <https://doi.org/10.1111/jpim.12025>
- Markham, S. K., Ward, S. J., Aiman-Smith, L., & Kingon, A. I. (2010). The valley of death as context for role theory in product innovation. *Journal of Product Innovation Management*,

REFERENCES

- 27(3), 402–417. <https://doi.org/10.1111/j.1540-5885.2010.00724.x>
- Martins, R. A. (1999). *Sistemas de Medição de Desempenho: Um Modelo para Estruturação do Uso*. University of São Paulo.
- Martinsuo, M., & Poskela, J. (2011). Use of evaluation criteria and innovation performance in the front end of innovation. *Journal of Product Innovation Management*, 28(6), 896–914. <https://doi.org/10.1111/j.1540-5885.2011.00844.x>
- Mazur, K. (2017). Methodological aspects of innovation performance measurement in the IT sector. *Management*, 21(2), 14–27. <https://doi.org/10.1515/manment-2017-0002>
- McCarthy, I. P., & Gordon, B. R. (2011). Achieving contextual ambidexterity in R&D organizations: A management control system approach. *R&D Management*, 41(3), 240–258.
- Medini, K., & Boucher, X. (2016). Configuration of Product-Service Systems value networks - Evidence from an innovative sector for sludge treatment. *CIRP Journal of Manufacturing Science and Technology*, 12, 14–24. <https://doi.org/10.1016/j.cirpj.2015.10.003>
- Medori, D., & Steeple, D. (2000). A framework for auditing and enhancing performance measurement systems. *International Journal of Operations & Production Management*, 20(5), 520–533. <https://doi.org/10.1108/01443570010318896>
- Melnyk, S. A., Hanson, J. D., & Calantone, R. J. (2010). Hitting the target...but missing the point: Resolving the paradox of strategic transition. *Long Range Planning*, 43(4), 555–574. <https://doi.org/10.1016/j.lrp.2009.11.004>
- Meredith, J. R., Raturi, A., Amoako-Gyampah, K., & Kaplan, B. (1989). Alternative research paradigms in operations. *Journal of Operations Management*, 8(4), 297–326. [https://doi.org/10.1016/0272-6963\(89\)90033-8](https://doi.org/10.1016/0272-6963(89)90033-8)
- Mettänen, P. (2005). Design and implementation of a performance measurement system for a research organization. *Production Planning & Control*, 16(2), 178–188. <https://doi.org/10.1080/09537280512331333075>
- Miles, R. E., & Snow, C. C. (2003). *Organizational Strategy, Structure, and Process* (21st ed.). Stanford University Press.
- Morgan, D. L. (1997). *The focus group as qualitative research* (2nd, Ed.). London: SAGE Publications.
- Morisawa, T. (2002). *Building performance measurement systems with the balanced scorecard approach*.
- Morse, J. M. (2000). Determining sample size. *Qualitative Health Research*, 10(1), 3–5. <https://doi.org/10.1177/104973200129118183>
- Mourtzis, D., Boli, N., & Fotia, S. (2017). Knowledge-based estimation of maintenance time for complex engineered-to-order products based on KPIs monitoring: A PSS approach. *Procedia CIRP*, 63, 236–241. <https://doi.org/10.1016/j.procir.2017.03.317>
- Mourtzis, Dimitris, Fotia, S., & Doukas, M. (2015). Performance indicators for the evaluation of product-service systems design: A Review. *IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2015, Tokyo, Japan. IFIP Advances in Information and Communication Technology, AICT-460 (Part II)*, 460, 592–601.

REFERENCES

- Nappi, M. M. L., Nappi, V., & Souza, J. C. (2019). Multi-criteria decision model for the selection and location of temporary shelters in disaster management. *Journal of International Humanitarian Action*, 4(1), 16. <https://doi.org/10.1186/s41018-019-0061-z>
- Narayana, M. G. P. L. (2005). A framework approach to measure innovation maturity. *IEEE International Engineering Management Conference*, II, 765–769. <https://doi.org/10.1109/IEMC.2005.1559252>
- Neely, A. (2005). The evolution of performance measurement research: Developments in the last decade and a research agenda for the next. *International Journal of Operations & Production Management*, 25(12), 1264–1277. <https://doi.org/10.1108/01443570510633648>
- Neely, A. (2007). The servitization of manufacturing: An analysis of global trends. *14th European Operations Management Association Conference, Ankara, Turkey.*, 1–10. <https://doi.org/10.1007/s12063-009-0015-5>
- Neely, A., Bourne, M., Mills, J., Platts, K., & Richards, H. (2002). *Strategy and performance: Getting the measure of your business* (1st ed.). Cambridge: Cambridge University Press.
- Neely, A., Gregory, M., & Platts, K. (1995). A literature review and research agenda. *International Journal of Operations & Production Management*, 15(4), 80–116. <https://doi.org/https://doi.org/10.1108/01443579510083622>
- Neely, A., Richards, H., Mills, J., & Platts, K. (1997). Designing performance measures: A structured approach. *International Journal of Operations & Production Management*, 17(11), 1131–1152.
- Nilsson, S., & Ritzén, S. (2014). Exploring the use of innovation performance measurement to build innovation capability in a medical device company. *Creativity and Innovation Management*, 23(2), 183–198. <https://doi.org/10.1111/caim.12054>
- Nishikawa, H., Schreier, M., & Ogawa, S. (2013). User-generated versus designer-generated products: A performance assessment at Muji. *International Journal of Research in Marketing*, 30(2), 160–167. <https://doi.org/10.1016/j.ijresmar.2012.09.002>
- Niven, P. R. (2006). *Balanced scorecard step-by-step: Maximizing performance and maintaining results* (Second). New Jersey: Wiley.
- Nobelius, D., & Trygg, L. (2002). Stop chasing the front end process — Management of the early phases in product development projects. *International Journal of Project Management*, 20, 331–340. [https://doi.org/10.1016/S0263-7863\(01\)00030-8](https://doi.org/10.1016/S0263-7863(01)00030-8)
- Nudurupati, S. S., Bititci, U. S., Kumar, V., & Chan, F. T. S. (2011a). State of the art literature review on performance measurement. *Computers and Industrial Engineering*, 60(2), 279–290. <https://doi.org/10.1016/j.cie.2010.11.010>
- Nudurupati, S. S., Bititci, U. S., Kumar, V., & Chan, F. T. S. (2011b). State of the art literature review on performance measurement. *Computers & Industrial Engineering*, 60(2), 279–290. <https://doi.org/10.1016/j.cie.2010.11.010>
- O'Dwyer, M., & Ledwith, A. (2010). Size matters: Market orientation and NPD in small and large firms. *International Journal of Product Development*, 12(2), 107. <https://doi.org/10.1504/IJPD.2010.034991>

REFERENCES

- OECD. (2002). *Frascati Manual: Proposed standard practice for surveys on research and experimental development*. Paris.
- OECD. (2005). Oslo Manual: Guidelines for collecting and interpreting innovation data. In *OECD/European Communities* (3rd ed.). Paris.
- OECD. (2011). *OECD Science, Technology and Industry Scoreboard 2011*. <https://doi.org/http://dx.doi.org/10.1787/888932484797> OECD
- OECD. (2017). *Entrepreneurship at a Glance 2017*. https://doi.org/10.1787/entrepreneur_aag-2017-en
- Oliveira, M. G., Phaal, R., Probert, D., Cunha, V. P., & Rozenfeld, H. (2011). A starting point for addressing product innovativeness in the Fuzzy Front-End. *International Journal of Technology Intelligence and Planning*, 7(4), 309. <https://doi.org/10.1504/IJTIP.2011.045092>
- Osterwalder, A., & Pigneur, Y. (2005). Clarifying business models: Origins, present, and future of the concept. *Communications of the Association for Information Systems*, 15(May), 1–125. <https://doi.org/10.1.1.83.7452>
- Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.-H. (2007). *Engineering design: A systematic approach* (Third ed.). London: Springer-Verlag.
- Pan, J.-N., & Nguyen, H. T. N. (2015). Achieving customer satisfaction through product-service systems. *European Journal of Operational Research*, 247(1), 179–190. <https://doi.org/10.1016/j.ejor.2015.05.018>
- Panizzolo, R., Biazzo, S., & Garengo, P. (2010). New product development assessment: Towards a normative-contingent audit. *Benchmarking: An International Journal*, 17(2), 173–194. <https://doi.org/10.1108/14635771011036294>
- Parthasarthy, R., & Hammond, J. (2002). Product innovation input and outcome: Moderating effects of the innovation process. *Journal of Engineering and Technology Management*, 19(1), 75–91. [https://doi.org/10.1016/S0923-4748\(01\)00047-9](https://doi.org/10.1016/S0923-4748(01)00047-9)
- Pattikawa, L. H., Verwaal, E., & Commandeur, H. R. (2006). Understanding new product project performance. *European Journal of Marketing*, 40(11/12), 1178–1193. <https://doi.org/https://doi.org/10.1108/03090560610702768>
- Pavitt, K. (1990). What we know about the strategic management of technology. *California Management Review*, 32(3), 17–26. <https://doi.org/10.2307/41166614>
- Pawar, K. S., & Driva, H. (1999). Performance measurement for product design and development in a manufacturing environment. *International Journal of Production Economics*, 60–61, 61–68. [https://doi.org/10.1016/S0925-5273\(98\)00195-9](https://doi.org/10.1016/S0925-5273(98)00195-9)
- Pearson, a W., Nixon, W. a, & Kerssens-van Drongelen, I. C. (2000). R&D as a business - What are the implications for performance measurement? *R & D Management*, 30(4), 355–366. <https://doi.org/10.1111/1467-9310.00190>
- Pfeffer, J., & Sutton, R. (1999). Knowing “What” to do is not enough: Turning knowledge into action. *California Management Review*, 42(I).
- Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2006). Technology management tools: Concept, development and application. *Technovation*, 26(3), 336–344.

REFERENCES

- <https://doi.org/10.1016/j.technovation.2005.02.001>
- Pigosso, D. C. A. (2012). Ecodesign maturity model: A framework to support companies in the selection and implementation of ecodesign practices (University of São Paulo). <https://doi.org/10.1017/CBO9781107415324.004>
- Pigosso, D. C. A., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. *Journal of Cleaner Production*, 59, 160–173. <https://doi.org/10.1016/j.jclepro.2013.06.040>
- Pillai, A. S., Joshi, A., & Rao, K. S. (2002). Performance measurement of R&D projects in a multi-project, concurrent engineering environment. *International Journal of Project Management*, 20(2), 165–177. [https://doi.org/10.1016/S0263-7863\(00\)00056-9](https://doi.org/10.1016/S0263-7863(00)00056-9)
- PMI. (2008). Organizational project management maturity model (OPM3®). In *Book* (2nd ed.). Atlanta: Project Management Institute, Inc.
- Post, C. (2012). Deep-level team composition and innovation: The mediating roles of psychological safety and cooperative learning. *Group & Organization Management*, 37(5), 555–588. <https://doi.org/10.1177/1059601112456289>
- Prajogo, D. I., & Ahmed, P. K. (2006). Relationships between innovation stimulus, innovation capacity, and innovation performance. *R&D Management*, 36(5), 499–515.
- Prajogo, D. I., & McDermott, C. M. (2011). The relationship between multidimensional organizational culture and performance. *European Journal of Marketing*, 31(7), 712–735. <https://doi.org/10.1108/EL-01-2014-0022>
- Prajogo, D. I., & Sohal, A. S. (2006). The integration of TQM and technology/R&D management in determining quality and innovation performance. *Omega*, 34(3), 296–312. <https://doi.org/10.1016/j.omega.2004.11.004>
- Prencipe, A., & Tell, F. (2001). Inter-project learning: Processes and outcomes of knowledge codification in project-based firms. *Research Policy*, 30(9), 1373–1394. [https://doi.org/10.1016/S0048-7333\(01\)00157-3](https://doi.org/10.1016/S0048-7333(01)00157-3)
- Ramon, N. (2017). *Um modelo de referência para a maturidade da Capabilidade de inovação em micro e pequenas empresas de baixa tecnologia*. Universidade Federal do Rio de Janeiro.
- Rantala, T., & Ukko, J. (2018). Performance measurement in university–industry innovation networks: implementation practices and challenges of industrial organisations. *Journal of Education and Work*, 31(3), 247–261. <https://doi.org/10.1080/13639080.2018.1460655>
- Ravelomanantsoa, M. S., Ducq, Y., & Vallespir, B. (2019). A state of the art and comparison of approaches for performance measurement systems definition and design. *International Journal of Production Research*, 57(15–16), 5026–5046. <https://doi.org/10.1080/00207543.2018.1506178>
- Reid, S. E., & de Brentani, U. (2010). Market vision and market visioning competence: Impact on early performance for radically new, high-tech products. *Journal of Innovation Management*, 27, 500–518. <https://doi.org/https://doi.org/10.1111/j.1540-5885.2010.00732.x>

REFERENCES

- Ringel, M., Zablit, H., Grassl, F., Manly, J., & M, C. (2018). *The most innovative companies 2018: Innovators go all in on digital*. Boston.
- Rodrigues, V. P., Pigosso, D. C. A., & McAlloone, T. C. (2017). Measuring the implementation of ecodesign management practices: A review and consolidation of process-oriented performance indicators. *Journal of Cleaner Production*, 156, 293–309. <https://doi.org/10.1016/j.jclepro.2017.04.049>
- Rodríguez, N. G., Pérez, M. J. S., & Gutiérrez, J. A. T. (2008). Can a good organizational climate compensate for a lack of top management commitment to new product development? *Journal of Business Research*, 61(2), 118–131. <https://doi.org/10.1016/j.jbusres.2007.06.011>
- Rogers, H., Ghauri, P., & Pawar, K. S. (2005). Measuring international NPD projects: An evaluation process. *Journal of Business & Industrial Marketing*, 20(2), 79–87. <https://doi.org/10.1108/08858620510583678>
- Rogliger, M., Poppelbuß, J., & Becker, J. (2012). Maturity models in business process management. *Business Process Management Journal*, 18(2), 328–346. <https://doi.org/10.1108/14637151211225225>
- Rothwell, R. (1992). Successful industrial innovation- critical factors for the 1990s. *R&D Management*, 22, 221–239.
- Rouse, P., & Putterill, M. (2003). An integral framework for performance measurement. *Management Decision*, 41(8), 791–805. <https://doi.org/10.1108/00251740310496305>
- Roy, S., & Mitra, J. (2018). Tacit and explicit knowledge management and assessment of quality performance of public R&D in emerging economies: An Indian perspective. *Journal of Organizational Change Management*, 31(1), 188–214. <https://doi.org/10.1108/09574090910954864>
- Rytter, N. G., Boer, H., & Koch, C. (2007). Conceptualizing operations strategy processes. *International Journal of Operations & Production Management*, 27(10), 1093–1114. <https://doi.org/10.1108/01443570710820648>
- Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, 48, 9–26. [https://doi.org/10.1016/0377-2217\(90\)90057-I](https://doi.org/10.1016/0377-2217(90)90057-I)
- Sarac, M., Ertan, Y., & Yucel, E. (2014). How do business strategies predict firm performance? *The Journal of Accounting and Finance*, 61(1), 121–134.
- Sartorius, K., Eitzen, C., Trollip, N., & Uliana, E. (2011). CSIR the Motivational Role of Interactive Control in the Research Sector: a case study. *SAJEMS*, 14(4), 379–392.
- Saunila, M. (2017). Innovation performance measurement: A quantitative systematic literature review. *Proceedings of the European Conference on Innovation & Entrepreneurship*, 596–601.
- Saunila, M., Pekkola, S., & Ukko, J. (2014). The relationship between innovation capability and performance The moderating effect of measurement. *Journal of Management Development*, 63(2), 234–249. <https://doi.org/10.1108/MBE-09-2016-0047>
- Saunila, M., & Ukko, J. (2012). A conceptual framework for the measurement of innovation capability and its effects. *Baltic Journal of Management*, 7(4), 355–375.

REFERENCES

- <https://doi.org/10.1108/17465261211272139>
- Schemmann, B., Herrmann, A. M., Chappin, M. M. H., & Heimeriks, G. J. (2016). Crowdsourcing ideas: Involving ordinary users in the ideation phase of new product development. *Research Policy*, 45(6), 1145–1154. <https://doi.org/10.1016/j.respol.2016.02.003>
- Schuh, G., Rozenfeld, H., Assmus, D., & Zancul, E. (2008). Process oriented framework to support PLM implementation. *Computers in Industry*, 59(2–3), 210–218. <https://doi.org/10.1016/j.compind.2007.06.015>
- Scuotto, V., Del Giudice, M., Peruta, M. R. della, & Tarba, S. (2017). The performance implications of leveraging internal innovation through social media networks: An empirical verification of the smart fashion industry. *Technological Forecasting and Social Change*, 120, 184–194. <https://doi.org/10.1016/j.techfore.2017.03.021>
- Seidel, V. P., & Fixson, S. K. (2013). Adopting design thinking in novice multidisciplinary teams: The application and limits of design methods and reflexive practices. *Journal of Product Innovation Management*, 30(S1), 19–33. <https://doi.org/10.1111/jpim.12061>
- Serrano-bedia, A. M., López-fernández, M. C., & García-piqueres, G. (2018). Complementarity between innovation knowledge sources: Does the innovation performance measure matter? *Cuadernos de Economía y Dirección de La Empresa*, 21(1), 53–67. <https://doi.org/10.1016/j.brq.2017.09.001>
- Shane, S., Venkatarman, S., & MacMillan, I. (1995). Cultural differences in innovation championing strategies. *Journal of Management*, 21(5), 931–952. <https://doi.org/10.1177/014920639502100507>
- Sheasley, W. D. (1999). Leading the technology development process. *Research Technology Management*, (May-June), 49–55. <https://doi.org/10.1086/250095>
- Sivasubramaniam, N., Liebowitz, S. J., & Lackman, C. L. (2012). Determinants of new product development team performance: A meta-analytic review. *Journal of Product Innovation Management*, 29(5), 803–820. <https://doi.org/10.1111/j.1540-5885.2012.00940.x>
- Song, L. Z., Song, M., & Di Benedetto, Anthony, C. (2009). A staged service innovation model. *Decision Sciences*, 40(3), 571–599. <https://doi.org/10.1111/j.1540-5915.2009.00240.x>
- Song, M. X., & Parry, M. E. (1996). What separates Japanese new product winners from losers. *Journal of Product Innovation Management*, 13(5), 422–439. [https://doi.org/10.1016/0737-6782\(96\)00055-0](https://doi.org/10.1016/0737-6782(96)00055-0)
- Souitaris, V. (2002). Firm-specific competencies determining technological innovation: A survey in Greece. *R and D Management*, 32(1), 61–77. <https://doi.org/10.1111/1467-9310.00239>
- Spanò, R., Allini, A., Caldarelli, A., & Zampella, A. (2017). Controlling innovation and innovating control: Insights from a knowledge intensive network. *Business Process Management Journal*, 23(6), 1359–1384.
- Spithoven, A., Frantzen, D., & Clarysse, B. (2010). Heterogeneous firm-level effects of knowledge exchanges on product innovation: Differences between dynamic and lagging product innovators. *Journal of Product Innovation Management*, 27(3), 362–381. <https://doi.org/10.1111/j.1540-5885.2010.00722.x>

REFERENCES

- Stindt, D., Quariguasi Frota Neto, J., Nuss, C., Dirr, M., Jakowczyk, M., Gibson, A., & Tuma, A. (2017). On the attractiveness of product recovery: The forces that shape reverse markets. *Journal of Industrial Ecology*, 21(4), 980–994. <https://doi.org/10.1111/jiec.12473>
- Strang, K. D. (2011). Leadership substitutes and personality impact on time and quality in virtual new product development projects. *Project Management Journal*, 42(1), 73–90. <https://doi.org/10.1002/pmj>
- Striteska, M., & Spickova, M. (2012). Review and comparison of performance measurement systems. *The Journal of Organizational Management Studies*, 2012, 1–13. <https://doi.org/10.5171/2012.114900>
- Suomala, P. (2004). Multifaceted new product development performance: Survey on utilization of performance measures in Finnish industry. *Performance Measurement and Management Control Superior Organizational Performance*, 1–27. Retrieved from http://webhotel2.tut.fi/cmc/pdf/Suomala-Multifaceted_NPD_performance.pdf
- Szymanski, D. M., Kroff, M. W., & Troy, L. C. (2007). Innovativeness and new product success: Insights from the cumulative evidence. *Journal of the Academy of Marketing Science*, 35(1), 35–52. <https://doi.org/10.1007/s11747-006-0014-0>
- Tangen, S. (2004a). Evaluation and Revision of Performance Measurement Systems. Royal Institute of Technology Stockholm.
- Tangen, S. (2004b). Performance measurement: From philosophy to practice. *International Journal of Productivity and Performance Management*, 53(8), 726–737. <https://doi.org/10.1108/17410400410569134>
- Tangen, S. (2005). Improving the performance of a performance measure. *Measuring Business Excellence*, 9(2), 4–11. <https://doi.org/10.1108/13683040510602830>
- Tatikonda, M. V., & Rosenthal, S. R. (2000). Technology novelty, project complexity, and product development project execution success: A deeper look at task uncertainty in product innovation. *HPAC Heating, Piping, Air Conditioning*, 72(2), 74–87. <https://doi.org/10.1109/17.820727>
- The readi-watch offering. (2019). Retrieved September 18, 2020, from <https://gbinnovation.ie/products/>
- Thuriaux, B. (2006). The why, what, and how of management innovation. *Harvard Business Review*, 84(6), 139.
- Tidd, J., Bessant, J., & Pavitt, K. (2005). *Managing innovation integrating technological, market and organizational change* (3rd ed.). West Sussex: John Wiley & Sons.
- Tingström, J., Swanström, L., & Karlsson, R. (2006). Sustainability management in product development projects - the ABB experience. *Journal of Cleaner Production*, 14(15–16), 1377–1385. <https://doi.org/10.1016/j.jclepro.2005.11.027>
- Tipping, J. W., Zeffren, E., & Fusfeld, A. R. (1995). Assessing the value of your technology. *Research Technology Management*, 38(No 5), 22–39.
- Tolonen, A., Shahmarichatghieh, M., Harkonen, J., & Haapasalo, H. (2015). Product portfolio management - targets and key performance indicators for product portfolio renewal over life cycle. *International Journal of Production Economics*, 170, 468–477.

REFERENCES

- <https://doi.org/10.1016/j.ijpe.2015.05.034>
- Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, 14, 207–222. <https://doi.org/10.1111/1467-8551.00375>
- Tung, A., Baird, K., & Schoch, H. P. (2011). Factors influencing the effectiveness of performance measurement systems. *International Journal of Operations & Production Management*, 31(12), 1287–1310. <https://doi.org/10.1108/01443571111187457>
- Tuomela, T. S. (2005). The interplay of different levers of control: A case study of introducing a new performance measurement system. *Management Accounting Research*, 16(3 SPEC. ISS.), 293–320. <https://doi.org/10.1016/j.mar.2005.06.003>
- Turban, E., & Frenzel, L. E. (1992). *Expert systems and applied artificial intelligence* (1st ed.). Upper Saddle River: Prentice Hall.
- Turner, T. J., Bititci, U. S., & Nudurupati, S. S. (2005). Implementation and impact of performance measures in two SMEs in Central Scotland. *Production Planning & Control*, 16(2), 135–151. <https://doi.org/10.1080/0953728051233133048>
- Ulrich, K. T., & Eppinger, S. D. (2008). *Product Design and Development* (4th ed.). Boston: McGraw-Hill.
- United Nations, U. (2008). *International standard industrial classification of all economic activities (ISIC)* (4th ed.). New York.
- Urban, G. L., & von Hippel, E. (1988). Lead user analyses for the development of new industrial products. *Management Science*, 34(5), 569–582. <https://doi.org/10.1017/CBO9781107415324.004>
- van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- van Eck, N. J., & Waltman, L. (2014). Visualizing bibliometric networks. In *Measuring Scholarly Impact: methods and practice* (pp. 285–320). https://doi.org/10.1007/978-3-319-10377-8_13
- Verganti, R. (1997). Leveraging on systemic learning to manage the early phases of product innovation projects. *R&D Management*, 27(4), 377–392. <https://doi.org/10.1111/1467-9310.00072>
- Verganti, R. (2008). Design, meaning, and radical innovation: A metamodel and a research agency. *Journal of Product Innovation Management*, 15, 436–456. <https://doi.org/10.1111/j.1540-5885.2008.00313.x>
- Verhaeghe, A., & Kfir, R. (2002). Managing innovation in a knowledge intensive technology organisation (KITO). *R&D Management*, 32(5), 409–417. <https://doi.org/10.1111/1467-9310.00272>
- Vernadat, F. B. (1996). *Enterprise Modeling and Integration: Principles and Applications* (1st ed.). London: Chapman and Hall.
- Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Management Production Management*, 22(2), 195–

REFERENCES

219. <https://doi.org/10.1108/01443570210414329>
- Walter, A., Parboteeah, K. P., Riesenhuber, F., & Hoegl, M. (2011). Championship behaviors and innovations success: An empirical investigation of university spin-offs. *Journal of Product Innovation Management*, 28(4), 586–598. <https://doi.org/10.1111/j.1540-5885.2011.00826.x>
- Wang, Y., Wang, Y., & Horng, R. (2010). Learning and innovation in small and medium enterprises. *Industrial Management & Data Systems*, 110(2), 175–192. <https://doi.org/10.1108/02635571011020296>
- Werner, B. M., & Souder, W. E. (1997). Measuring R&D performance- State of the art. *Research Technology Management*, 40(2), 34–42. <https://doi.org/10.1080/08956308.1997.11671115>
- Wheelwright, S. C., & Clark, K. B. (1992). *Revolutionizing product development: quantum leaps in speed, efficiency and quality* (1st ed.). New York: The Free Press.
- Woodman, R. W., Sawyer, J. E., & Griffin, R. W. (1993). Toward a theory of organizational creativity. *Academy of Management Review*, 18(2), 293–321.
- Yang, J. Y. J. (2009). A balanced performance measurement scorecard approach for product service systems. *2009 International Conference on Business Intelligence and Financial Engineering*. <https://doi.org/10.1109/BIFE.2009.129>
- Yin, R. K. (2003). *Case Study Research: Design and Methods* (3rd ed.). London: SAGE Publications.
- Zhang, Q., & Doll, W. J. (2001). The fuzzy front end and success of new product development: A causal model. *European Journal of Innovation Management*, 4(2), 95–112. <https://doi.org/10.1108/14601060110390602>
- Zieba, M., & Zieba, K. (2014). Knowledge management critical success factors and the innovativeness of KIBS companies. *Engineering Economics*, 25(4), 458–465. <https://doi.org/10.5755/j01.ee.25.4.6494>
- Zobel, A. K. (2017). Benefiting from open innovation: A multidimensional model of absorptive capacity. *Journal of Product Innovation Management*, 34(3), 269–288. <https://doi.org/10.1111/jpim.12361>

APPENDIX I. SYSTEMATIC LITERATURE REVIEW PROTOCOL

The appendix presents the protocol followed in this research to perform the systematic literature review (SLR): i) planning, ii) execution and iii) synthesis, based the procedure by (Brereton et al., 2007; Tranfield et al., 2003) adapted to the research field of OM.

The first step (planning) involves the definition of the keywords to gather relevant literature. Papers from experts in the innovation management and new product development (NPD) fields were used to identify initial keywords, which were later refined in iterative cycles of development, and testing in the electronic databases. The resulting keywords “innovation process”, “performance measurement” and synonyms in Figure I.1 illustrate the final search string. Web of Science (WoS) and Scopus databases were selected due to their advanced web search mechanisms, high volume of indexed publications and proven relevance (Adriaanse & Rensleigh, 2013).

Innovation process AND	“innovation process” OR “innovation management” OR “innovation planning” OR “front end of innovation” OR “innovation front end” OR “fuzzy front end” OR (“innovation” AND (“early stages” OR “early phases”)) OR “research & development” OR “research and development” OR R&D AND (“product development” OR “technology development”) OR “new product development” OR “product innovation” OR “innovation design” OR “product lifecycle management” OR “product life cycle management” OR “product service system”
Performance indicators OR	“Performance measurement” OR “performance evaluation” OR “indicator” OR “metric” OR “measure” OR “index”
Additional search phrases	“Innovation audit” OR “Innovation performance” OR “Innovation front end measurement”

Figure I.1. Search string for the systematic review.

Note in Figure I.1 that a few terms are not the usual keywords related to the innovation process; however, they are indispensable for a comprehensive search in the literature. For example, “product lifecycle management” is a highly associated expression with the innovation process in manufacturing companies to deal with sustainability-oriented innovation (Tolonen, Shahmarichatghieh, Harkonen, & Haapasalo, 2015). Likewise, “product-service systems” is associated with innovation in the context of servitisation, focusing on new product and service combined to offer innovative offers (T. S. Baines et al., 2007; Medini & Boucher, 2016).

As part of the first step, the review should also specify the inclusion criteria, so the method is replicable and scientific. The material collection of this study covered peer-reviewed

articles indexed in either database (WoS/Scopus) to obtain a comparable research body. The search was not limited to a group of journals nor time to encompass a broader range from journals to peer-reviewed conference papers. The seven inclusion criteria are as follows:

- i) Available in at least in the databases or cited in one of the identified articles;
- ii) Articles in English;
- iii) Peer-reviewed articles;
- iv) Comprises one of the keywords for indicator in the title, abstract and keywords or full text;
- v) Articles considering process-based view, by presenting one of the keywords for innovation process in the title, abstract and keywords or full text;
- vi) Articles specifying dimensions or categories in the full text to organise the indicators;
- vii) Articles presenting a clear linkage between the innovation process success rates (sales/profit, schedule performance) and the dimensions.

Publications out of this scope were excluded from the systematic review. The selected studies were further assessed in term of quality. Problem definition, research background, research method, results and contributions, and insights were the five items analysed. Acceptable papers scored at least a two, using the scoring system for those five items defined: (1) totally present, (0.5) partially and (0) not present. Note that this quality ranking was an internal metric for selecting papers to this study, not reflecting any comparison amongst the authors.

The second step (execution) refers to the ongoing search within the two electronic databases, where publications are identified and assessed according to the inclusion criteria. The search fields cover management, business, planning development, economics, engineering (all kinds), operations research, computer science, multidisciplinary sciences, and social sciences mathematical methods. The articles selected via the inclusion criteria were thoroughly read and assessed in terms of quality. Then, the researchers also performed cross-referencing to check citations and reference lists for additional relevant studies. These cross-referenced publications were then applied the same selection criteria described above. In short, the protocol of the second step (execution) is as follows:

- Cross the results in order to eliminate duplicates between WoS and Scopus.

- Exporting of the results of the searches for the publications spreadsheet and application of criteria i, ii, iii, and iv.
- Application of criteria i, ii, iii, and iv by reading the title, keywords and summary of the article. Application of the criteria for inclusion and exclusion of articles and decision of A (approved), R (rejected) and I (unavailable).
- Application of criteria v, vi and vii: partial reading of the article, including introduction, results and conclusion. Application of the criteria for inclusion and exclusion of articles and decision of A (approved), R (rejected) and I (unavailable).
- Application of criteria vii: full reading of the articles. Application of quality analysis standards for articles and decision of A (approved), R (rejected) and I (unavailable).

In the third step (synthesis), the relevant publications, as well as indicators, are analysed and classified. The publication spreadsheet included publication year, source, industry type, sample size, and research method. The indicator spreadsheet presented two main parts. The first included indicators' attributes recorded from the publications: title, formula/scales, purpose, unit of measurement, number of citations and references. The second part of contained the classifications: performance dimensions, rapid assessment and in-depth indicators, quantitative and qualitative indicators, and leading and lagging indicators.

The review also performed an independent two-stage evaluation to assign the classifications. In some cases, when no consensus was found, the results were then discussed to arrive at an agreement. In this way, the dimensions were identified, catalogued and clustered to synthesise them into a higher level of categories (cf. Dziallas & Blind, 2018). Then, the PIS were further classified into the rapid assessment/in-depth quantitative/qualitative, leading/lagging criteria according to their definitions.

The criteria are also defined to extract the PIs from the publications. Researchers followed previous criteria of SLR on indicators (Costa et al., 2014). Indicators needed to present the title, associated with either their purpose or formula/scales. Moreover, indicators dealing exclusively with technicalities of the product, such as physical characteristics, materials, were not considered.

APPENDIX II. JOURNAL KEEPING FOR ACTION RESEARCH

This appendix presents examples of the AR journals maintained for Company TRFR and Company TRPT in the screens captured (due confidentiality reasons the text has been redacted). The journal maintained in this research record the following information cycle number; date; format of the AR activity (what/who); planned actions; implemented actions; results; outcomes; lessons learned; and reflection of emerging questions to be addressed in the next cycle (see Figure II.1 and Figure II.2).

As mentioned before, Company TRFR mainly produces power transformers, being classified under the 27 division as a manufacturer of electric motors, generators, transformers and electricity distribution and control apparatus of the ISIC classification (United Nations, 2008). This European manufacturing company has more than 70 years of experience in the field, with approximately 240 employees and annual revenue between €10M and €50M. This company is part of a conglomerate led by a holding company, which owns the assets of the constituent companies but does not actively participate in running a business's day-to-day processes and operations.

Journal Keeping						
			Company/BU size: Medium		ISIC classification Division 27: 2710	
			Number of Hours: 621		Number of people involved: 12	
			Months: 13		Number of depts/areas: 7	
			Average per week: 12		Average experience (years): 17	
Cycle	Date	Format (what/who)	Hours	Planned actions	Implemented actions	Outcomes
1	19-02-2019		1.00			
1	20-02-2019		2.00			
1	21-02-2019		3.00			
1	22-02-2019		3.00			

Figure II.1. Journal keeping used for Company TRFR.

APPENDICES

Company TRTP can be located in the transport sector as a European manufacturer of measuring, testing, navigating and control equipment, classified under 26 division of the ISIC classification (United Nations, 2008). This company has a little more than 20 years of experience in the field, with approximately 191 employees and annual revenue between €10M and €50M. Company TRTP is part of a conglomerate led by the same holding company as the previous one, that does not actively participate in running a business's day-to-day processes and operations. These two companies have a distinct board of directors, distinct locations, industrial plants and staff, and therefore, independent companies.

Journal Keeping

Company/BU size: Medium ISIC classification: Division 26: 2651

Number of Hours: 328 Number of people involved: 13

Months: 6 Number of depts/areas: 11

Average per week: 14 Average experience (years): 11

Cycle	Date	Format (what/who)	Hours	Planned actions	Implemented actions	Outcomes	Lessons learned	Reflecti
1	01-07-2019		3.00					
1	01-07-2019		1.15					

Figure II.2. Journal keeping used for Company TRPT

APPENDIX III. EVALUATION QUESTIONNAIRE

This appendix presents the questionnaire developed to evaluate the PF results according to the company perception after its application. It includes a set of criteria framework and model evaluation related to utility, consistency, scope, precision, broadness, objectivity, clarity, depth, coherence, clarity, instrumentality, simplicity and forecast adapted from (Barquet, 2015; Pigosso, 2012).

i) Utility: How do you evaluate the general utility of the performance framework in supporting companies in the measurement of performance and selection of the most suitable innovation practices to be implemented?

- ☐ (4) Very satisfactory
- ☐ (3) Satisfactory
- ☐ (2) Needs improvement
- ☐ (1) Unsatisfactory

Comments, suggestions, critics:

ii) Consistency: How do you evaluate the consistency of the nine dimensions of performance used in the PF?

- ☐ (4) Very satisfactory
- ☐ (3) Satisfactory
- ☐ (2) Needs improvement
- ☐ (1) Unsatisfactory

Comments, suggestions, critics:

iii) Scope: How do you evaluate the performance framework in relation to the adequacy of the scope of the proposition of the improvement projects?

- ☐ (4) Very satisfactory
- ☐ (3) Satisfactory
- ☐ (2) Needs improvement
- ☐ (1) Unsatisfactory

Comments, suggestions, critics:

iv) Precision: How do you evaluate the performance framework in relation to the precision of the innovation capability profile provided?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

v) Broadness: How do you evaluate the performance framework in relation to its applicability in manufacturing companies from different sectors?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

vi) Objectivity: How do you evaluate the objectivity of the performance framework in performing the diagnosis of the company and proposing the improvement projects?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

vii) Clarity: How do you evaluate the performance framework concerning the clarity in which the results are presented, e.g., the innovation capability profile?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

viii) Depth: How do you evaluate the performance framework in relation to the depth of the diagnosis (the innovation capability profile) and the proposition of improvement projects?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

ix) Coherence: How do you evaluate the coherence of the diagnosis (the innovation capability profile) and the improvement projects proposed in the performance framework?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

x) Instrumentality: How do you evaluate the performance framework in relation to its instrumentality in the innovation capability profile (e.g., workshop and materials) and the proposition of the innovation practices (project charters)?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

xi) Simplicity: How do you evaluate the performance framework in relation to the simplicity of the results presented?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

xii) Forecast: How do you evaluate the performance framework in relation to the definition of the next steps to be taken after the proposition of the improvement projects?

☐ (4) Very satisfactory

☐ (3) Satisfactory

☐ (2) Needs improvement

☐ (1) Unsatisfactory

Comments, suggestions, critics:

APPENDIX IV. BIBLIOMETRIC ANALYSIS OF THE SYSTEMATIC REVIEW

This appendix presents the bibliometric analysis of the SLR results, i.e., the bibliometric analysis of the publications retrieved in the systematic review.

Figure IV.1 depicts the summary of the selection of studies. By using the search criteria, 1,068 potential articles were identified. 105 were duplicated in both databases (WoS/Scopus). 903 had their main text in English. Based on the title, abstract and keywords criteria, 252 papers were excluded. Then, the introduction and conclusion of the remaining 651 articles were read and analysed. Some full texts of relevant articles were not accessible through the mentioned databases (less than 15%). In such cases, the authors were asked for their articles directly. The full texts of the remaining 502 articles were screened in more detail. In total, 93 articles matched all the inclusion/quality criteria. Additional 30 cross-referenced publications were selected through an analysis of citation and references. The final selection resulted in 123 papers.

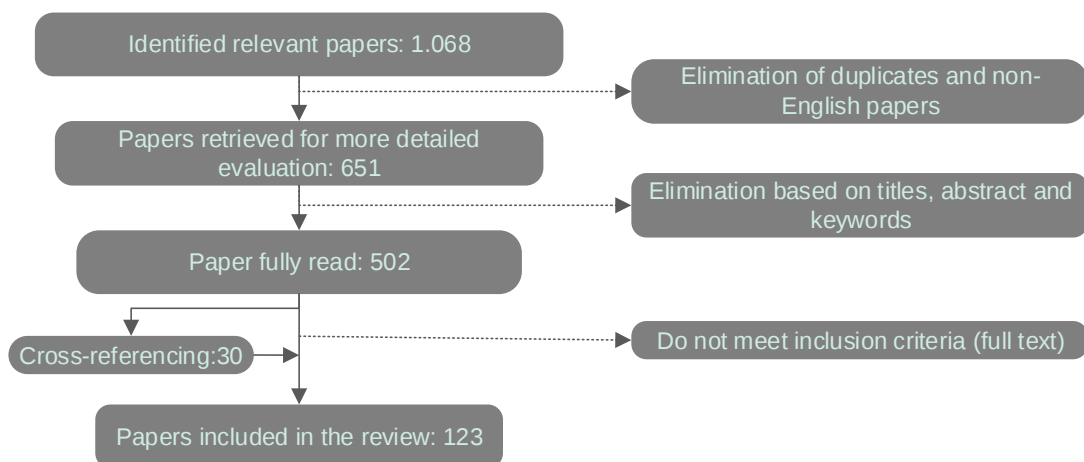


Figure IV.1. Systematic review paper selection summary.

Publications development

Figure IV.2 illustrates the development of publications per year. First, the number of publications between 1983 and 1995 is inexpressive. For 7 of the 35 years, no publication was identified from the databases. Notably, from 2004 onwards, the research focus on innovation indicators increases significantly, with a publication peak in 2018 (11). The overall trend characterises an increase in publications over 1983-2018. The increase may be due to a series of innovation surveys, especially in Europe (EU, 2016; OECD, 2005, 2011).

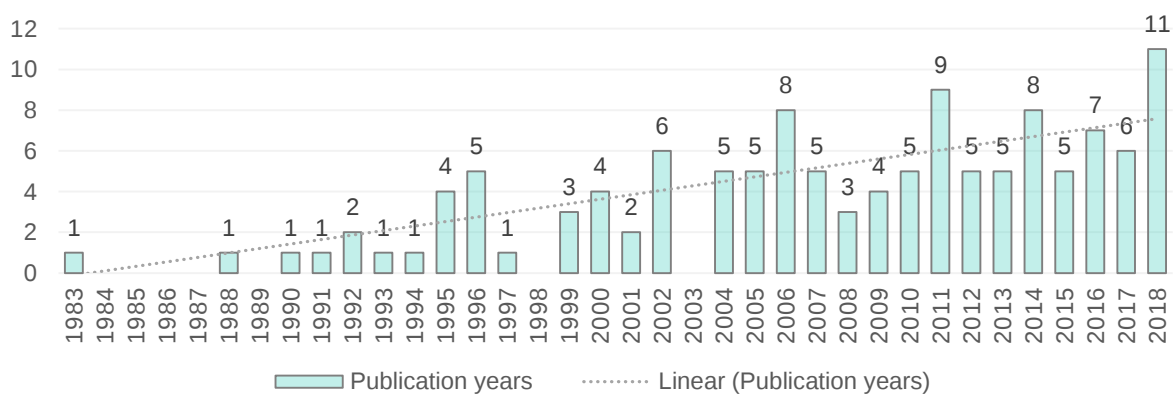


Figure IV.2. Publication numbers per year (1983-2018).

Figure IV.3 shows the number of publications per journals. Most papers have been published in the *Journal of Product Innovation Management* (JPIM) followed by the *Academy of Management Journal* (AMJ), and *International Journal of Production Economics* (IJPE). This finding is in accordance with their relevance. JPIM ranks 6th among the world's top journals in Engineering, with an impact factor of 4.305. AMJ is first in Management of Technology and Innovation Development, while IJPE is the 8th in Business, Management and Accounting (Clarivate Analytics, 2019).



Figure IV.3. Number of publications per journal (1983-2018).

Methods used to study innovation

Figure IV.4 indicates that quantitative methods are most frequent (65) in comparison with qualitative methods (43) in the publications retrieved. Note that seven studies addressed only dimensions (what to measure), not providing any indicator to use.

Surveys are the most recurrent applied research method (59), either used individually or jointly with panels of experts (5). These surveys have an exploratory purpose of building theory focusing on classifications and definitions (e.g., Lee & Markham, 2016). Typical data analysis techniques are descriptive and correlation analysis. Conversely, case research is the most common qualitative method applied (24) (e.g., Rogers et al., 2005), methodologically close to longitudinal cases (5) (e.g., Driva, Pawar, & Menon, 2001). Additional qualitative methods are SLR (13) (e.g., Becheikh et al., 2006). In short, the identified articles perform different methods to study innovation indicators, with simulation/modelling and action research presenting the further potential for future research.

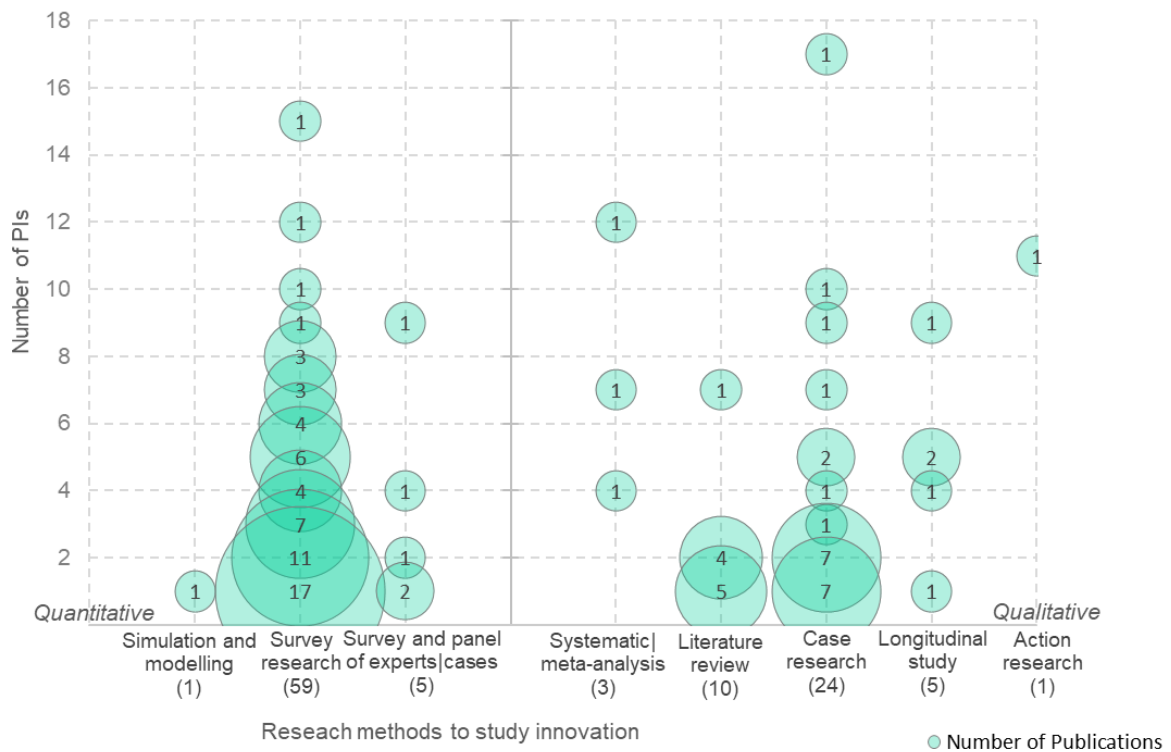


Figure IV.4. Frequency of use research methods (1983-2018).

Publications and company size

Distinct company sizes and innovation indicators are investigated intermittently in the identified publications. SMEs account for 29% of surveys, cases research and SLRs. The surveys

presented the most substantial application of indicators featuring SMEs. Several studies investigated international indicators compilations across countries (e.g., Dubiel et al., 2016; Eling et al., 2016; Lee and Markham, 2016; Markham and Lee, 2013). For instance, Lee & Markham (2016) sampling includes small and large companies in distinct geographical areas Asia (77%:23%); North America (52%:48%); Europe (59%:41%).

Case research occasionally presents SMEs (40%). Tolonen et al. (2015), for instance, selected ten companies representing both large and small businesses to investigate indicators. In another example, Driva, Pawar, & Menon (2001) analysed several indicators used in a small company and further indicators they intended to measure in the future.

Furthermore, SLRs seldom address small companies' issues. 23% of the studies addressed issues related to SMEs. For example, Adams et al. (2006) discussed indicators (e.g., R&D intensity) not suited for small companies. Additional reviews, (Becheikh et al., 2006; Dziallas & Blind, 2018), suggested dimensions and corresponding indicators with sporadic discussions on SMEs.

Publications at the industry level

The industry analysis of the selected literature is based on the ISIC (International standard industrial classification of all economic activities) classification (United Nations, 2008). The manufacturing industry accounts for 81% of the selected articles. This meaningful participation of the manufacturing industry is most likely due to the attention given to performance measurement research in the operations management (OM) field, which evolved from the total quality management movement.

Additional publications correspond to scientific research and development (R&D) for further application into machinery, electronics and automobile industry, representing 9% of the sample. Finally, the remaining studies are situated in the service sector (9%). This observation demonstrates an emerging shift in the research efforts from manufacturing to the service industry. This change may have resulted from specific trends, e.g., communication and information technology and software industry grow (Dziallas & Blind, 2018) as well as extended focus on services into product offers for customers (T. Baines & Lightfoot, 2013). Articles that did not describe a specific industry branch were excluded from this analysis (approximately 1%).

Co-citation analysis

Recent advances in information visualisation technologies and online data storage have eased the process of visualising bibliometric networks. Among the recommended tools, the *VOSViewer* from van Eck and Waltman, (2014, 2010) has a prominent role in most studies. According to Leydesdorff et al. (2013), the clustering algorithm of *VOSViewer* tool results in highly influential groups of studies.

Before the analysis, a substantive examination of the dataset was undertaken to create the co-citation network, a key bibliometric network to inform the coverage and breadth of a SLR. Every record of the selected studied was exhaustively verified. As recommended, other obvious errors in the dataset importation from the electronic databases were corrected in line with the current best practice for bibliometric analysis. Lastly, the parameter established for the inclusion of the studies in the analysis was set at ten citations.

The visualisation of the publication's co-citation network is shown in Figure IV.5. Each circle in the visualisation represents a publication – journal or proceeding. The size of a circle reflects the number of citations a publication has received (at least then). Publications that are close to each other in the visualisation tend to be more strongly related, based on co-citations, than publications that are located far away from each other.

Five main clusters can be distinguished in Figure IV.5. The first cluster, and more widespread, is depicted in purple refers to technology and innovation management. The cluster in yellow is from the same disciplinary background but strictly focused on R&D. Managerial accounting can be seen in red, while business and its stemming cluster organisational management is demonstrated in blue. Then, engineering design and technology from a manufacturing perspective can be visualised in green. The diversity shown in this network reinforces that the field of innovation research is multidisciplinary entwined within technology and innovation management and managerial accounting.

The density of these publications is also worthy of note. In total, 68 journals and two proceedings are illustrated in the co-citation network (in Figure IV.5, each circle represents a source). The most frequently cited were *Journal of Product Innovation Management* (560 citations), *Strategic Management Journal* (172 citations), *R&D Management* (158 citations). Together these journals alone account for more than 25% of all citations while the top ten cover 47% (see Figure IV.3 for journals). This broad coverage of journals indicates that these publications form a body of seminal work that proceeding studies use as a foundation.

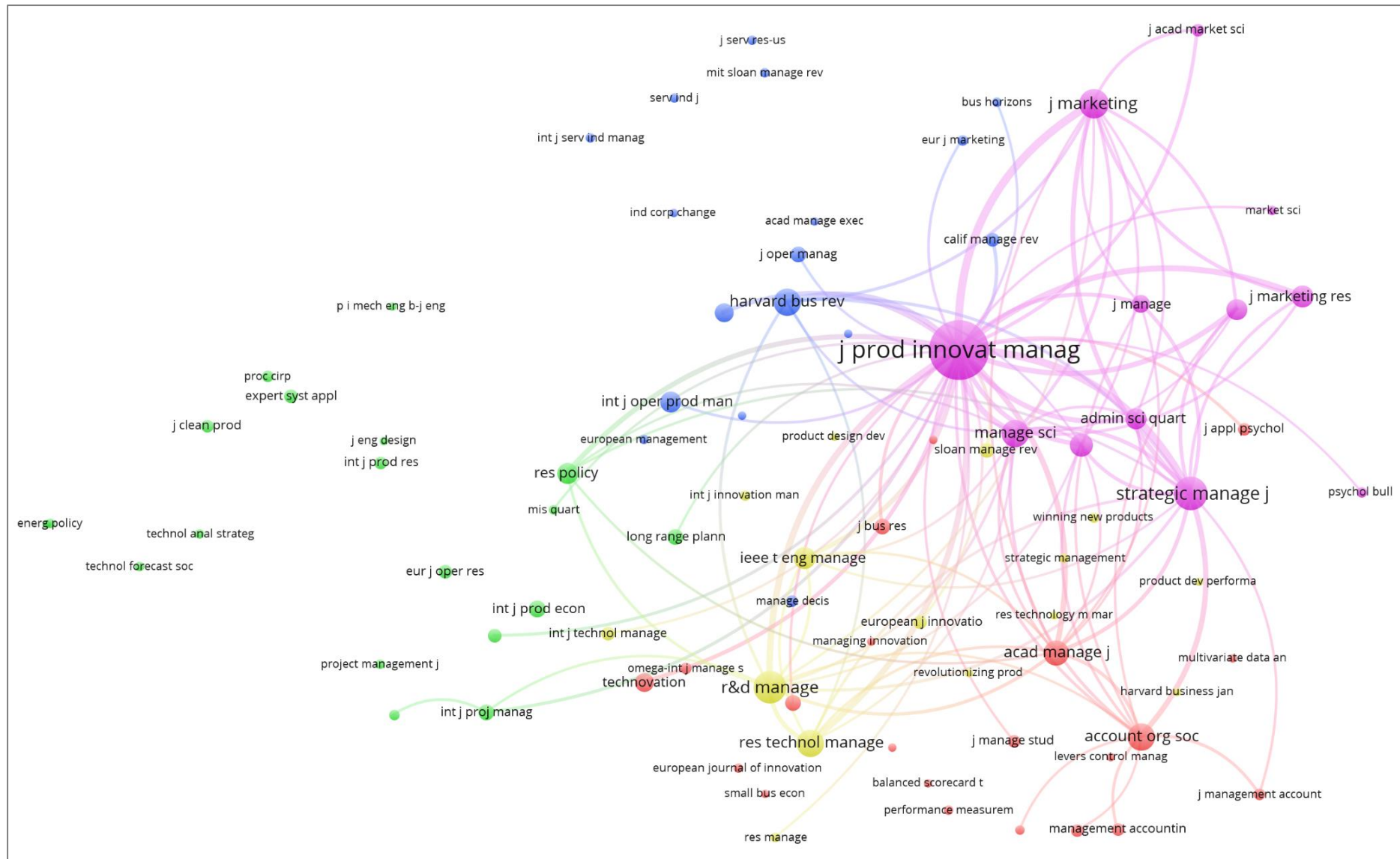


Figure IV.5. Co-citation network of publications visualisation by VOSView.

It is important to note that *Harvard Business review* appointed by Neely (2005) as the most-cited journal in his systematic review in 2005 and *Journal of Operations & Production Management* as the second were, respectively, in fifth and in twelfth place in this performed here. Now the top journal is *Journal of Product Innovation Management*. This may be explained by the fact that in the 2000s, it was the managerial accounting literature that dealt with innovation measurement and management (to a limited extent), and from 2010 onward technology and innovation management came to play a more significant role.

The 251 papers⁶⁶ included in the dataset provide 3.440 citations, cover 5.048 studies and 3.564 leading authors. The most frequently cited authors were: Cooper (137 citations), Griffin (72 citations), Neely (52), Kaplan (48) and Chiesa (26). There were only five authors whose work were cited more than 26 times. They present distinct disciplinary backgrounds – technology and innovation management (Cooper and Griffin), the same background with a greater focus on R&D (Chiesa), and managerial accounting (Neely and Kaplan).

⁶⁶The number of publications is not 123 papers selected because the co-citation network counts the studies referenced as well (as long as it has at least 10 citations).

APPENDIX V. DATABASE OF PERFORMANCE INDICATORS

This appendix presents in full the database of the retrieved PIs via the systematic literature review. Table V.1 indicates their dimension by the ID, then the sub-dimension, followed by the general parameters and the classifications type of indicator – rapid assessment (RAP), and in-depth (DEP); leading (LEAD), lagging (LAG) and quantitative (QT), qualitative (QL).

Table V.1. Database of performance indicators.

ID	Sub-dimensions	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IS1]	Strategic orientation	Level employees aware of, sharing the innovation goal, policies and values	To measure the innovation strategy 'sharedness' and awareness level among employees	'Level of awareness and clarity of goals according to: 1=Innovation strategy is known and shared only among senior management. 5=Innovation strategy is clearly defined and communicated to all employees. Complemented by percentage of time employees aware of, sharing the innovation goal, policies and values	Dimensionless	RAP	LEAD	QL	7	(Adams et al., 2006; Birchall & Tovstiga, 2006; Cooper & Edgett, 2012; Cooper & Kleinschmidt, 2007; Cormican & O'Sullivan, 2004; Tipping et al., 1995)
[IS2]	Strategic orientation	Spending reflects the innovation strategy	To measure the perception of alignment between the spending (resources given) to the innovation program or projects and the business strategy	'The corporate goals in our new product projects portfolio truly reflects our business's strategy' according to: 1=No, spending breakdown is inconsistent with the Company's business strategy. 5=Spending consistent with the strategy.	Dimensionless	RAP	LEAD/ LAG	QL	5	(Cooper et al., 2004; Cormican & O'Sullivan, 2004; Killen et al., 2008; Tipping et al., 1995; Tolonen et al., 2015)
[IS3]	Strategic orientation									

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		Innovation long-term planning (years, product generations)	To measure the long-term planning for innovation (new products)	'What best reflects what the Company has been practising so far': 1=We focus on our current product line planning. 5=The product innovation programme has a long-term thrust and focus (5-15 years)	Dimensionless	RAP	LEAD	QL	4	(Adams et al., 2006; Chiesa et al., 1996; Cooper & Kleinschmidt, 1995; Cormican & O'Sullivan, 2004)
[IS4]	Strategic orientation	Frequency of product strategy plan use/update	To measure the effectiveness of the new product strategic planning	Number of updated in the strategic planning during the Company year	No of updates	DEP	LEAD/LAG	QT	4	(Adams et al., 2006; Cormican & O'Sullivan, 2004; Crossan & Apaydin, 2010; Tipping et al., 1995)
[IS5]	Strategic orientation	Commitment to differentiated funding sources for innovation projects	To measure the existence of diversification of funding strategy for innovation projects	'Are there financial resources (contributions, member fees, government grants, program services, investments, and product sales) to pursue 'white space' innovations?' ('yes/no')	Dimensionless	DEP	LEAD/LAG	QL	3	(Adams et al., 2006; Chiesa et al., 1996; Kahn et al., 2006)
[IS6]	Strategic orientation	Environmental hostility and dynamism that drives innovation strategy	To measure the surrounding environment of the company that drives the strategy, including the innovation strategy	'How would you describe the environment in which the Company operates?' 1= Very safe, little threat to the survival and well-being 7= Very risky, a false step can mean my firm's undoing of my firm; very stressful, exacting, hostile, hard to keep afloat 1= Rich in investment and marketing opportunities; an environment in which my firm's initiatives can control to its own advantage 7=An environment in which my firm's initiatives count little against strong, competitive political and advantage technological forces	Dimensionless	DEP	LEAD	QL	2	(Atuahene-Gima, 1995; García-Zamora, González-Benito, & Muñoz-Gallego, 2013)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IS7]	Strategic orientation	Strategies are flexible enough to respond to changes in the environment	To measure the strategies responsiveness to the surrounding environment	Do you agree or disagree with these statements 'strategies are flexible enough to respond to changes in the environment'? 1=strongly agree 5=strongly disagree	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)
[IS8]	Strategic orientation	'Newness' and meaningfulness strategies	To measure the degree to which any new product strategy has functional relevance to its potential user	Not provided.	NA	DEP	LAG	NA	1	(Szymanski, Kroff, & Troy, 2007)
[IS9]	Strategic orientation	Proportion of products 'first to market'	To measure the ratio of product innovation first to the market in a period (1, 3, 5 years)	Percentage of significant product innovations that were first to market in a period (1, 3, 5 years) in relation to total	% of products	DEP	LAG	QT	2	(C. Loch, Stein, & Terwiesch, 1996; Prajogo & McDermott, 2011)
[IS10]	Strategic orientation	Global innovation culture strategies	To measure the global innovation cultural strategies to respond to the behavioural environment	'To create a 'truly global' innovation culture, the Company': 1=strongly agree 7=strongly disagree - Strongly encourages contributions from team members in different countries. - Emphasises responsiveness to differences in local markets. - Achieves a high degree of innovation interdependence among our affiliates, worldwide. - Strongly endorses informal coordination of innovation activities across country units.	Dimensionless	DEP	LEAD	QL	1	(de Brentani, Kleinschmidt, & Salomo, 2010)
[IS11]	Strategic orientation	Global presence strategy	To measure the global presence in the strategic planning. It is indicated for large multinational companies.	'Our innovation effort is aimed at making the Company truly 'global' (operating in all hemispheres)': 1=strongly agree 7=strongly disagree - We have defined arenas of strategic	Dimensionless	DEP	LEAD	QL	1	(de Brentani et al., 2010)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				thrust (e.g., product-market, technology). From a strategic perspective, the international innovation program: - Has a planning process with active involvement from all our innovation group, worldwide. - Is specific about levels of resource commitment for our international innovation effort.						
[IS12]	Strategic orientation	Global product 'harmonisation' strategy	To measure the global product 'harmonisation' strategy respond to the behavioural environment	'An important underlying strategy of the Company is to develop 'truly global' products': 1=strongly agree 7=strongly disagree - For international products, we have similar quality standard worldwide - A key strategy in our global NPD program is to centralise operations to achieve greater standardisation of 'core' products across markets. - We aim for product consistency by maintaining high levels of control over production and marketing. -When launching new products to international markets, the strategy is - To undertake a simultaneous launch in all or most international markets in which we operate. - To emphasise the creation of a strong brand identity, worldwide.	Dimensionless	DEP	LEAD	QL	1	(de Brentani et al., 2010)
[IS13]	Strategic orientation	Value of strategic investment for new product development	To measure the ratio between strategic investments for new product development and total budget	Innovation budget or investments/Total budget or investments for the period	% (Monetary units/ Monetary units)	DEP	LAG	QT	1	(Tolonen et al., 2015)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IS14]	Strategic orientation	Return on innovation/new products over the past five years	To measure the revenue or profit from new products launched in the past five years	Revenue or Profit from new products for over the past years	Monetary units	DEP	LAG	QT	1	(A. M. Anderson, 2008)
[IS15]	Strategic orientation	Ratio of innovation spend vs revenue	To measure the ratio of strategic spending or investments for innovation versus total revenue	Innovation spending/ total revenue achieved by the Company in the period	% (Monetary units/ Monetary units)	DEP	LAG	QT	1	(A. M. Anderson, 2008)
[IS16]	Strategic leadership	Top management support for innovation	To measure to what degree the top management actively encourages the submission of new ideas	'What best reflects what the Company has been practising so far': 1=Leaders do not address innovation visibly. 5=Leaders visibly drive innovation. Senior management actively encourages the submission of new ideas	Dimensionless	RAP	LEAD	QL	4	(Cooper & Kleinschmidt, 1995; Cormican & O'Sullivan, 2004; Rodríguez, Pérez, & Gutiérrez, 2008)
[IS17]	Strategic leadership	Project leaders encourage learning and improvement	To measure the perception of what degree project leaders support improvement, learning, and innovation towards 'excellence'	'What best reflects what the Company has been practising so far': 1=strongly disagree 5=strongly agree - Senior managers actively encourage change and implement a culture of improvement, learning, and innovation towards 'excellence'. - Employees can share and are encouraged to help the organisation implement changes. - There is a high degree of unity of purpose in our company, and we have eliminated barriers between individuals and/or departments.	Dimensionless	DEP	LEAD	QL	2	(Prajogo & Ahmed, 2006; Saunila, Pekkola, & Ukko, 2014)
[IS18]	Strategic leadership	Project leaders encourage change and sharing	To measure the perception of what degree project leaders maintaining channels of sharing and	'What best reflects what the Company has been practising so far': 1=strongly disagree 5=strongly agree - Project leaders build and maintain	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			dissemination of innovation	virtual and physical channels for sharing and disseminating information and innovation.						
[IS19]	Strategic leadership	Clear innovation roles	To measure the existence of clear innovation roles	Existence of human resources policies to define individuals to innovation manager roles, team leaders, technology radar or similar ('Yes/No')	Dimensionless	DEP	LEAD	QL	3	(Adams et al., 2006; Crossan & Apaydin, 2010; Souitaris, 2002)
[IS20]	Strategic leadership	Leadership decision-making under uncertainty	To measure the perception of leadership decision-making under uncertainty	'When confronted with decision-making situations involving uncertainty, senior management': 1=Typically adopts a cautious, 'wait-and-see', posture in order to minimise the probability of making costly decisions. 7=Typically adopts a bold, aggressive posture in order to maximise the probability of exploiting potential opportunities.	Dimensionless	DEP	LEAD	QL	1	(Covin & Slevin, 1989)
[IS21]	Strategic leadership	Project leaders share similar beliefs	To measure the project leaders shared beliefs about the future of the organisation.	'What best reflects what the Company has been practising so far': 1=strongly disagree 5=strongly agree Senior executives share similar beliefs about the future direction of this organisation.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[IS22]	Strategic leadership	Recognition of innovation importance	To measure the recognition given to innovation activities	Number of pages in the annual report devoted to innovation activities and results/ (Total number of pages)	No of pages (absolute or relative)	DEP	LEAD/ LAG	QT	1	(Chiesa et al., 1996)
[IS23]	Strategic leadership	Senior management accountable for new product results	To measure the perception of senior management accountability for new product results	'What best reflects what the Company has been practising so far': 1=strongly disagree 5=strongly agree Senior management is accountable	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				for new product results (e.g., number of new products, revenue, profit)						
[IS24]	Strategic leadership	Champion behaviour	To measure the perception of 'champion' leadership behaviour toward innovation	'What best reflects what the Company's leadership has been practising so far': 0=not at all 4= frequently, if not always - Expresses enthusiasm and confidence - Gets the right people involved - Persists under adversity	Dimensionless	DEP	LEAD	QL	3	(Howell, Shea, & Higgins, 2005; Strang, 2011; Walter, Parboteeah, Riesenhuber, & Hoegl, 2011)
[IE1]	Openness	Recognition of open innovation opportunities	To measure the perception of the importance of openness	'For the Company, what percentage of time do the innovation projects involve the following': % of time (Never, about 25%, 50%, 75%, virtually always) - Find that key problems that must be solved with skills that reside outside our firm.	% of time	RAP	LEAD	QT	3	(Dubiel et al., 2016; Gurtner & Reinhardt, 2016; Saunila et al., 2014)
[IE2]	Openness	Exploitation of open innovation opportunities	To measure the percentage of time collaborative projects are undertaken	'For the Company, what percentage of time do the innovation projects involve the following': % of time (Never, about 25%, 50%, 75%, virtually always) - External collaboration with the supplier of component parts - External collaboration with a firm much smaller than us - External collaboration with a firm much larger than us - Facilitate collaboration internally focused open innovation system - Facilitate collaboration externally focused open innovation system	% of time	RAP	LEAD/ LAG	QT	2	(Dubiel et al., 2016; Markham & Lee, 2013)
[IE3]	Openness	Alliances and network	To measure the number of resources dedicated to building alliances and networking	Number of employees dedicated to fomenting and establishing external relationships for the innovation/R&D projects	Nº of employees	DEP	LEAD	QT	1	(Lazarrotti et al., 2011)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IE4]	Openness	Number of collaborations with customers, suppliers, competitors, universities	To measure collaboration intensity with external organisations	Number of projects developed in collaboration with: - Customer - Suppliers - Competitors - Cross-industry firms - Consulting firms - University and colleges	№ of projects (absolute or relative)	DEP	LEAD/	QT	4	(Dubiel et al., 2016; Gurtner & Reinhardt, 2016; Inauen & Andrea Schenker-Wicki, 2011; Saunila et al., 2014)
[IE5]	Openness	Rate of social media tools used to gather information of customers and products in the front-end	To measure the percentage of time social media-driven open innovation in collaborative projects	'How often the Company use social media tools to gather information about your customers and products in the front-end?' % of time (Never, about 25%, 50%, 75%, virtually always) - Blogs /Wikis/Ratings and reviews -Twitter /YouTube - Monitor content distribution to other sites (e.g., Facebook, Connect, ShareThis, etc.) - External social network presence (e.g., Facebook, MySpace) - Branded social network/community - Discussion forums or innovation hubs (centralised customer community to create innovation)	% of time	DEP	LEAD	QT	1	(Du, Yalcinkaya, & Bstieler, 2016)
[IE6]	Openness	Creation of an open corporate culture for a global innovation program	To measure the perception of an open corporate culture for the innovation program. Indicated for large multinational companies.	'What best reflects the Company's global innovation program': 1=strongly disagree 7=strongly agree - Program for recognises and strongly rewards entrepreneurship. - Program actively encourages employees worldwide, to submit new product ideas.	Dimensionless	DEP	LEAD	QL	1	(de Brentani et al., 2010)
[IE7]	Openness	External scanning in open innovation (OI) initiatives	To measure the perception of open innovation initiatives	'What best reflects what the Company has been practising so far?' 1=not at all	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			being developed in the company ('scanning').	7=extensively - Participating in professional association activities; - Attending scientific or professional conferences; - Attending trade shows/exhibitions; - Establishing contacts with researchers at universities; -Reading specialised journals and magazines. -Screening the start-up community.						
[IE8]	Openness	Strategic assessment into bringing external knowledge in OI initiatives	To measure the strategic assessment into bringing external knowledge to the company through open innovation initiatives.	'What best reflects what the Company has been practising so far, to assess external knowledge?' 1=not at all 7=extensively - Evaluating fit with our internal competencies - Verifying applicability to market segments - Assessing potential strategic benefits for our business - Appointing business lines for unsolicited ideas and knowledge	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[IE9]	Openness	Integrating external knowledge in OI initiatives	To measure the degree to which the company has access to external knowledge through open innovation initiatives	'What best reflects what the Company has been practising so far to access external knowledge?' 1=not at all 7=extensively -New kinds of product operations and facilities -Technological expertise in new areas R&D skills and resources in new technical areas -Engineering skills and resources in new technological areas	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IE10]	Openness	Resource recognition in OI initiatives	To measure the perception of recognising the needs and potential of the internal knowledge of the company	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree - We have a thorough understanding of our firm's technological needs - We have a clear overview of current internal knowledge gaps - We recognise internal innovation problems that may require external knowledge -We have a common/consistent understanding of internal knowledge gaps throughout the firm	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[IE11]	Openness	Recombining knowledge in OI initiatives	To measure the integration and linking strategies of the company's internal knowledge and the external resources	'What best reflects what the Company has been practising so far?' 1=not at all 7=extensively - Creating combinations from external and internal knowledge - Integrating different types and sources of external and internal knowledge - Linking external knowledge with our firm's in-house capabilities - Combining external and internal resources into novel configurations (e.g., R&D results, products)	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[IE12]	Servitisation orientation	Servitisation diversification strategy	To measure the diversification of products and services through the percentage of the total budget spent on products, services, mix	'What best reflects what the Company has been practising so far (money or people)?' -% spent on Goods. -% spent on Services. -%t spent on Mix Goods/Services.	% (Monetary units/ Monetary units) % (Nr of people/ Nr of people)	RAP	LAG	QT	3	(Lee & Markham, 2016; Markham & Lee, 2013; Pan & Nguyen, 2015)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IE13]	Servitisation orientation	Attractiveness of downstream opportunities for Product-Service Systems (PSS)	To measure the attractiveness of downstream opportunity for PSSs as a function of the power of distribution channels	Not provided.	NA	DEP	LEAD	NA	1	(T. Baines & Lightfoot, 2013)
[IE14]	Servitisation orientation	Conformance of customer relationships to potentialise PSS	To measure the achievement e of customer relationships to potentialise PSS	Conformance to customer requirements for service-focused operations (Actual value achieved for the service i/Target specification i)	% of achievement	DEP	LEAD	QT	1	(T. Baines & Lightfoot, 2013)
[IE15]	Servitisation orientation	Availability and service delivery performance	To measure the availability and service delivery performance	Not provided.	NA	DEP	LEAD	NA	1	(T. Baines & Lightfoot, 2013)
[IE16]	Servitisation orientation	Flexibility of service systems to meet particular customer needs	To measure the flexibility of service systems to meet particular customer needs	Not provided.	NA	DEP	LEAD	NA	2	(T. Baines & Lightfoot, 2013; Yang, 2009)
[IE17]	Servitisation orientation	Proficiency of service design	To measure how well the company is able to design a service and deliver value to the customers	‘What best reflects what the Company has been practising so far?’ 1=omitted altogether 7=done excellently - Developing a clear value proposition of the service. - Designing the service to ensure that it delivers the promised value proposition. - Integrating state-of-the-art technologies into service design.	Dimensionless	DEP	LEAD	QL	1	(L. Z. Song, Song, & Di Benedetto, Anthony, 2009)
[IE18]	Servitisation orientation	Financial return on servicing activity	To measure return on investment (ROI) from servicing to indicate the potential of PSS	Percentage of ROI from servicing activities.	% (Monetary units/ Monetary units)	DEP	LAG	QT	1	(Chirumalla, Bertoni, Parida, Johansson, & Bertoni, 2013)
[IE19]	Servitisation orientation	Hour spend on product servicing	To measure the total hours staff spent on services to indicate the potential of PSS	$\sum$ Hour spend on product servicing	Hours	DEP	LEAD	QT	1	(Chirumalla et al., 2013)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IE20]	Servitisation orientation	Number of service specialists	To measure the number of service specialists to indicate the potential of PSS	Σ № of service specialists	№ of people	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[IE21]	Sustainability orientation	Sustainability criteria for innovation in new product development	To measure the importance given to sustainability criteria in the product innovation process.	'How important are the following sustainability practices in innovation?' % of time (Never, about 25%, 50%, 75%, virtually always) - Environmental sustainability - Social sustainability (e.g., compliance with ethical guidelines; community affairs; minority purchases) - Sustainability criteria for New Product Development process	% of time	RAP	LEAD	QT	3	(Chung, Chao, Chen, & Lou, 2016; Du et al., 2016; Markham & Lee, 2013)
[IE22]	Sustainability orientation	Develop sustainability policies	To measure the development of internal policies to deal with sustainability issues in the innovation process	'To what degree does the Company do the following?' 1=not at all 5= extremely - Develop sustainability policies - Manage your product's carbon footprint - Select suppliers and partners based on sustainability criteria	Dimensionless	DEP	LEAD	QL	1	(Du et al., 2016)
[IE23]	Sustainability orientation	Use of triple bottom line (TBL) for product planning	To measure the use of the TBL (economic, social, environmental perspectives) in the product planning	'To what degree does the Company do the following?' 1=not at all 5= extremely - Use the triple bottom line for product planning	Dimensionless	DEP	LEAD	QL	1	(Du et al., 2016)
[IE24]	Sustainability orientation	Inclusion of sustainability initiatives in the innovation budget	To measure the inclusion of sustainability initiatives (related to products) in innovation budget	'To what degree does the Company do the following?' 1=not at all 5= extremely - Include sustainability initiatives in your innovation budget	Dimensionless	DEP	LEAD	QL	1	(Du et al., 2016)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[IE25]	Sustainability orientation	Use of sustainability criteria for new product development	To measure to what extent sustainability criteria are used during the new product development process.	Nº of sustainability aspects covered by the elements according to the ISO140001 during the project planning	Nº of sustainability aspects	DEP	LEAD	QT	1	(Du et al., 2016)
[IE26]	Sustainability orientation	Development of environment-friendly products	To measure the percentage of environment/social-friendly products developed by the company	Nº of products produced under actively environmental or social standards (at least by ISO14001)	Nº of products (absolute or relative)	DEP	LEAD	QT	1	(Alegre et al., 2006)
[IE27]	Sustainability orientation	Number of methods and tools used for sustainability in the innovation process	To measure the number of methods or tools used for integrating sustainability criteria into the innovation process	Σ Nº of methods/tools used for sustainability	Nº of methods/tools	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[IE28]	Sustainability orientation	Sustainability initiatives that lead to certifications	To measure to the ratio of sustainability initiatives which lead to certifications in product development	Number/Percentage of sustainability initiatives that lead to certifications (e.g., ISO) in relation to the total number of improvement initiatives in product development	Nº of initiatives (absolute or relative)	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[IE29]	Sustainability orientation	Safety and sustainability concerning recalls	To measure the average number of recalls as a proxy of safety and sustainability	Average number of product recalls (per project)	Average Nº of product recalls (per project)	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[IE30]	Sustainability orientation	Safety and sustainability concerning failure	To measure the average number of failures due to bad design	Average number of failures due to bad design (per project)	Average of Nº of failures (per project)	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[IE31]	Sustainability orientation	Environmental product innovation	To measure the perception of innovations (improvements/modifications) of products toward	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree - Has the Company implemented products design modifications geared toward reducing the quantity of	Dimensionless	DEP	LAG	QL	1	(Amores-Salvadó, Martín-de Castro, & Navas-López, 2015)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			environment-friendliness	material used in their elaboration? - Has the Company implemented products design modifications geared toward increasing the product's useful lifetime? - Has the Company implemented products design modifications by using recyclable components?						
[IE32]	Sustainability orientation	Use of environmental management systems in the innovation process	To measure the use of environmental management systems to support the development of the innovation process.	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Does the Company have a written environmental policy? - Are the Company's environmental impacts clearly defined and documented? - Does the company have measurable environmental targets? - Are the Company's environmental responsibilities well defined? - Does the Company organise environmental learning sessions for employees? - Does the company have improved its environmental information communication structures? - Does the Company have its own periodical procedures to communication results?	Dimensionless	DEP	LEAD	QL	1	(Amores-Salvadó et al., 2015)
[KM1]	Idea management	Percentage of ideas actively generated by formal/informal activities	To measure the rate of generated ideas according to formal and informal activities of the innovation process	'What best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) -Ideas actively generated by formally planned activities (including brainstorming sessions, competitor analysis, trend analysis, customer	% of time	RAP	LEAD	QT	7	(Adams et al., 2006; Brattström et al., 2018; Cooper & Edgett, 2012; Cormican & O'Sullivan, 2004; Eling et al., 2016;

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				observation, etc.) to fill identified gaps in our existing product portfolio - Ideas actively generated by formally planned activities because in general, we need more ideas - Ideas actively generated by informal activities (e.g. time provided for ideation to recognizes "idea" people) to fill identified gaps in our existing product portfolio - Actively generated by informal activities because in general, we need more ideas - Ideas come without specific prompting from a wide variety of people						Lettice, Roth, & Forstenlechner, 2006; C. Loch et al., 1996; Markham & Lee, 2013)
[KM2]	Idea management	Rate of product ideas reviewed or approved (per phase)	To measure the rate of ideas approved per stage of the innovation process	$\sum \text{N^{o}} \text{ of product ideas approved for stage} / \sum \text{total}$	% (N ^o of ideas/ total N ^o of ideas)	RAP	LEAD	QT	4	(Birchall & Tovstiga, 2006; Chiesa et al., 1996; Markham & Lee, 2013; Tuomela, 2005)
[KM3]	Idea management	Rate of new product vs enhancement ideas evaluated in the last year	To measure the rate of new product ideas <i>versus</i> enhancement ideas evaluated in the last year	$\sum \text{N^{o}} \text{ new product ideas} / \sum \text{N^{o}} \text{ product enhancement ideas evaluated in the last year}$	% (N ^o of ideas/ N ^o of enhancement ideas)	DEP	LEAD	QT	1	(Chiesa et al., 1996)
[KM4]	Idea management	Availability and use of tools and techniques for promoting creativity	To measure the availability and use of tools and techniques for promoting creativity for the innovation process	Not provided.	NA	DEP	LEAD	NA	1	(Adams et al., 2006)
[KM5]	Idea management	Rate of team leaders trained in creativity techniques	To measure the rate of team leaders trained in creativity techniques	$\sum \text{N^{o}} \text{ of team leaders (champions/ project managers, etc.) trained in creativity techniques} / \sum \text{total N^{o}} \text{ of employees}$	N ^o of leaders/ N ^o of employees	DEP	LEAD	QT	1	(Chiesa et al., 1996)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[KM6]	Idea management	Existence of project-related intellectual assets management	To measure the practices to maintain intellectual assets management	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree Our company manages its own intellectual assets, e.g. special techniques, patents, copyrights, licenses	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[KM7]	Idea management	Extent of usage of distinct idea generation sources	To measure the degree to which formal idea generation sources	$\sum$ No of ideas according to generation sources (internal departments or market research or external people or suppliers/ technology monitoring)/ $\sum$ Total No of ideas	No idea per source/ Total No of ideas	DEP	LEAD	QT	3	(Crossan & Apaydin, 2010; Eling et al., 2016; Markham & Lee, 2013)
[KM8]	Knowledge repository	Knowledge absorptive capacity	To measure the frequency and, therefore, the knowledge absorptive capacity indirectly	$\sum$ Sum of 24 ratings of the frequency into four main categories: 1: Low frequency 5: High frequency - Capacity in knowledge acquisition in the R&D process in reference to techniques and products from diverse sources; - Capacity in knowledge assimilation in learning new techniques - Capacity in knowledge transformation as the R&D personnel discuss the future R&D strategy/plan with other functions - Capacity in knowledge utilization as to acquire more	Dimensionless	DEP	LEAD	QL	2	(Gurtner & Reinhardt, 2016)
[KM9]	Idea management	Knowledge acquisition vs knowledge absorptive capacity	To measure the frequency of knowledge acquisition vs knowledge absorptive	Average of ‘Use of scientific knowledge sources’ and ‘Use of industrial knowledge sources’ / Knowledge absorptive capacity = AVG [KM17 KM18]/[KM8]	Dimensionless	DEP	LAG	QL	1	(Wang et al., 2010)
[KM10]	Knowledge repository	Rate of R&D projects that lead to innovations	To measure the rate of R&D projects that lead to new or enhanced products, process	$\sum$ No of R&D projects that lead to new or enhanced products, process innovations, licences, patents/ $\sum$ Total No of projects	% (No of R&D projects/ No total projects)	DEP	LAG	QT	2	(W. B. Brown & Gobeli, 1992; Chiesa et al., 1996)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			innovations, licences, patents							
[KM11]	Knowledge repository	Numbers or value of patents developed in the company (versus brought in)	To measure the total numbers or value of patents brought in (considering patents developed internally or acquired)	Σ Number of patents from R&D/Annual expenditure on R&D	% (Monetary units/Monetary units)	DEP	LEAD/ LAG	QT	8	(Adams et al., 2006; W. B. Brown & Gobeli, 1992; Chiesa et al., 1996; Cooper & Kleinschmidt, 1986; Crossan & Apaydin, 2010; Markham & Lee, 2013; Roy & Mitra, 2018; Tipping et al., 1995)
[KM12]	Knowledge repository	Number of licences in/out over the last 3 years	To measure the total number of licences in/out over the last 3 years	Σ No of licences actively brought in/ No of licences actively given to external parties over the last three years	% (No of licenses/ or monetary units)	DEP	LEAD/ LAG	QT	1	(Chiesa et al., 1996)
[KM13]	Knowledge repository	Percentage of active patents	To measure the percentage of active company's patents	Percentage of active patents from the company's assets which are incorporated into or used to defend its commercial products or processes	% of active patents used in products	DEP	LEAD/ LAG	QT	1	(Tipping et al., 1995)
[KM14]	Knowledge repository	Rate of knowledge repository accesses	To measure the rate of knowledge repository/ innovation portal accesses	Number of in the knowledge repository/ innovation portal of the company in a year	Number of accesses	DEP	LEAD	QT	1	(Gerlach & Brem, 2017)
[KM15]	Knowledge repository	Return from intellectual property assets	To measure the revenue or profit from intellectual property assets	Revenue from intellectual property assets (patents /copyright (software or database)	Monetary units	DEP	LAG	QT	1	(Bose, 2004)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[KM16]	Knowledge repository	Diversity of knowledge sources	To measure the frequency of different knowledge sources being used during the innovation process	'What best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) - Techniques/products from competitors - Techniques/products from academic research institutions - Published patents in the industry - Technical publications academic databases - The required R&D knowledge and experiences are documented in our organisation - Our organisation has a standardised administration process in managing and acquiring knowledge for R&D processes and techniques - Our organisation has a well-established knowledge system in saving the R&D outcomes	% of time	RAP	LEAD/ LAG	QT	1	(Markham & Lee, 2013; Wang et al., 2010)
[KM17]	Information flow	Use of scientific knowledge sources	To measure the frequency of scientific knowledge sources used for acquiring knowledge for the innovation process	$\sum$ Sum of the ratings of the frequency of adopting knowledge from: 1=Low frequency 5= High frequency - Industry's R&D Centres - Governmental and industrial research units - Universities and other academic institutes	Dimensionless	DEP	LEAD	QL	1	(Wang et al., 2010)
[KM18]	Information flow	Use of industrial knowledge sources	To measure the frequency of industrial knowledge sources used for acquiring knowledge for the innovation process	$\sum$ Sum of the ratings of the frequency of adopting knowledge from: 1=Low frequency 5=High frequency - Material or equipment suppliers - Customers - Satellite companies - Competitors	Dimensionless	DEP	LEAD	QL	1	(Agostini & Nosella, 2017; Wang et al., 2010)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[KM19]	Information flow	Utilisation rate of inventory knowledge	To measure the utilisation rate of inventory knowledge	Not provided.	NA	DEP	LEAD	NA	1	(Chen, Ren, Bao, Liu, & Ma, 2013)
[KM20]	Information flow	Frequency and effectiveness of supplier' progress reviews	To measure the frequency and effectiveness of supplier' progress reviews/analysis	Not provided	NA	DEP	LEAD	NA	2	(H. Driva, Pawar, & Menon, 2000; Rogers et al., 2005)
[KM21]	Information flow	Clarity and quality of conclusions in technology assessments	To measure the clarity and quality of conclusions in technology assessments	Peer-review assessment of conclusions in technology assessments for technology prospections or for the internal departments (including R&D)	Dimensionless	DEP	LEAD	QL	1	(C. H. Loch & Tapper, 2002)
[KM22]	Information flow	Use of customers as a source of information	To measure the number of customers-driven projects as a proxy for customer's sources	$\sum$ Number of customer-driven new product projects/ $\sum$ Total number of new product project	% of customer-driven projects	DEP	LEAD	QT	1	(Adams et al., 2006)
[KM23]	Information flow	Participation in collaborative research projects	To measure the number of collaboration projects, university links or attendance at trade shows	$\sum$ № of collaboration in research projects, university links or attendance at trade shows per year	Dimensionless	DEP	LEAD	QL	1	(Crossan & Apaydin, 2010; Rantala & Ukko, 2018)
[KM24]	Information flow	Success rate of co-operation project with knowledge exchange	To measure the success rate of co-operation project with universities or other industrial partners characterizes with knowledge exchange	Not provided.	NA	DEP	LEAD	NA	1	(Chen et al., 2013)
[KM25]	Information flow	External recognition	To measure the number of awards/external news as a proxy for innovation efforts external recognition	$\sum$ № of external awards and invited lectures by the professional staff over a relevant time period	№ of awards	DEP	LEAD	QT	1	(Tipping et al., 1995)
[KM26]	Information flow	Published works	To measure the number published works developed	№ of scientific publications and patents by the professional staff over a relevant time period	№ of publications	DEP	LEAD	QT	2	(Roy & Mitra, 2018; Tipping et al., 1995)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[KM27]	Information flow	Time-off for creative things and generation of tacit knowledge	To measure the time given for employees to generate, share, exchange and experiment innovative ideas/solutions.	'What best reflects what the Company has been practising so far?' 1 = Employees carry out their regular duties, and after that, they can begin the creativity-related activity. 5 = We provide time and resources for employees to generate, share/exchange and experiment with innovative ideas/solutions.	Dimensionless	RAP	LEAD	QL	2	(Cooper & Kleinschmidt, 1995, 2007)
[KM28]	Information flow	Reward for employees sharing and using knowledge	To measure the reward systems in place for employees sharing and using knowledge	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree" - Employees are rewarded for sharing and using knowledge.	Dimensionless	DEP	LEAD	QL	1	(Zieba & Zieba, 2014)
[KM29]	Information flow	Employees are valued for what they know	To measure the perceived value given to employees for what they know	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree - Employees are valued for what they know are offered career advancement opportunities	Dimensionless	DEP	LEAD	QL	1	(Zieba & Zieba, 2014)
[KM30]	Information flow	Problem-solving skill of the staff involved in the innovation process	To measure the problem-solving skill of the staff involved in the innovation process qualitatively	'What best reflects what the Company has been practising so far?' 0 = No idea regarding the problem 1= All of the team members severely lacked in problem-solving capabilities, and the problem-solving process was very unstructured 2-3 = Because team members were lacking in problem-solving capabilities, and the problem-solving process was not smooth 3-5= Problem-solving capabilities of the members were moderate, and the problem-solving process was OK 5-7= Problem-solving capabilities of the members were fine; the	Dimensionless	DEP	LEAD	QL	1	(Chang & Ahn, 2005)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				problem-solving went fine with several ideas to address the problem 7-9= Problem-solving capabilities of the team members were very good, and the problem-solving process went smooth with many new ideas to address the problem 10 = Complete understanding of the problem and extremely smooth problem-solving process						
[KM31]	Information flow	Learning skill of the staff involved in the innovation process	To measure the learning skill of the staff involved in the innovation process	'What best reflects what the Company has been practising so far?' 0 = Not understanding at all 1= Very little understanding of the business principle of strategy game 2-3 = Some understanding of the business principle of a strategy game, but not complete 3-5=Moderate understanding of the business principle of a strategy game 5-7= Comfortable understanding of the business principle of a strategy game 7-9= Very comfortable understanding of the business principle of a strategy game 10 = Complete understanding of the business principle of a strategy game	Dimensionless	DEP	LEAD	QL	1	(Chang & Ahn, 2005)
[KM32]	Information flow	Increase in the rate of knowledge resources	To measure the increase in the rate of knowledge resources used in the innovation process	Not provided.	NA	DEP	LEAD	NA	1	(Chen et al., 2013)
[KM33]	Information flow	Adequacy of physical resources for innovation projects	To measure the adequacy of the physical resources for innovation projects	Not provided	NA	DEP	LEAD	NA	1	(Adams et al., 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[KM34]	Information flow	Frequency of knowledge exchange improvements	To measure the frequency of knowledge exchange improvements during innovation projects	Not provided	NA	DEP	LEAD	NA	1	(Chen et al., 2013)
[OC1]	Culture	Organisational climate for innovation	To measure to climate values for innovation in the organisation	'What percentage of time does the Company reflects these values' % of time (Never, about 25%, 50%, 75%, virtually always) - Open to the constructive conflict that occurs within the innovation process - Failure is understood to be a natural part of the innovation process - Both innovation and risk-taking are valued for career development - Recruitment parameters include consideration for innovation potential - Managers establish objectives in the areas of innovation including training, measures and results - These established objectives are used in the performance review process - Our organisation is a learning organisation - Effectively communicates its innovation values internally - Effectively communicates its innovation values externally	% of time	RAP	LEAD	QT	3	(N. Anderson & West, 1996; Dayan & Di Benedetto, 2009; Rodríguez et al., 2008)
[OC2]	Culture	Commitment to risky projects	To measure the perceived commitment to risky projects from the senior management	'What best reflects what the Company has been practising so far?' 1= The top management promotes the development of innovative strategies, even knowing that it is likely that something may go wrong. 2= The top management accepts	Dimensionless	DEP	LEAD	QL	3	(N. Anderson & West, 1996; Cormican & O'Sullivan, 2004; Rodríguez et al., 2008)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				occasional failures and considers them as something natural in business. 3= The top management supports innovation and change. 4= The top management promotes employees' creativity and risk assumption. 5= The top management likes "playing with risk".						
[OC3]	Culture	Concern with innovativeness over profit	To measure the perceived concern with innovativeness over profit from senior management	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree Board of directors and senior management have a higher concern with innovativeness over profit	Dimensionless	DEP	LEAD	QL	1	(Abbey & Dickson, 1983)
[OC4]	Culture	Creativity is rewarded and recognised	To measure the culture of creativity recognition and rewards	Not provided.	NA	DEP	LEAD	NA	2	(Amabile, Conti, Coon, Lazenby, & Herron, 1996; Saunila et al., 2014)
[OC5]	Culture	Support for experimentation	To measure the perceived support for experimentation for R&D and others	Not provided.	NA	DEP	LEAD	NA	3	(Crossan & Apaydin, 2010; Damanpour, 1991; Markham & Lee, 2013)
[OC6]	Culture	Degree of accommodation of failure	To measure the degree of accommodation of failure that arises from trying out	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree Failures and mistakes are tolerated and not punished	Dimensionless	DEP	LEAD	QL	3	(Cooper & Kleinschmidt, 2007; Cormican & O'Sullivan, 2004; Saunila et al., 2014)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[OC7]	Culture	Autonomy in pursuing innovation	To measure the degree of freedom that the personnel have in 'people bending the rules of the organisation to develop the innovation, or be allowed to bypass certain personnel procedures to get people committed to an innovation'	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree An innovation champion should... - make it possible for the people working on an innovation to bend the rules of the organisation to develop the innovation - make it possible for the people working on an innovation to bypass standard operating procedures to develop the innovation - be allowed to bypass certain budgetary procedures to get funds for an innovation - be allowed to bypass certain personnel procedures to get people committed to an innovation	Dimensionless	DEP	LEAD	QL	1	(Shane, Venkatarman, & MacMillan, 1995)
[OC8]	Culture	Personnel autonomy	To measure the degree of freedom personnel has in day to day operating decisions such as work and how to solve job problems	Not provided.	NA	DEP	LEAD	NA	2	(Abbey & Dickson, 1983; Cormican & O'Sullivan, 2004)
[OC9]	Culture	Work environment support for innovation	To measure the current work environment in terms of structure reward system to support innovation	'What best reflects what the Company has been practising so far?' 1 = At the moment, the Company does not have incentives/rewards for development teams. 5 = Employees are recognised and rewarded for creativity and innovative ideas, and there is a structured reward system in place	Dimensionless	RAP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[OC10]	Culture	Senior management actively encourages the	To measure the perceived active encouragement for submission of new	'What best reflects what the Company has been practising so far?' 1=strongly disagree	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		submission of new product ideas	product ideas from senior management	5=strongly agree Senior management actively encourages a culture of submission of new product ideas						
[OC11]	Culture	All employees participate in generating ideas	To measure the sense of participation of all employees participate in the generation of ideas.	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree All employees participate in generating ideas	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)
[OC12]	Culture	The company permits the emergence of 'intrapreneurs' or product champions	To measure the perceived encouragement of 'intrapreneurs' or product champions in the company	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree The organisation permits the emergence of 'intrapreneurs' or product champions	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)
[OC13]	Culture	Early involvement	To measure the percentage of projects with early involvement of production functions	Percentage of projects with early involvement of manufacturing, supplier, procurement/ total number of projects	% of projects	DEP	LEAD	QT	2	(C. Loch et al., 1996; Rogers et al., 2005)
[OC14]	Culture	Trust between area or departments	To measure the perceived trust between areas or departments of the company	'What best reflects what the Company has been practising so far?' 1= We trusted in the working relationship with the other department. 2= It was sincere and honest with us. 3= Its actions always met our expectations. 4= We believed the information is provided. 5= It fulfilled the promises made. 6= It was sincerely concerned about our interests. 7 = We trusted in the other department's capacity to carry out its work appropriately	Dimensionless	DEP	LEAD	QL	1	(Rodríguez et al., 2008)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[OC15]	Structure	Project's work environment	To measure the perceived project's work environment fostered by the company	Not provided.	NA	DEP	LEAD	NA	3	(Adams et al., 2006; Amabile et al., 1996; Prajogo & Ahmed, 2006)
[OC16]	Structure	Reward system based on collectiveness	To measure to what degree the reward system is based on collectiveness instead of individual benefits	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree Our reward system is more group-based than individual-based	Dimensionless	DEP	LEAD	QL	1	(Parthasarthy & Hammond, 2002)
[OC17]	Structure	Organisational structures for conducting the innovation process	To measure the implementation of organisational structures for conducting the innovation process	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree Implementation of new or altered organisational structures	Dimensionless	DEP	LAG	QL	2	(García-Zamora et al., 2013; Tipping et al., 1995)
[OC18]	Structure	Corporate flexibility and responsiveness to change	To measure the perceived corporate flexibility and responsiveness to change in the innovation process	Not provided.	NA	DEP	LEAD	NA	1	(Adams et al., 2006)
[OC19]	Structure	Company's attractiveness for new staff	To measure the perceived the organisation capacity to attract new and qualified personnel	Survey focused on the attractiveness of the organisation as a place to work and undertake innovative activities	Dimensionless	DEP	LEAD	QL	1	(Geisler, 1995)
[OC20]	Structure	Administrative intensity	To measure the ratio of managers to total employees	Ratio of managers to total employees in an organisation in innovation-related areas and else	% (№ of managers/ № of employees)	DEP	LEAD	QT	1	(Damanpour, 1991)
[OC21]	Structure	Organisation structure decision-making scale	To measure the organisation structure for the decision-making process in terms of relying on experts and	'What best reflects what the Company has been practising so far?' 1 = A strong emphasis on giving the most to say in decision-making to formal line managers	Dimensionless	DEP	LEAD	QL	1	(Covin & Slevin, 1989)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			channels of communication	1 = A strong insistence on a uniform managerial style throughout the firm 1= Highly structured channels of communication and a highly restricted important financial and operating information 7 = A strong tendency to let the expert in a say in decision-making to formal line given situation have the most say in managers decision-making, even if this means temporary bypassing of formal line authority 7= Managers' operating styles allowed to range freely from the very formal to the very informal 7 = Open channels of communication with access to important financial and operating information flowing quite freely throughout the organisation						
[OC22]	Structure	Job satisfaction in innovation-related areas and else	To measure job satisfaction in innovation-related areas and else	Comprehensive survey about job satisfaction and stress	Dimensionless	DEP	LEAD	QL	2	(W. B. Brown & Gobeli, 1992; Keller, 2001)
[OC23]	Structure	Adaptiveness of R&D personnel to technology changes	To measure the perceived adaptiveness of R&D personnel to technology change	Not provided.	NA	DEP	LEAD	NA	1	(Amabile et al., 1996)
[OC24]	Structure	Productivity growth in innovative sales	To measure the productivity growth in innovative (new to the market) sales	$[\log(1 + \text{new sales/employees for the last two years}) - \log(1 + \text{new sales/employees for the two years before that})]$	% (monetary units/monetary units)	DEP	LAG	QT	1	(Belderbos, Carree, & Lokshin, 2004)
[OC25]	Structure	Functional diversity	To measure the number of functional areas represented in the teams	$\sum N_{\text{of functional areas (departments) represented on the team whose members were fully involved in the project rather than being } ad \text{ hoc specialists or}}$	Nº of areas or departments	DEP	LEAD	QT	1	(Dayan & Di Benedetto, 2009; Keller, 2001)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				consultants who were engaged only for a limited time						
[PFM1]	Balance	Formalised portfolio management	To measure to what degree there is formal portfolio management.	'What the percentage of innovation projects does the Company review as part of the portfolio management?' % of time (Never, about 25%, 50%, 75%, virtually always) - Radical innovation projects reviewed - More innovative projects reviewed - Incremental project reviewed - All firm's project reviewed	% of time	RAP	LEAD	QT	2	(Beringer, Jonas, & Kock, 2013; Markham & Lee, 2013)
[PFM2]	Balance	Portfolio balance	To measure the balance of the portfolio selection in terms of long-term versus short-term	No long-term innovation projects/ No of short-term innovation projects in bubble charts with four quadrants	No of projects	DEP	LEAD	QT	1	(A. M. Anderson, 2008; Tolonen et al., 2015)
[PFM3]	Balance	Balance high vs low risk	To measure the balance of high <i>versus</i> low risk of new product projects selected	Budget for high innovation projects/ Budget low innovation projects in bubble charts with four quadrants	% (monetary units/monetary units)	DEP	LEAD	QT	2	(Crossan & Apaydin, 2010; Tolonen et al., 2015)
[PFM4]	Balance	Use of economic and benefit models	To measure to what extent the company uses economic/benefit models or simulations to base their decisions.	Not provided.	NA	DEP	LEAD	NA	2	(Crossan & Apaydin, 2010; D. L. Hall & Nauda, 1990)
[PFM5]	Balance	Size of the portfolio	To measure the number of innovation projects (or new products) being developed	$\sum$ No of the number of innovation projects (or new products and components)/ Total No of undergoing projects.	No of projects	DEP	LEAD	QT	3	(H. Driva et al., 2000; Killen et al., 2008; Tolonen et al., 2015)
[PFM6]	Balance	Mindset of the portfolio decision-making effectiveness	To measure the effectiveness of the mindset of the portfolio decision making	'What best reflects what the Company has been practising so far?' Scales not provided - At all times, we have an overview of all the projects in our NPD portfolio	Dimensionless	DEP	LEAD	QL	1	(Kester, Hultink, & Griffin, 2014)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				- We have DEP knowledge about each project in our NPD portfolio - We understand how each project relates to other projects in our NPD portfolio - We know at all times how many projects are in which stage of development - We can readily anticipate where bottlenecks may occur in our development pipeline						
[PFM7]	Balance	Focus of the portfolio decision making effectiveness	To measure the perceived focus of the portfolio decision-making effectiveness	'What best reflects what the Company has been practising so far? Scales not provided -We focus our innovation resources to achieve our portfolio priorities -It is clear which projects in our portfolio have priority -Nothing distracts us from executing our priorities - Our resource allocation in the short term reflects our long-term priorities - We work in a focused manner and do not easily get distracted from our priorities	Dimensionless	DEP	LEAD	QL	1	(Kester et al., 2014)
[PFM8]	Balance	Agility of the portfolio decision making effectiveness	To measure the perceived agility of the portfolio decision making effectiveness	'What best reflects what the Company has been practising so far? Scales not provided -We readily change the composition of our portfolio to respond to new strategic opportunities -We proactively change the composition of our portfolio to anticipate market changes -We implement decisions fast -Our portfolio decision-making processes are speedy enough to assure that we can quickly act upon	Dimensionless	DEP	LEAD	QL	1	(Kester et al., 2014)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				new opportunities -We rapidly change our portfolio priorities when we detect a new market opportunity						
[PFM9]	Balance	Maximal value of portfolio management	To measure perceived maximal value of portfolio management achieved.	'What best reflects what the Company has been practising so far?' -Our portfolio contains several high-impact projects in terms of revenues -Over the past three years, we maximized the return on investment from our portfolio -We believe that the current composition of our portfolio will maximize long-term (>3 years) profitability -We believe that the current composition of our NPD portfolio will maximize market share growth over the long term (>3 years)	Dimensionless	DEP	LEAD/ LAG	QL	2	(A. M. Anderson, 2008; Kester et al., 2014)
[PFM10]	Balance	Portfolio balance	To measure the portfolio balance in continuing decisions	'What percentage of the time does the Company use a defined innovation strategy to?' % of time (Never, about 25%, 50%, 75%, virtually always) - Formulate investment decisions - Formulate platform decisions - Formulate project selection decisions	% of time	RAP	LEAD	QT	3	(Cooper et al., 2004; Kester et al., 2014; Killen et al., 2008)
[PFM11]	Balance	Innovation portfolio strategic alignment	To measure the alignment of the innovation projects aligned with the business's objectives	'What percentage of the time does the Company use a defined innovation strategy to?' % of time (Never, about 25%, 50%, 75%, virtually always) -Formulate project continuation decisions -Formulate decisions within active projects	% of time	RAP	LEAD	QT	4	(Cormican & O'Sullivan, 2004; Kester et al., 2014; Killen et al., 2008; Tipping et al., 1995; Tolonen et al., 2015)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[PFM12]	Evaluation tools	Level of proficiency in portfolio management	To measure the perceived efficiency in the portfolio management	‘What best reflects what the Company has been practising so far?’ 1. Issue not recognized 2. Initial efforts are made toward addressing issue 3. Right skills are in place 4. Appropriate methods are used 5. Responsibilities are clarified 6. Continuous improvement is underway	Dimensionless	DEP	LEAD	QL	1	(Suomala, 2004)
[PFM13]	Evaluation tools	Post project appropriateness in the light of results	To measure the appropriateness of project selections in the light of results post-projects	Not provided.	NA	DEP	LEAD	NA	1	(Adams et al., 2006)
[PFM14]	Evaluation tools	Use of market criteria in portfolio selection	To measure the perceived use of market criteria when evaluating projects in the portfolio selection	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 7=strongly agree -Fulfilling customer needs was used as an evaluation criterion when evaluating product concepts -Market potential was used as an evaluation criterion when evaluating product ideas -Market potential was used as an evaluation criterion when evaluating product concepts -Probability of commercial success was used as an evaluation criterion when evaluating product concept	Dimensionless	DEP	LEAD	QL	1	(Martinsuo & Poskela, 2011)
[PFM15]	Evaluation tools	Use of strategic criteria in portfolio selection	To measure the perceived use of strategic criteria when evaluating projects in the portfolio selection	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 7=strongly agree - Possibility of new markets, new product platforms, new technologies	Dimensionless	DEP	LEAD	QL	1	(Martinsuo & Poskela, 2011)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				were used as a criterion when evaluating projects product concepts -Fit with business strategy was used as a criterion when evaluating projects						
[PFM16]	Evaluation tools	Use of technical criteria in portfolio selection	To measure the perceived use of technical criteria when evaluating projects in the portfolio selection	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Manufacturing feasibility was used as an evaluation criterion - Probability of technical success (e.g., technology availability, project complexity) was used as an evaluation criterion -Technical feasibility was used as an evaluation criterion	Dimensionless	DEP	LEAD	QL	1	(Martinsuo & Poskela, 2011)
[PM1]	Project efficiency	Commitment of resources for new product projects	To measure the percentage of time resources (funding/ people) are committed to the development of innovation projects	'What percentage of time is the following practice employed in development teams in the Company?' % of time (Never, about 25%, 50%, 75%, virtually always) Teams are given the needed resources to be effective.	% of time	RAP	LEAD/ LAG	QT	3	(Adams et al., 2006; Cooper & Kleinschmidt, 1995, 2007)
[PM2]	Project efficiency	Project efficiency comparisons between budget and actual performance achieved	To measure the achievement between budget and actual values (project costs, project duration, revenue forecasting).	$(\sum \text{Actual value } i / \text{Target value } i)$, where i is project costs, project duration, revenue forecasting for (at least six months, 1, 2, 3 after launch)	% of achievement	DEP	LEAD/ LAG	QT	8	(A. M. Anderson, 2008; W. B. Brown & Gobeli, 1992; Chiesa, Frattini, Lazzarotti, & Manzini, 2004; Chiesa & Masella, 1996; Detzen, Verbeeten, Gamm, & Möller, 2018; H.

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
										Driva et al., 2000; Rodríguez et al., 2008; Rogers et al., 2005)
[PM3]	Project efficiency	Innovation speed per stage	To measure the average completion time of innovation projects per stage	Project time from the beginning of project approval to the end of market launch	Time (months/days)	DEP	LAG	QT	2	(Kessler & Chakrabarti, 1996; Rogers et al., 2005)
[PM4]	Project efficiency	Technical performance success	To measure the perceived technical performance success of the innovation project	‘What best reflects the last innovation project for the Company, considering the project technical success criteria?’ 1= Significantly worse than expectations 3= Achieved our pessimistic estimate 5= Exactly on target 7= Achieved our optimistic estimate 9= Significantly better than expectations	Dimensionless	DEP	LAG	QL	2	(Chiesa et al., 1996; Tatikonda & Rosenthal, 2000)
[PM5]	Project efficiency	Project complexity	To measure the perceived project complexity. This indicator can be measured with traditional indicators of projects complexity in terms of number of systems, sub-systems, and components.	‘What best reflects the last innovation project for the Company:’ 1= No impact at all 7= Great impact - On average, a design change in one product module was expected to impact the design effort for other product modules this much - On average, a design change in one manufacturing stage was expected to impact the design effort for other manufacturing stages this much - A design change in the product technologies was expected to impact the design effort for the manufacturing technology this much	Dimensionless	DEP	LEAD	QL	1	(Tatikonda & Rosenthal, 2000)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[PM6]	Project efficiency	Project execution success	To measure the perceived success of projects performed	‘What best reflects the last innovation project for the Company, considering the project unit-cost and time-to-market success criteria?’ 1= Significantly worse than expectations 3= Achieved our pessimistic estimate 5= Exactly on target 7= Achieved our optimistic estimate 9= Significantly better than expectations	Dimensionless	DEP	LEAD	QL	4	(Cooper & Edgett, 2012; Griffin & Page, 1993; Rogers et al., 2005; Tatikonda & Rosenthal, 2000)
[PM7]	Project efficiency	Projects are termination when appropriate	To measure to what degree projects are terminated when necessary ("gate with teeth")	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree Projects are terminated if and when necessary	Dimensionless	DEP	LEAD	QL	2	(Cooper & Edgett, 2012; Cormican & O’Sullivan, 2004)
[PM8]	Project efficiency	Pre-development market and feasibility studies	To measure if the company performs activities of market and feasibility studies before engaging in the projects	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree Pre-development market and feasibility studies are undertaken	Dimensionless	DEP	LEAD	QL	1	(Cormican & O’Sullivan, 2004)
[PM9]	Project efficiency	Time-to-market accuracy	To measure the accuracy in determining the length of time it takes from idea until its being available for sale	Actual length of time it takes from idea until its being available for sale vs planned.	% (time - months, person-years/ time - months, person-years)	DEP	LEAD/ LAG	QT	6	(Birchall & Tovstiga, 2006; W. B. Brown & Gobeli, 1992; H. Driva et al., 2000; Griffin & Page, 1993; Lakiza et al., 2018; Reid & de Brentani, 2010; Tuomela, 2005)
[PM10]	Project efficiency	Average innovation project	To measure the average innovation project development time	Average innovation project development time	Time (months or person-years)	DEP	LEAD	QT	3	(Alegre et al., 2006; Atuahene-Gima, 1995; Henttonen et al.,

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		development time								2016; Zhang & Doll, 2001)
[PM11]	Project efficiency	Average innovation projects working hours	To measure the average number of innovation projects working hours	Average number of innovation projects working hours	Time (hours)	DEP	LEAD	QT	3	(Alegre et al., 2006; Chiesa et al., 2004; Zhang & Doll, 2001)
[PM12]	Project efficiency	Average cost per innovation project	To measure the average cost per innovation project	Average cost per innovation project	Monetary units	DEP	LEAD/ LAG	QT	5	(Alegre et al., 2006; Atuahene-Gima, 1995; Pattikawa, Verwaal, & Commandeur, 2006; Woodman, Sawyer, & Griffin, 1993; Zhang & Doll, 2001)
[PM13]	Project efficiency	Global satisfaction with innovation projects efficiency	To measure the perceived global satisfaction with innovation projects efficiency	Survey within most departments the global satisfaction degree with innovation projects efficiency	Dimensionless	DEP	LEAD	QL	2	(Alegre et al., 2006; Chiesa et al., 1996)
[PM14]	Project efficiency	Focus on the development of innovation projects	To measure the perceived focus the development of innovation projects	$\sum$ Nº of parallel projects in the department/area/business unit according to the classification of innovation projects (radical and new to the Company)/Total number of projects	Nº of projects	DEP	LEAD	QT	1	(C. Loch et al., 1996)
[PM15]	Project efficiency	Innovation project merit	To measure the perceived project desirability, expected utility, and strategic need of the project	Score given by the innovation managers*factors. Factors= project desirability, expected utility, strategic need, development time & cost, stage of innovation, product life before obsolescence, potential technical interactions with existing products, technology spin-offs)	Dimensionless	DEP	LEAD/ LAG	QL	1	(Pillai et al., 2002)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[PM16]	Project efficiency	Efficiency of requirement identification	To measure the efficiency of customer requirements identification	Not provided.	NA	DEP	LEAD	NA	1	(Dimitris Mourtzis, Fotia, & Doukas, 2015)
[PM17]	Project efficiency	Value maximisation of innovation projects	To measure the expected traditional financial indicators	Financial indicators (NPV, ECV, IRR, COGS, sales turnover, commercial prospect, size of financial opportunity, market attractiveness)	Monetary units	DEP	LEAD/ LAG	QT	3	(Chiesa et al., 2004; Griffin & Page, 1993; Lakiza et al., 2018; Mazur, 2017; Tolonen et al., 2015)
[PM18]	Project efficiency	Number of financial high-value indicators	To measure the number of high-value financial high-value indicators for innovation projects	$\sum$ Number of high-value indicators for innovation projects above a certain threshold	Nº of financial indicators	DEP	LEAD/ LAG	QT	1	(Tolonen et al., 2015)
[PM19]	Project efficiency	Use of lessons learned from past projects	To measure the number of lessons learned used in new projects	$\sum$ Nº of lessons learned used in different projects or $\sum$ Nº of lessons captured during a period	Nº of lessons	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[PM20]	Project efficiency	Design lifecycle time per project	To measure the average lifecycle time per project	Average of time elapsed from the design to production per project (lifecycle in the company)	Time (months/years)	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[PM21]	Project efficiency	Target rigidity of project parameters	To measure the perceived target rigidity of project parameters	'What best reflects what the Company has been practising so far?' 1=Not true at all 5=Completely true -After the determination of the project parameters, they were fixed with no leeway for negotiations -After an accepted review, the goal parameters had to be realised -The original goal definition was a fixed standard according to which the project's progress was measured	Dimensionless	DEP	LEAD	QL	1	(Detzen et al., 2018)
[PM22]	Project efficiency	Time to breakeven per new product	To measure the time to breakeven per new product family	Time to breakeven per new product family in the period considered	Time (months or person-years)	DEP	LEAD	QT	2	(Birchall & Tovstiga, 2006; Griffin & Page, 1993)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[PM23]	Tools	Degree of use of project management tools	To measure the percentage of time the projects the PM structures/tools	'What percentage of time are the following PM practices employed in the Company?' % of time (Never, about 25%, 50%, 75%, virtually always) -A distinct Division or Venture with its own Profit & Loss statement -A separate R&D or similar to permanent multifunctional staff -Project management is treated as a separate function ("Project office") with a "New Product Committee" of functional resource owners -A "New Product Committee" of functional resource owners is assembled -Marketing/ Engineering /R&D /Production /Other drives development of new products - The structure is a sequential workflow through each function In collaboration projects, what % use Formal Partnership agreements	% of time	RAP	LEAD	QT	3	(Chiesa et al., 1996; Markham & Lee, 2013; Rogers et al., 2005; Souitaris, 2002)
[PM24]	Tools	Frequency of post-launch reviews	To measure the frequency of formal post-launch review procedures	'What best reflects what the Company has been practising so far?' 1=Not known 2=Annually review 3=Semi-annually review 4=Quarterly review 5= Monthly review or more often than monthly review	Dimensionless	RAP	LEAD	QL	3	(Adams et al., 2006; Atuahene-Gima, 1995; Cooper & Edgett, 2014a)
[PM25]	Tools	Ratio of certified processes	To measure the ratio of certified processes used in innovation projects.	$\sum$ Number of certified processes (with standards, e.g., ISO or documented processes) used in the project/ $\sum$ Total number of projects	% of certified processes per project	DEP	LAG	QT	2	(Chiesa et al., 1996; Rogers et al., 2005)
[PM26]	Tools	Use of computer-	To measure the percentage of new	Percentage of products in electronic format (e.g. on CAD database, use of PDM)	% of products	DEP	LEAD	QT	2	(Chiesa et al., 1996; Parthasarthy &

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		integrated development	products in electronic format							Hammond, 2002)
[PM27]	Tools	Voice of the customer (VoC) in innovations	To measure the perceived use of (VoC) to capture insights to be used in the IFE	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree The voice of the customer is built into all innovations	Dimensionless	DEP	LEAD	QL	1	(Cormican & O’Sullivan, 2004)
[PM28]	Tools	Social tools adoption in innovation projects	To measure the number of social tools adopted in innovation projects	$\sum$ № of successful social tools (e.g., ethnography, design thinking, observation, focus group) adoption per project	№ of tools	DEP	LEAD	QT	1	(Chirumalla et al., 2013)
[PM29]	Coordination	Internal shared decisions	To measure the degree to which departments share decisions about innovation projects	Not provided.	NA	DEP	LEAD	NA	3	(Chiesa et al., 1996; Kivimäki et al., 2000; Souitaris, 2002)
[PM30]	Coordination	Informal internal communication	To measure the frequency of informal internal communications	Frequency of informal discussions concerning new ideas for innovation projects	№ of meetings	DEP	LEAD	QT	3	(Chiesa et al., 1996; Kivimäki et al., 2000; Souitaris, 2002)
[PM31]	Coordination	Communication within projects	To measure the perceived effectiveness of internal and external communication within innovation projects	‘What best reflects what the Company has been practising so far?’ % of time (Never, about 25%, 50%, 75%, virtually always) -There was frequent communication within the team. -The team members often communicate in spontaneous meetings, phone conversation, etc. -Important information was kept away from other team members in a certain situation. -In our team, there were conflicts - regarding the openness of the information flow. -The team members were happy with the timeliness in which they received	% of time	RAP	LEAD	QT	6	(Chiesa et al., 1996; Keller, 2001; Kivimäki et al., 2000; Rodríguez et al., 2008; Sivasubramanian, Liebowitz, & Lackman, 2012; Souitaris, 2002)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				information from other team members. -The team members were happy with the precision of the information received from other team members. -The team members were happy with the usefulness of the information received from other team members						
[PM32]	Coordination	Time-to-market management	To measure the perceived management and knowledge of the time-to-market for a typical innovation project	'For a typical innovation project, please indicate the typical length of time (in weeks) spent on each of these activities in the Company?'	Time (weeks/ months)	RAP	LEAD/ LAG	QT	6	(Chiesa et al., 1996; Keller, 2001; Kivimäki et al., 2000; Rodríguez et al., 2008; Sivasubramanian et al., 2012; Souitaris, 2002)
[PM33]	Coordination	Internal communication frequency	To measure the frequency of internal communication in terms of the number of innovation committees	$\sum$ No of committees in an organisation and the frequency of innovation committee meetings	No of meetings	DEP	LEAD	QT	2	(Damanpour, 1991; Souitaris, 2002)
[PM34]	Coordination	Internal communication face-to-face	To measure the number of face-to-face contacts among people to discuss innovation	$\sum$ No of contacts (face-to-face and others) among people at the same and different levels to discuss innovation	No of contacts	DEP	LEAD	QT	2	(Damanpour, 1991; Souitaris, 2002)
[PM35]	Coordination	Internal communication between R&D and marketing	To measure the perceived internal communication R&D and marketing within innovation projects	'What best reflects what the Company has been practising so far?' 1=R&D department does not think that it needs to work with marketing in developing new products 2=Technical people want better coordination with marketing but lack the skills to analyse the business applications from a technical idea 2=Technical people know how to develop applications of a technology, but lack of methods for working	Dimensionless	DEP	LEAD	QL	1	(Maier et al., 2012)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				backwards from a customer need to selecting product concept 3=Work closely with marketing, but has difficulties in sorting out where responsibilities lie between technical concept and product concept 4=Close coordination between R&D and marketing departments, but has not figures out how to develop new products effectively 5=Close coordination, with the technical person in charge of marketing and taking the lead in technical marketing and new market development						
[PM36]	Coordination	Communication of user needs analyses during innovation projects	To measure to what degree the user needs analyses are communicated to all related to the project	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree User needs analyses are undertaken and communicated to all related to the project	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)
[PM37]	Coordination	Facilitation for coordinating between cross-functional teams	To measure the percentage of time the there is a process-owner to facilitate coordination between cross-functional teams	'What best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) We use a facilitating "process owner" to help the cross-functional teams move through stages and management review	% of time	DEP	LEAD	QT	1	(Markham & Lee, 2013)
[PM38]	Coordination	Cross-functional discussions for top decision-making	To measure if the decision-making at top levels is characterised by cross-functional discussions	Not provided.	NA	DEP	LEAD	NA	1	(Adams et al., 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[PM39]	Coordination	Internal collaboration of cross-functional teams	To measure the perceived internal collaboration of cross-functional teams	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Joint planning and early involvement of production and marketing groups in new product decision making Improved cooperation in implementing new product decisions made by R&D	Dimensionless	DEP	LEAD	QL	1	(Jassawalla & Sashittal, 1999)
[PM40]	Coordination	Percentage of projects with the involvement of customers	To measure the percentage of projects with the involvement of customers	Frequency of formal meetings with the presence of customers concerning new ideas (in the IFE)	No of meetings	DEP	LEAD	QT	1	(Adams et al., 2006)
[PM41]	Coordination	Percentage of projects with the involvement of suppliers	To measure the percentage of projects with the involvement of suppliers	Frequency of formal meetings with the presence of suppliers concerning new ideas (in the IFE)	No of meetings	DEP	LEAD	QT	1	(Urban & von Hippel, 1988)
[PM42]	Coordination	Percentage of projects coordinated with distinct business units	To measure the percentage of projects in cooperation with distinct business units	$\sum$ Number of projects in coordinated with distinct BUs/ $\sum$ Total number of projects	% (of projects with BUs/ projects)	DEP	LEAD	QT	1	(Kerssens-van Drongelen & Bilderbeek, 1999)
[PM43]	Coordination	Efficiency of collaboration	To measure the perceived efficiency of project collaboration	Not provided.	NA	DEP	LEAD	NA	1	(Dimitris Mourtzis et al., 2015)
[TM1]	Technology potential	Constantly thinking of new technology	To measure perceived mindset for planning the development of new technology	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -We are constantly thinking of the next generation of technology.	Dimensionless	DEP	LEAD	QL	2	(Cormican & O’Sullivan, 2004; Prajogo & Ahmed, 2006)
[TM2]	Technology potential	Level of new technologies monitoring	To measure the perceived importance of monitoring new technologies	‘What best reflects what the Company has been practising so far?’ % of time (Never, about 25%, 50%, 75%, virtually always) -Technology is not a major issue for	% of time	RAP	LEAD	QT	3	(Birchall & Tovstiga, 2006; Markham & Lee, 2013; Verhaeghe & Kfir, 2002)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				our company. -We follow up, from time to time, on technological advancements that may impact our current product and/or services. -We regularly follow up on technological advancements that may impact our current products and/or services. -We regularly follow up on technological advancements that may improve our current products and/or services, & markets & adjacent technologies that may bring about a complete breakthrough in our activities.						
[TM3]	Technology potential	Acquire project technological capabilities in advance of needs	To measure the perceived importance of acquiring project technological capabilities in advance of needs	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -Our company always attempts to stay on the LEAD edge of new technology in our industry. -We pursue long-range programmes in order to acquire technological capabilities in advance of our needs.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[TM4]	Technology potential	Technology Innovativeness vs product innovativeness	To measure the perceived importance of innovativeness in technology <i>versus</i> product innovativeness	Not provided.	NA	DEP	LEAD	NA	1	(Serrano-bedia, López-fernández, & García-piqueres, 2018; Szymanski et al., 2007)
[TM5]	Technology potential	Degree of technology radicalness of new products	To measure the degree of technology radicalness of new products	Not provided.	NA	DEP	LAG	NA	1	(Pattikawa et al., 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TM6]	Technology potential	Balance of targeted technology performance vs actual	To measure the balance between targeted technology performance vs actual	$[\sum \text{Number of technology target requirement } i / \text{Actual } i]$, where i is technical feasibility, technical gap, familiarity of technology, technical track record, technical results of today - proof of concept	% of achievement	DEP	LEAD	QT	1	(Tolonen et al., 2015)
[TM7]	Technology potential	Enhancement of the unit's technology competence	To measure the perceived enhancement of the technology competence	Not provided.	NA	DEP	LAG	NA	1	(Cho & Lee, 2005)
[TM8]	Technology potential	Technological turbulence	To measure the perceived technological turbulence within the company environment	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -The technology in our market is changing rapidly. -Technological changes provide big opportunities in our markets. -It is very difficult to forecast where the technologies in our markets will be in the next five years.	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[TM9]	Technology potential	Technology-related capability performance	To measure the perceived overall technology-related capability performance of the company	'What best reflects what the Company has been practising so far?' 1= behind competition 7= ahead of competition -Technology development capabilities -New product development capabilities -Manufacturing capabilities	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[TM10]	Technology potential	Technology push vs need pull	To measure the force drivers of innovation technology push <i>versus</i> need pull	Not provided.	NA	DEP	LEAD/ LAG	NA	1	(Rothwell, 1992)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TM11]	Technology potential	Mix of technology development vs acquirement	To measure the ratio of investment in internal development <i>versus</i> tech acquirement	Volume in monetary units of investment in internal development in spending/ Volume of investment in tech acquirement	% (monetary units/monetary units)	DEP	LEAD	QT	2	(Cho & Lee, 2005; Sartorius, Eitzen, Trollip, & Uliana, 2011)
[TM12]	Technology potential	Importance of intellectual property (IP) for protecting technology development	To measure the importance of IP as a major component of new product development strategy	'How often intellectual property is a major component of the Company's technology development?' % of time (Never, about 25%, 50%, 75%, virtually always)	% of time	RAP	LEAD/ LAG	QT	2	(Lilien, Morrison, Searls, Sonnack, & Hippel, 2002; Markham & Lee, 2013)
[TM13]	Technology potential	Degree of technology tools used	To measure the percentage of time innovation projects apply technology tools	'For each technology tools, what best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) -Lean New Product Development -Design for Manufacturing, Assembly, Testing, DFX -Failure Mode & Effect Analysis (FMEA) -Six Sigma Analysis -TRIZ (Theory of Inventive Problem Solving) -Theory of Constraints -Rapid Prototyping Systems -Performance Modelling & Simulation Systems -Virtual Reality/Virtual Design/Cave Technology -Remote Collaborative Design Systems -Product Data Management Systems - Portfolio Management Software -Customer Needs/Requirements Analysis Software -Project Management Systems.	% of time	RAP	LEAD	QT	3	(Adams et al., 2006; Markham & Lee, 2013)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TM14]	Technology potential	Technology novelty	To measure the perceived degree of technology novelty developed in the company	'What best reflects what the Company has been practising in comparison to major competitors?' 1=behind 3=comparable 5=leader -The level of newness (novelty) of our firm's new products is... -The speed of the new product development process is... -The number of new has introduced to the market is... - The number of our new products that are first to market (early market entrants) is...	Dimensionless	DEP	LEAD	QL	3	(Cho & Lee, 2005; Prajogo & McDermott, 2011; Tatikonda & Rosenthal, 2000)
[TM15]	Technology potential	Extension of technology and product range	To measure the perceived extension of product range within main product field	'What best reflects what the Company has been practising in comparison to major competitors?' 1= Much worse 4= At the same level 7= Much better -Extension of product range within main product field through technologically new products -Extension of product range within main product field through technologically improved products -Extension of product range outside main product field	Dimensionless	DEP	LEAD	QL	2	(Alegre et al., 2006; Jayaram & Narasimhan, 2007)
[TM16]	Technology potential	Technology diversification	To measure the spread of the patent portfolio over technology classes	$1/\sum (N_i/N)^2$, where N=denote the number of patents in the technology portfolio of a certain firm that are assigned to technology class i	% (patents/patents) ²	DEP	LAG	QT	1	(Leten, Belderbos, & Looy, 2007)
[TM17]	Technology potential	Technology coherence	To measure the as the degree to which technologies share the same underlying knowledge base (i.e.,	$(\sum R^*P)/\sum P$, where $R=(O+O)/(E+E)$ and $E=O*(N/T)$; O_{ij} number of cited patents of technology class j in citing patent grants of technology class i, and $T=\sum N$; N_j be the total number of	No of patents	DEP	LAG	QT	1	(Leten et al., 2007)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
			technologically related technologies)	patents that are classified in technology class j, and weighted by the patent counts in each technology field (Pj).						
[TM18]	Technology potential	Time to breakeven per new technology	To measure the time to breakeven per new technology developed by the company	Time to breakeven per new technology developed	Time (months or person-years)	DEP	LAG	QT	1	(Birchall & Tovstiga, 2006)
[TM19]	Technology potential	Profit from new technologies	To measure the profit from new technologies used in new products or licenses	Profit from new technologies	Monetary units	DEP	LAG	QT	1	(Birchall & Tovstiga, 2006)
[TM20]	Technology potential	External technological resource access	To measure the perceived access the external technological resources	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 7=strongly agree -We have a thorough understanding of our firm’s technological needs -We have a clear overview of current internal knowledge gaps -We recognise internal innovation problems that may require external knowledge -We have a common/consistent understanding of internal knowledge gaps throughout the firm	Dimensionless	DEP	LEAD	QL	1	(Zobel, 2017)
[TM21]	Research & Development	Strategic importance of R&D	To measure the perceived importance of lead-edge R&D for the company.	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Our R&D pursues truly innovative and lead-edge research. -Our R&D strategy is mainly characterized by high-risk projects with a chance of high return. -R&D plays a major part in our business strategy	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006; Prajogo & Sohal, 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TM22]	Research & Development	R&D intensity	To measure the ratio of between R&D investments by turnover	Expending R& D activities/ total turnover (money/ number of people)	% (monetary units/monetary units) or (№ people/Total № people)	RAP	LEAD/ LAG	QT	4	(Brattström et al., 2018; Ebersberger & Herstad, 2011; Kleinknecht, 1987; Parthasarthy & Hammond, 2002)
[TM23]	Research & Development	Funding adequacy for R&D projects	To measure the financial resources and funding adequacy for R&D projects	‘What best reflects what the Company has been practising so far?’ 1=Primary demand for the product or service was beginning to grow. The market was new; the technology and competition were just beginning to emerge. 2=Demand was growing at 10% or more annually in real terms. The competition and technology structure of the market was still changing rapidly. 3=The products or services in the market were familiar to the majority of prospective customers. Technology and competitive structure of the market was fairly stable. 4=Products or services were viewed as commodities by a vast majority of customers.	Dimensionless	DEP	LEAD/ LAG	QL	1	(Atuahene-Gima, 1995)
[TM24]	Research & Development	Slack of resources for changes in the company’s budget/funding	To measure the number of changes in the budget and sources of finance as a proxy for the slack of resources	Average of the № of changes in the company’s budget and sources of finance during the last three years	№ of changes	DEP	LEAD/ LAG	QT	1	(Damanpour, 1991)
[TM25]	Research & Development	R&D or technology	To measure the R&D or technology acquisition	Σ R&D or technology acquisition expenditure per product	Monetary units	DEP	LEAD/ LAG	QT	1	(Chiesa et al., 1996)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		acquisition cost per product	cost per new product develop							
[TM26]	Research & Development	Ratio of cost/benefit of completed R&D projects	To measure the ratio between the cost of completed R&D projects and revenue from new product	Actual cost expenditure of completed R&D projects/ revenue from new product development (3 or 5 years) after launch	% (monetary units/monetary units)	DEP	LAG	QT	1	(Chiesa et al., 1996)
[TM27]	Research & Development	Virtual reality tools as a source of testing new technology	To measure the degree of use of virtual reality tools as a source of testing new technology	'For each technology tools, what best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) -Virtual Reality -Virtual Design -Cave Technology	% of time	DEP	LEAD	QT	1	(Markham & Lee, 2013)
[TM28]	Research & Development	Level of latest technological innovations	To measure the perceived level of the latest technological innovations in the company against the industry	'What best reflects what the Company has been practising in comparison to major competitors?' 1=Worst in industry 5=Best in industry -The use of the latest technological innovations in our new products.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[TM29]	Research & Development	Technological competitiveness	To measure the perceived technological competitiveness of the company against the industry	'What best reflects what the Company has been practising in comparison to major competitors?' 1=Worst in industry 5=Best in industry -The use of the latest technological innovations in our new products.	Dimensionless	DEP	LAG	QL	2	(Prajogo & Ahmed, 2006; Prajogo & McDermott, 2011)
[TM30]	Research & Development	'Updated-ness' or novelty of technology used in processes	To measure the 'updated-ness' or novelty of technology used in processes of the company against the industry	'What best reflects what the Company has been practising in comparison to major competitors?' 1=Worst in industry 5=Best in industry -The level of newness (novelty) of our firm's new products.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TM31]	Research & Development	Speed of adoption of the latest technological innovations in processes	To measure the perceived speed of adoption of the latest technological innovations in processes against the industry	'What best reflects what the Company has been practising in comparison to major competitors?' 1=Worst in industry 5=Best in industry -The speed with which we adopt the latest technological innovations in our processes.	Dimensionless	DEP	LEAD	QL	2	(Prajogo & Ahmed, 2006; Prajogo & McDermott, 2011)
[TM32]	Research & Development	Rate of changes in processes, techniques & technology	To measure the perceived rate of changes in processes, techniques and technology against the industry	'What best reflects what the Company has been practising in comparison to major competitors?' 1=behind 3=comparable 5=leader -The rate of change in our processes, techniques and technology is...	Dimensionless	DEP	LEAD	QL	2	(H. Driva et al., 2000; Prajogo & McDermott, 2011)
[TM33]	Research & Development	Technology synergy	To measure the perceived technology synergy	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Product was totally new to the firm. -Product process was totally new to the firm. -Product involved technology totally new to the firm.	Dimensionless	DEP	LEAD/ LAG	QL	2	(Atuahene-Gima, 1995; Pattikawa et al., 2006)
[TM34]	Research & Development	Technical knowledge resources	To measure the technical knowledge resources in terms of staff	$\sum \text{No of tech employees} / \sum \text{Total No of employees}$	No of employees/ total employees	DEP	LEAD	QT	1	(Damanpour, 1991)
[TM35]	Research & Development	Ratio between R&D spending and profit per product family	To measure the ratio between R&D spending and profit per product family	R&D spending/ profit per product family	% (monetary units/monetary units)	DEP	LAG	QT	1	(Birchall & Tovstiga, 2006)
[TEAM1]	Cross-functionality	Cross-functional team	To measure the percentage of time of perceived cross-functionality between team cooperation	'What percentage of time are the following practices employed for the development teams in the Company?'	% of time	RAP	LEAD	QT	2	(Cooper & Kleinschmidt, 1995; Damanpour, 1991)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				% of time (Never, about 25%, 50%, 75%, virtually always) -Good cross-functional cooperation on the team (e.g. representatives not too much time and effort wasted on politics, conflicts, interdepartmental prejudices, etc.).						
[TEAM2]	Cross-functionality	Identifiable project team leader	To measure the percentage of time distinct identifiable project team leader practices	'What percentage of time are the following practices employed for the teams in the Company?' % of time (Never, about 25%, 50%, 75%, virtually always) -A professional project/program manager whose only job is project management- -A full-time project leader borrowed from a full-time position for a single project- -A part-time project leader who has other duties- -The project team is self-directed -A process owner serves as leader -A project champion who reside - anywhere in the organisation mover project along-	% of time	RAP	LEAD	QT	3	(Cooper et al., 2004; Markham & Lee, 2013; Sivasubramania m et al., 2012)
[TEAM3]	Cross-functionality	Cross-functional training	To measure the percentage of time of cross-functional training occurs	'What percentage of time are the following practices employed for the development teams in the Company?' % of time (Never, about 25%, 50%, 75%, virtually always) -Cross-functional team training occurs -Cross-functional/Multidisciplinary goals and objectives are established for teams -Team goals and objectives are related to the company strategy	% of time	RAP	LEAD	QT	4	(Cooper et al., 2004; C. Loch et al., 1996; Markham & Lee, 2013; Rogers et al., 2005)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TEAM4]	Cross-functionality	Team member flexibility, multi-skilling and training use	To measure the perceived Team member flexibility, multi-skilling and training use	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree - Employee flexibility, multi-skilling and training are actively used to support performance improvement	Dimensionless	DEP	LEAD	QL	2	(Prajogo & Ahmed, 2006; Sivasubramanian et al., 2012)
[TEAM5]	Cross-functionality	Dedicated Innovation group	To measure the existence of a dedicated project group assigned to the innovation task	‘What percentage of time are the following practices employed for the development teams in the Company?’ % of time (Never, about 25%, 50%, 75%, virtually always) -Teams have the skill set needed to be effective -Teams are given the needed resources to be effective -Teams are 100% co-located -Teams are a virtual team and only meet electronically -Teams are made up of people that are globally dispersed -Overall, how often are your teams effective	% of time	RAP	LEAD	QT	2	(Adams et al., 2006; Cooper & Kleinschmidt, 1995)
[TEAM6]	Cross-functionality	Team member communication	To measure the perceived team member communication	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Our company has maintained both ‘top-down’ and ‘bottom-up’ communication processes.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)
[TEAM7]	Cross-functionality	Team member satisfaction regularly measured	To measure the perceived team member satisfaction	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Employee satisfaction is formally and regularly measured.	Dimensionless	DEP	LEAD	QL	1	(Prajogo & Ahmed, 2006)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[TEAM8]	Cross-functionality	Interaction frequency of the project team	To measure the perceived interaction frequency relating to the regularity of contact and communication within the project team	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Regular contacts with each other -Organisational members meet frequently to talk -Lots of giving and taking -Members keep each other informed -Real attempts to share information -Members share information with each other -members feel understood and accepted -Members influence each other -Minority's view is listened to	Dimensionless	DEP	LEAD	QL	1	(Kivimäki et al., 2000)
[TEAM9]	Cross-functionality	Virtual team members seamlessly communicate with each other	To measure the perceived communication of team members with each other seamlessly	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -Virtual team members seamlessly communicate with each other.	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)
[TEAM10]	Cross-functionality	Team potency	To measure the perceived team potency	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -Members have confidence in the team -This team gets a lot done -No task is too tough for the team -This team does high-quality work -This is a high performing team -This team can solve any problem -This team is very productive	Dimensionless	DEP	LEAD	QL	2	(A. M. Anderson, 2008; Howell & Shea, 2006)
[TEAM11]	Cross-functionality	Team cohesiveness	To measure the team cohesiveness	Not provided.	NA	DEP	LEAD	NA	2	(Dayan & Di Benedetto, 2009;

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
										Sivasubramanian et al., 2012)
[TEAM12]	Cross-functionality	Transactive memory system for team members	To measure the perceived transactive memory system for team members (the way in which groups collectively encode, store, and retrieve knowledge)	Not provided.	NA	DEP	LEAD	NA	1	(Dayan & Di Benedetto, 2009)
[TEAM13]	Cross-functionality	Team learning	To measure the team learning skills	Not provided.	NA	DEP	LEAD	NA	2	(Cho & Lee, 2005; Dayan & Di Benedetto, 2009)
[TEAM14]	Cross-functionality	Degree of novelty the team has achieved	To measure the degree of novelty the team has achieved	$\sum$ No of concepts the team has achieved in a given project, which can be rated as germinal, original, and revolutionary	No of new concepts	DEP	LEAD	QT	1	(Bissola, Imperatori, & Colonel, 2014)
[TEAM15]	Cross-functionality	Degree of resolution the team has achieved	To measure the perceived degree of resolution the team has achieved	'What best reflects what the team has been practising so far?' 1=Low attendance 7=High attendance -How well the output meets the expressed needs, which can be rated as adequate, appropriate, logical, useful, and valuable	Dimensionless	DEP	LEAD	QL	1	(Bissola et al., 2014)
[TEAM16]	Cross-functionality	Degree of elaboration and synthesis the team has achieved	To measure the perceived degree of elaboration and synthesis, the team has achieved	'What best reflects what the team has been practising so far?' 1=Low attendance 7=High attendance Overall design and quality of the components, which can be rated as attractive, complex, elegant, expressive, organic, and well crafted.	Dimensionless	DEP	LEAD	QL	1	(Bissola et al., 2014)
[TEAM17]	Team stability	Team innovative behaviour	To measure the team's innovative behaviour in the innovation process	'What percentage of time are the following practices employed for the	% of time	RAP	LEAD	QT	1	(Post, 2012)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator				#	References
				development teams in the Company?' % of time (Never, about 25%, 50%, 75%, virtually always) -Our team creates new ideas which are transformed into useful applications -In our company, we tolerate individuals who do things in a different way -We are willing to try new ways of doing things and seek unusual, novel solutions -We encourage people to think and behave in original and novel ways -When we see new ways of doing things, we are last at adopting them -When we cannot solve a problem using conventional methods, we improvise on new methods							
[TEAM18]	Team stability	Team adaptability	To measure the perceived team's ability to adapt and to react early and with little effort to changed conditions and unforeseen events	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -We were able to identify specific areas that were affected by changes early on -We were able to develop change plans at an early stage in order to manage emerging changes -We were able to initiate arrangements for specific areas in order to manage changes with little effort at an early stage -If activities within the development process did not lead to the intended results, changes could be implemented soon and with little	Dimensionless	DEP	LEAD	QL	1		(Detzen et al., 2018)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				effort -We were able to react early and with little effort to changed conditions and unforeseen events						
[TEAM19]	Team stability	Team process autonomy	To measure perceived team's process autonomy to organise and determine the extent of certain activities.	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -My project team was free to choose and organise the ways and means for goal attainment. -Within the project's progress, my project team was free to determine a convenient time for attaining certain activities. -Within goal attainment, my project team was free to organise and determine the extent of certain activities.	Dimensionless	DEP	LEAD	QL	1	(Detzen et al., 2018)
[TEAM20]	Team stability	Team 'at stakeness'	To measure the involvement of team members in producing an outcome of a team effort as a product that is constructed jointly	Not provided.	NA	DEP	LEAD	NA	2	(Alegre et al., 2006; Jayaram & Narasimhan, 2007)
[TEAM21]	Team stability	Development team self-esteem	To measure the perceived self-esteem the development team	Not provided.	NA	DEP	LEAD	NA	2	(Keller, 1986; Kessler & Chakrabarti, 1996)
[TEAM22]	Team stability	Propensity of an individual to innovate	To measure the propensity of an individual to innovate	Not provided.	NA	DEP	LEAD	NA	1	(Keller, 1986)
[TEAM23]	Team stability	Individual skills are effectively leveraged within and between project teams	To measure the perception if the individual skills are effectively leveraged within and between project teams.	'What best reflects what the Company has been practising so far?' 1=strongly disagree 5=strongly agree -Individual skills are effectively	Dimensionless	DEP	LEAD	QL	1	(Cormican & O'Sullivan, 2004)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				leveraged within and between project teams						
[TEAM24]	Team stability	Team tenure	To measure the team tenure using as a proxy the percentage of people having a pertinent degree	Percentage of people having a pertinent degree (with respect all the people devoted to technological innovation). Time is also used as a proxy for tenure.	% of people years	DEP	LEAD	QT	1	(Bantel & Jackson, 1989; Sivasubramanian et al., 2012)
[TEAM25]	Team stability	All team members are mutually accountable	To measure the perceived accountability of all team members of development teams	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -All team members are mutually accountable	Dimensionless	DEP	LEAD	QL	1	(Cormican & O’Sullivan, 2004)
[TEAM26]	Team stability	Team members are empowered to make decisions	To measure the perception of team members are empowerment to make decisions	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Team members are empowered to make decisions	Dimensionless	DEP	LEAD	QL	1	(Cormican & O’Sullivan, 2004; Dayan & Di Benedetto, 2009; Saunila et al., 2014)
[TEAM27]	Team stability	Team members' rewards are equitable	To measure the perception of the reward system	‘What best reflects what the Company has been practising so far?’ 1=strongly disagree 5=strongly agree -Team members' rewards are equitable	Dimensionless	DEP	LEAD	QL	1	(Cormican & O’Sullivan, 2004; Dayan & Di Benedetto, 2009; Saunila et al., 2014)
[TEAM28]	Team stability	Teamwork quality	To measure the quality of teamwork.	Not provided.	NA	DEP	LEAD	NA	1	(Dayan & Di Benedetto, 2009)
[TEAM29]	Team stability	Time spent on innovation outside formal projects	To measure the time spent on innovation-related activities outside formal projects	Time spent on innovation-related activities outside formal projects	Time (hours)	DEP	LEAD	QT	1	(Lakiza et al., 2018; Nilsson & Ritzén, 2014)
[MA1]	Market research and testing	Degree of use of market research tools	To measure the percentage of use market research (e.g., focus group, customer	‘For each market research tools/technique presented, what best reflects what the Company has been practising so far?’	% of time	RAP	LEAD/ LAG	QT	2	((Adams et al., 2006; Markham & Lee, 2013)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator				#	References
			site visits, etc.) tools in innovation projects.	% of time (Never, about 25%, 50%, 75%, virtually always) -Focus Groups (interview as a group for needs) -Customer Site Visits (observe and interview at their workplace) -Ethnography (observe customers and their environment for needs) -Lead Users (analysis and/or inclusion) -Voice of the Customer (1-on-1 in-depth interviews for needs) -Creativity Sessions (professionally moderated) -Online focus groups, online surveys etc. -Online communities, net ethnography, virtual shopping, semiotics							
[MA2]	Market research and testing	Collection and use of market information	To measure the perceived collection and use of market information in innovation projects.	‘What best reflects what the Company has been practising so far?’ 1= not an accurate description 7= a very accurate description -Listens to opinions of customers. -Uses customer information to improve the quality of products and services. -Company objectives are based mainly on customer needs. -Uses customer information to develop new products or services. -Uses market research data in managing products and services. -Uses market research data in segmenting markets. -Obtains ideas from customers to improve products and services. -Company personnel have adequate	Dimensionless	DEP	LEAD	QL	1	(Atuahene-Gima, 1995)	

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				information about customers and competitors. -Values customer input in new product/service planning.						
[MA3]	Market research and testing	Market analysis, planning and monitoring	To measure the importance of market analysis, planning & monitoring in the R&D and innovation projects.	'What best reflects what the Company has been practising so far?' 1=not at all 5= highly important - Commercial feasibility of R&D plans innovation projects -Number of staff in a market intelligence role -R&D contact hours with (final) customers -Formalised technology gate-keeping function in place	Dimensionless	DEP	LEAD	QL	2	(Birchall & Tovstiga, 2006; Verhaeghe & Kfir, 2002)
[MA4]	Market research and testing	Reaching the customer	To measure the percentage of time customers are used to articulate needs	'How often customer-driven information is used?' % of time (Never, about 25%, 50%, 75%, virtually always) -Determine customer needs by reviewing buying habits -Determine the articulated needs of existing customers - Determine the articulated needs of potential customers -Determine the unarticulated needs of customers -Determine the unarticulated needs of potential customers - Track trends to predict future needs of customers -Track trends to predict future needs of potential customers	% of time	DEP	LEAD	QT	2	(Markham & Lee, 2013; Verhaeghe & Kfir, 2002)
[MA5]	Market research and testing	Market learning tools	To measure the perception of the use of market learning tools	'How often market learning tools are used?' -We tried to keep our market opportunity options open as long as	Dimensionless	DEP	LEAD	QL	1	(Reid & de Brentani, 2010)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
				possible for the new technology. -We tried to develop several potential technological scenarios before choosing market(s) to pursue. -We use forecasting and market estimation techniques before making a market selection. -We use several forecasting and market estimation techniques in combination before market selection.						
[MA6]	Market research and testing	Proactive market orientation	To measure the perception of proactive market orientation of the company	'How often the Company adopts proactive market orientation? - We continuously try to discover additional needs of our customers of which they are unaware. - We incorporate solutions to unarticulated customer needs in our new products and services. - We brainstorm on how customers use our products and services.	Dimensionless	DEP	LEAD	QL	2	(García-Zamora et al., 2013)
[MA7]	Market research and testing	Benchmarking activities	To measure the number of benchmarking activities used to monitor the market	$\sum$ No of benchmarking activities undertaken used to monitor the market	No of benchmarking	DEP	LEAD	QT	1	(Lettice et al., 2006)
[MA8]	Market research and testing	Use of competitor orientation	To measure the competitor orientation to acquire market information	Not provided.	NA	DEP	LAG	NA	2	(Healy, Ledwith, & O'Dwyer, 2014; O'Dwyer & Ledwith, 2010)
[MA9]	Market research and testing	Competitor intensity	To measure the perceived competitor intensity to acquire market information and dissemination	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Competitors offer very intensity aggressive prices to our customers -Competitors offer new or improved products to our customers -The competitors have easily replaceable offers to ours	Dimensionless	DEP	LAG	QL	1	(García-Zamora et al., 2013)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[MA10]	Market research and testing	Customer satisfaction indicators for new products	To measure the customer satisfaction indicators	Customer satisfaction indicators for new products (20 options)	Dimensionless	DEP	LEAD	QL	3	(W. B. Brown & Gobel, 1992; Edgett & Snow, 1996; Griffin & Page, 1993)
[MA11]	Market research and testing	Product testing proficiency	To measure the perceived product testing proficiency. It can be used for service as well.	'For each customer testing tools/technique presented, what best reflects what the Company has been practising so far?' % of time (Never, about 25%, 50%, 75%, virtually always) -Alpha Testing (early tests with users) -Beta Testing (tests of working models by users) -Gamma Testing (testing with the ideal product) -Pre-test Markets (including Simulated Testing Marketing, information acceleration) -Test Markets or pilot product releases -Concept Engineering (formal method for concept development) -Concept Tests (customer evaluation of concept statements) -Trade-off Analysis (conjoint, discrete choice modelling) -Fusing qualitative and quantitative or qualiquant methods	% of time	RAP	LEAD/ LAG	QT	2	(Markham & Lee, 2013)
[MA12]	Market research and testing	Market budget attainability	To measure the attainability of the market budget	$(\sum \text{Actual market budget } i / \text{Target or original market budget } i)$	% of achievement	DEP	LEAD	QT	2	(Cooper & Edgett, 2012; Griffin & Page, 1993)
[MA13]	Market research and testing	Field trials	To measure the number of field trials	$\sum \text{Nº of field trials of the new product within the project}$	Nº of field trials	DEP	LEAD	QT	1	(H. Driva et al., 2000)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
[MA14]	Market monitoring	Launch products	To measure of new products launched in last year, 3 or 5 years	$\sum$ № of products launched in a given period	№ of products	DEP	LEAD	QT	3	(Cooper & Edgett, 2012; Helen Driva et al., 2001; Strang, 2011)
[MA15]	Market monitoring	Market monitoring proficiency	To measure the perceived market monitoring in terms of indicators measured after the launch	'Which indicators are most important to the Company to monitor results after launch?' 1=Not applied, 2=Slightly applied, 3=Partially applied, 4=Applied, 5=Applied and collaborative -New Product sales as % of total sales -Profit from New Product sales -Total cost of New Product effort as a per cent of revenue -Project cost vs budget -% of the R&D budget allocated to Radical Innovations -Number of Innovative products achieved within the last N years -Number of projects/products at each stage of their life cycle -Number of new patents generated -Net Margin, ROI -Market share trends -Technical (level of service) -Environmental impacts -Social impact	Dimensionless	RAP	LEAD/ LAG	QL	5	(Griffin & Page, 1993; Markham & Lee, 2013; O'Dwyer & Ledwith, 2010; L. Z. Song et al., 2009; M. X. Song & Parry, 1996)
[MA16]	Market monitoring	Personnel proficiency	To measure the perceived personnel proficiency through the appearance and expertise of sales force and customer service personnel	'What best reflects what the Company has been practising so far?' 1=strongly disagree 7=strongly agree -Quality of the product was improved through the appearance and expertise of sales force and customer service personnel.	Dimensionless	DEP	LEAD	QL	1	(Atuahene-Gima, 1995)
[MA17]	Market monitoring	Formal post-launch reviews	To measure the quality of formal post-launch	'What best reflects what the Company has been practising so far?'	Dimensionless	DEP	LEAD	QL	1	(Atuahene-Gima, 1995)

APPENDICES

Table V.1. Database of performance indicators (continued).

ID	Sub-dimension	Title	Purpose	Formula and scales	Units	Type of indicator			#	References
		to analyse market indicators	reviews to analyse market indicators	1=not at all 7=highly - Quality of formal post-launch reviews to analyse market indicators						
[MA18]	Market monitoring	Adherence to a commercialisation schedule	To measure the adherence to a commercialisation schedule	(Σ Actual commercialisation schedule/Target commercialisation schedule for a new product	% of achievement	DEP	LEAD	QT	3	(Adams et al., 2006; Griffin & Page, 1993; Markham & Lee, 2013)
[MA19]	Market monitoring	Involvement customer service and support	To measure the involvement of customer service/ support	'Is customer service and customer support personnel part of the launch team?' ('Yes/No')	Dimensionless	DEP	LEAD	QL	1	(Kahn et al., 2006)
[MA20]	Market monitoring	Opening of new markets abroad and new domestic	To measure the perceived opening of new markets abroad or new domestic target groups orientations activities	'What best reflects what the Company has been practising in comparison to major competitors?' 1= Much worse 4= At the same level 7= Much better -Opening of new markets abroad -Opening of new domestic target	Dimensionless	DEP	LAG	QL	1	(Alegre et al., 2006; Spanò et al., 2017)
[MA21]	Market monitoring	Market share evolution	To measure the perceived market share evolution. Typically used with the market share or green market share.	'What best reflects what the Company has been practising in comparison to major competitors?' 1= Much worse 4= At the same level 7= Much better -Market share evolution	Dimensionless	DEP	LAG	QL	1	(Alegre et al., 2006)

APPENDIX VI. EVOLUTIONARY CHARACTERISATION OF PERFORMANCE LEVELS

This appendix presents in full the ‘soft’ and ‘hard’ description of the characterisation of each performance level from 1 to 4 for the nine dimensions of the PF. Table VI.1 presents the ‘soft’ description with the characteristic requirements from the literature, while Table VI.2 presents the ‘hard’ characterisation with benchmark values for the PIs.

Table VI.1. ‘Soft’ characterisation of the performance levels for each dimension.

Dimension	Level 1	Level 2	Level 3	Level 4
Innovation strategy Adapted from (Barczak & Kahn, 2012; Barczak, Kahn, & Moss, 2006; Cooper et al., 2000)	IS-IO1-1: No innovation/new product goals explicitly established in the strategy. IS-IO2-1: New projects are identified during the budget process and resources allocated accordingly. IS-Le1-1: Leadership decisions on funding drives new project selection. IS-Le2-1: Leadership has a short-term, tactical view of the innovation process.	IS-IO1-2: Unclear innovation/new product or unclear alignment between these and the strategy. IS-IO2-2: New projects are identified during the budget process and resources allocated accordingly. IS-Le1-2: Leadership related to R&D capability dictates new project’s priorities. IS-Le2-2: Leadership has short to mid-term strategic view of the innovation process.	IS-IO1-3: Innovation/new product goals clearly stated and aligned with the organisational strategic plan. IS-IO2-3: Innovation goals plan drive new project selection. IS-Le1-3: Leadership applies market studies to guide strategic plan priorities. IS-Le2-3: Leadership has mid-term strategic view of the innovation process.	IS-IO-4: Mission plan help define strategic areas for new opportunities and establish clear innovation/new product goals in the strategic plan. IS-IO2-4: Opportunity identification is ongoing and can predict the strategic plan real-time in order to respond to market forces and new technologies. IS-Le1-4: Leadership applies market studies to identify strategies buckets of resources to facilitate innovation in prospecting future exercises. IS-Le2-4: Leadership has a long-term, strategic view of the innovation process.
Knowledge management Adapted from	KM-IdM1-1: There is a flurry of innovation activities without any discipline surrounding the management of ideas.	KM-IdM1-2: There are individuals and/or organisational units dedicated to idea management. An idea database is maintained.	KM-IdM1-3: A common innovation process cuts across organisational groups, where different groups use their own tailored process.	KM-IdM1-4: There is a focus of interest is to share knowledge with other organisations, and to

APPENDICES

Table VI.1. 'Soft' characterisation of the performance levels for each dimension (continued).

Dimension	Level 1	Level 2	Level 3	Level 4
(Barczak & Kahn, 2012; Barczak et al., 2006; Cooper et al., 2000; Klimkó, 2001)	KM-InF1-1: No formalisation of the innovation process exists. There are no process owners, only occasional innovation champions. KM-R1-1: Data (e.g., criteria to evaluate ideas, projects) on past projects are irregularly stored and managed.	But ideas coming from external sources are inexistent. KM-InF1-2: There is an informal, decentralised innovation process that can be readily circumvented by anyone. Limited documentation on the innovation process. KM-R1-2: Minimum data on past projects are stored and managed.	KM-InF1-3: Documentation on the innovation process is available. There is apparent innovation process discipline, but time-critical projects may skip stages of the process. KM-R1-3: Records on past projects and documentation play an important role and are mandatory.	exploit common ways of knowledge creation and idea generation. KM-InF1-4: There are formal, documented processes. There are individuals and/or organisational units dedicated to knowledge management in the innovation process. KM-R1-4: The knowledge management function improves itself continuously, in an optimising manner.
Organisation and culture Adapted from (N. Anderson & West, 1996; Barczak & Kahn, 2012; Kahn et al., 2006)	OC-C1-1: No vision for innovation is provided. The organisation does not take risks in selecting projects. OC-C2-1: Top management focuses on costs and other factors rather than the innovation process. All ideas come from within the company. OC-C3-1: Constant evaluation and close supervision of personnel in day to day operating decisions. OC-S1-1: No reward system recognising entrepreneurship. OC-S2-1: No motivation and job satisfaction measurement.	OC-C1-2: Unclear innovation vision. The organisation undertakes risky projects with little to no regard to the mix appropriateness. OC-C2-2: Top management still focus on costs and other factors rather than the innovation process, and the budget decision does not favour innovation projects. OC-C3-2: Sporadic evaluation and supervision of personnel in day to day operating decisions. OC-S1-2: Informal recognition, but no reward system related to innovation endeavour. OC-S2-2: Sporadic motivation and job satisfaction measurement.	OC-C1-3: An innovation vision is aligned with the organisation's mission. The organisation assumes calculated risk-taking in selecting projects. OC-C2-3: Top management addresses innovation in board meetings, and part of the budget is destined for innovation projects. OC-C3-3: Freedom from evaluation and close supervision of personnel in day to day operating decisions. OC-S1-3: Reward system recognising entrepreneurship for top and middle management. OC-S2-3: Motivation and job satisfaction measurement.	OC-C1-4: A clearly stated, attainable, valuable shared vision is portrayed. The organisation assumes calculated risk-taking in a systematic way. OC-C2-4: Top management clearly supports the innovation process with the provision of budget and further resources. OC-C3-4: Organisations provide sufficient freedom to allow for the exploration of creative possibilities, but sufficient control to manage innovation in an effective and efficient fashion. OC-S1-4: Management rewards and recognises entrepreneurship from mostly anyone in the company. OC-S2-4: Motivation and job satisfaction measurement

APPENDICES

Table VI.1. 'Soft' characterisation of the performance levels for each dimension (continued).

Dimension	Level 1	Level 2	Level 3	Level 4
				integrated into the company's balanced scorecard.
Portfolio management Adapted from (Barczak & Kahn, 2012; Cooper et al., 2000; Kahn et al., 2006)	PFM-B1-1: No process for undertaking portfolio management. PFM-B2-1: There is no balance ponderation into the decision of initiating new innovation projects. PFM-EvT1-1: No concern over the prioritisation of projects being developed. Pet projects are prevalent. PFM-EvT2-1: Innovation projects may or may not be aligned with the organisation's mission/ strategic vision.	PFM-B1-2: The ability to secure funding drives the innovation portfolio selection. PFM-B2-2: The variety of innovation projects are supported with little to no regard to the mix appropriateness. PFM-EvT1-2: Projects' prioritisation is reviewed independently (within areas/departments), but some pet projects that do not fit with the mission may exist. PFM-EvT2-2: Most innovation projects are aligned with the budget decisions that may or may not be aligned with strategy.	PFM-B1-3: Portfolio decisions are made during budgeting, but resources can be made available should a new opportunity comes. PFM-B2-3: Decisions of trade-offs to balance innovation projects are made still informally to manage resources. PFM-EvT1-3: Projects in the portfolio are often prioritised. Very few, if any, pet projects exist unless approved by the management. PFM-EvT2-3: Most innovation projects are aligned with the organisation's mission/ strategic plan.	PFM-B1-4: A formal and systematic portfolio management process is in place. PFM-B2-4: There is a keen consideration for balancing the number of projects and available resources. PFM-EvT1-4: There is ranking or prioritisation of projects, with no pet projects in the mix. PFM-EvT2-4: All projects must be aligned with the organisation's mission/ strategic plan.
Project management Adapted from (Barczak & Kahn, 2012; Kahn et al., 2006; PMI, 2008)	PM-E1-1: No identifiable project leader. PM-E2-1: Functional areas only support those ideas which they originated. PM-T1-1: Pet projects are the ones only being managed. PM-T2-1: No project post-mortem reviews conducted.	PM-E1-2: Project leader(s) assigned to key projects. PM-E2-2: Functional areas only support those ideas which they originated, with eventual support of the technical or marketing areas. PM-T1-2: Most projects are standardised with project management tools and techniques. PM-T2-2: Project post-mortem reviews are conducted in an <i>ad-hoc</i> manner.	PM-E1-3: Project leader(s) assigned to most projects. PM-E2-3: Innovation activities between functional areas are coordinated through informal communication, not in a formalised and systematic way. PM-T1-3: Most projects are controlled with project management tools and techniques. PM-T2-3: Project post-mortem reviews are performed for most innovation projects.	PM-E1-4: Project leader(s) assigned to most projects with cross-functional teams underlie the innovation process. PM-E2-4: Innovation activities between functional areas are coordinated through formal and informal communication. PM-T1-4: Most projects are managed controlled with project management tools and techniques. PM-T2-4: Project post-mortem reviews are performed for all innovation projects.

APPENDICES

Table VI.1. 'Soft' characterisation of the performance levels for each dimension (continued).

Dimension	Level 1	Level 2	Level 3	Level 4
Technology management Adapted from (Prajogo & Sohal, 2006; Urban & von Hippel, 1988)	TM-TO1-1: Adoption of new technology only after well established and standardised. TM-TO2-1: Short-term view of technological capabilities in advance of needs. TM-P1-1: No effort in anticipating the potential of new practices and technologies. TM-R&D1-1: No use of IP protection strategies for R&D exploration. TM-R&D2-1: R&D intensity is not known nor compared.	TM-TO1-2: In the mainstream of technology in the company's industry. TM-TO2-2: Tactical view of technological capabilities in advance of needs. TM-P1-2: Punctual exercises to anticipate the full potential of new practices and technologies. TM-R&D1-2: Sporadic use of IP protection strategies for R&D exploration, but no clear guidelines. TM-R&D2-2: R&D intensity is inferior to other companies in the same sector and industry.	TM-TO1-3: Up to date with new technology, but not necessarily first. TM-TO2-3: Mid-range programs in order to acquire technological capabilities in advance of needs. TM-P1-3: Effort to anticipate the full potential of new practices and technologies, not in a systematic fashion. TM-R&D1-3: Use IP protection strategies for R&D exploration. TM-R&D2-3: R&D intensity is similar to other companies in the same sector and industry.	TM-TO1-4: Ongoing efforts to stay on the leading edge of new technology in the company's industry, translated into R&D. TM-TO2-4: Long-range programs in order to acquire technological capabilities in advance of needs. TM-P1-4: Effort to anticipate the full potential of new practices and technologies, systematically. TM-R&D1-4: Clear management of IP protection strategies for R&D exploration. TM-R&D2-4: R&D intensity is superior to other companies in the same sector and industry.
Team management Adapted from (Barczak & Kahn, 2012; Cooper et al., 2000; Kahn et al., 2006)	TEAM-Cr1-1: Innovation process is performed by individuals. Prevalent departmental silos. TEAM-Cr2-1: No attempts of cross-functional training for development teams. TEAM-St1-1: Champions shepherd projects and are a mainstay of project success TEAM-St2-1: No identifiable innovation or new product development area. Personnel take on too many projects.	TEAM-Cr1-2: Innovation process is decentralised with separate teams within each business unit/department. TEAM-Cr2-2: Champions shepherd cross-functional training for development teams. TEAM-St1-2: Projects are simply handled by department managers. TEAM-St2-2: Champions exist for each project, but not necessary for project success.	TEAM-Cr1-3: Departmental liaisons comprise the innovation process, with a cross-functional team. TEAM-Cr2-3: Departmental resources go into cross-functional training for development teams. TEAM-St1-3: Innovation is committee-focused (with cross-functional meetings). TEAM-St2-3: Full-time managers dedicated to innovation/new product development.	TEAM-Cr1-4: Cross-functional teams underlie the innovation process. Each project has a core team which remains on the project from beginning to end. TEAM-Cr2-4: Ongoing of cross-functional training for development teams. TEAM-St1-4: Innovation is team-focused. TEAM-St2-4: Full-time employees and managers dedicated to innovation/new product development.

APPENDICES

Table VI.1. 'Soft' characterisation of the performance levels for each dimension (continued).

Dimension	Level 1	Level 2	Level 3	Level 4
Market Adapted from (Barczak & Kahn, 2012; Cooper et al., 2000; Kahn et al., 2006)	MA-RT1-1: No market research performed; if any, market research is predominantly anecdotal evidence. Focus on current organisation needs and problems. MA-RT2-1: Customer/user is not involved in the innovation process nor the testing of ideas/concepts/products. MA-MgS1-1: No customer surveys nor impact analysis of the product in the market are performed.	MA-RT1-2: Market research is reactive in nature. Secondary research is performed once a project begins. Market studies are performed once a project begins. No market research function; primary market research is outsourced. MA-RT2-2: Pilot testing predominant form of testing. No real evaluation of testing with the user. MA-MgS1-2: Customer surveys are used to monitor the performance of the product in the market.	MA-RT1-3: Market research used to help develop product definition. A formal market research function exists in the organisation. MA-RT2-3: Concept testing, product testing, and market testing are used in some, but not all innovation projects. Results of testing are formally evaluated. MA-MgS1-3: Customer surveys and subject matter experts are used for informal monitoring of the product in the market.	MA-RT1-4: New Product definitions are based on market research with users and stakeholders. Market studies are ongoing, and market research has an integral relationship with innovation activities. MA-RT2-4: Concept, product and market testing are consistently undertaken and expected with all innovation projects. MA-MgS1-4: The product use phase in the market is monitored and managed.
Innovation environment Adapted from (Burger et al., 2013; Cagnin et al., 2005; Enkel et al., 2011)	IE-Op1-1: Little initiative to accidental opportunity spotting to collaborate with third parties. IE-Ser1-1: No focus on PSS in the IFE. Service elements are not part of the innovation process development. IE-Sus1-1: Sustainability concern is occasionally mentioned but not backed up with actions.	IE-Op1-2: Incipient management support and informal success sharing of opportunities to innovate with third parties. IE-Ser1-2: Service elements are added further down at the end of the development phase. IE-Sus1-2: Sustainability concern for sustainability is balanced with compliance and costs but is seen as a separate subject. Decisions for sustainability are based on a balanced risk/reward	IE-Op1-3: Written Open Innovation strategy and more formal success sharing of opportunities to innovate with third parties. IE-Ser1-3: Service ideas are also considered in the innovation process. Service elements are integrated into the development phase. IE-Su1s-3: Sustainability concern is a major business driver but not in total harmony with other goals. The business driver is its customers; thus productivity and efficiency are still more valued than sustainability	IE-Op1-4: Open innovation assessment of opportunities in a systematic way. Wide focus on external opportunities. IE-Ser1-4: Focus on developing PSS solutions from the beginning of the IFE. IE-Sus1-4: Sustainability concern drives the business in perfect harmony for all activities (sustainability-driven organisation).

Legend for the encoding used in Table VI.1.

APPENDICES

First grouping of letters: denotes the dimensions: **IS**- innovation strategy; **KM**- knowledge management; **OC**-organisation and culture; **PFM**-portfolio management; **PM**- project management; **TM**-technology management; **TEAM**-team management; **MA**-market and **IE**-innovation environment.

Second grouping of letters: denotes the sub-dimensions: **IO**-innovation orientation and **Le**-leadership; **IdM**-idea management, **InF**-informational flows and **R**-knowledge repository; **C**-organisational culture and **S**-organisational structure; **B**-portfolio balance and **EvT**-portfolio evaluation tools; **E**-project management efficiency and **T**-project management tools; **TO**-technology orientation, **P**-technology potential and **R&D**: R&D efficiency; **Cr**: team cross-functionality and **St**: team stability; **RT**: market research and testing and **MgS**: marketing and sales; **Op**: openness, **Ser**: servitisation and **Sus**: sustainability.

Number: the number just beside the sub-dimension denotes the order of that characteristic, and the number at the end refers to the performance level.

Reading example: **KM-InF1-1** Characterising practice 1 for dimension knowledge management, sub-dimension information flows, for performance level 1.

Table VI.2. 'Hard' characterisation of the performance levels for each dimension.

Performance dimension	Sub-dimension (requirement)	Performance indicator	Scale	Level 1	Level 2	Level 3	Level 4	Sample reference
Innovation strategy	Innovation orientation	(IS-IO1) [IS1] Level of awareness of innovation goals	5-point scale	≤2.5	2.5<value<3.5	3.5<value<4.0	≥4.0	135 firms (Cooper & Kleinschmidt, 1995)
		(IS-IO2) [IS2] Spending reflects the innovation strategy	5-point scale	≤2.1	2.1<value<3.2	N/A	≥4.1	60 firms (Killen et al., 2008)
	Innovation leadership	(IS-Le1) [IS16] Top management support for innovation	5-point scale	≤3.6	3.6<value<3.8	3.8<value<4.4	≥4.4	135 firms (Cooper & Kleinschmidt, 1995)
		(IS-Le2) [IS3] Innovation long-term planning	5-point scale	≤2.6	2.6<value<3.2	3.2<value<3.7	≥3.7	135 firms (Cooper & Kleinschmidt, 1995)
Innovation environment	Openness	(IE-Op1) [IE1] Recognition of open innovation opportunities	Discrete time-scale	≤25%)	25%<value<38%	38%<value<75%	≥75%	250 firms (Dubiel et al., 2016)
		[IE2] Promotion of open innovation	Discrete time-scale	≤25%	25%<value<35%	35%<value<48%	≥48%	453 firms (Markham & Lee, 2013)

APPENDICES

Table VI.2 'Hard' characterisation of the performance levels for each dimension (continued).

Performance dimension	Sub-dimension (requirement)		Performance indicator	Scale	Level 1	Level 2	Level 3	Level 4	Sample reference
	Servitisation	IE-Ser1	[IE12] Servitisation diversification strategy: goods, services or inseparable mix of both	Open	≤15%	15%<value<35%	35%<value<64%	≥64%	87 firms (Lee & Markham, 2016)
	Sustainability	IE-Sus1	[IE21] Sustainability criteria for innovation in new product development	Discrete time-scale	≤25%	25%<value<50%	50%<value<75%	≥75%	453 firms (Markham & Lee, 2013)
Knowledge management	Idea management	(KM-IdM1)	[KM1] Percentage of ideas actively generated by formal/informal activities	Discrete time-scale	≤18%	18%<value<39%	39%<value<60%	≥60%	163 firms (Eling et al., 2016)
			[KM2] Number of ideas reviewed per phase	Open	≤19%	19%<value<40%	40%<value<75%	≥75%	453 firms (Markham & Lee, 2013)
	Knowledge repository	(KM-R1)	[KM16] Diversity of knowledge sources	Discrete time-scale	≤2.0	2.0<value<3.5	3.5<value<4.0	≥4.0	49 firms (Wang et al., 2010)
	Information flows	(KM-InF1)	[KM27] Time-off for creative things and generation of tacit knowledge	5-point scale	≤2.0	2.0<value<3.5	3.5<value<4.0	≥4.0	49 firms (Wang et al., 2010)
Organisation and culture	Culture	(OC-C1 and OC-C2)	[OC1] Organisational climate for innovation (percentage of time the organisation reflects 9 climate items)	Discrete time-scale	≤25%	25%<value<50%	50%<value<75%	≥75%	717 responses (N. Anderson & West, 1996)

APPENDICES

Table VI.2 'Hard' characterisation of the performance levels for each dimension (continued).

Performance dimension	Sub-dimension (requirement)		Performance indicator	Scale	Level 1	Level 2	Level 3	Level 4	Sample reference
	Structure	(OC-S1 and OC-S2)	[OC9] Work environment support for innovation	5-point scale	≤2.0	2.0<value<3.4	3.4<value<4.0	≥4.0	194 firms (Prajogo & Sohal, 2006)
Portfolio management	Balance	(PFM-B1 and PFM-B2)	[PFM10] Portfolio balance	Discrete time-scale	≤25%	25%<value<60%	60%<value<75%	≥75%	60 firms (Killen et al., 2008)
			[PFM11] Innovation portfolio strategic alignment	Discrete time-scale	≤25%	25%<value<60%	60%<value<75%	≥75%	60 firms (Killen et al., 2008)
	Evaluation tools	(PFM-EvT1 and PFM-EvT2)	[PFM1] Formalised portfolio management	Discrete time-scale	≤25%	25%<value<60%	60%<value<71%	≥71%	60 firms (Killen et al., 2008)
Project management	Project Efficiency	(PM-E1)	[PM1] Commitment of resources for new product projects	Discrete time-scale	≤ 25%	25%<value<52%	52%<value<71%	≥71%	135 firms (Cooper & Kleinschmidt, 1995)
			[PM32] Time-to-market management	Open	No data collected	<45 weeks	45 -50 weeks	27 (reduce in approx. 40% in 8 years)	453 firms (Markham & Lee, 2013)
	Project management tools	(PM-T1)	[PM23] Degree of use of project management tools	Discrete time-scale	≤25%	25%<value<56%	56%<value<67%	≥67%	453 firms (Markham & Lee, 2013)
		(PM-T2)	[PM24] Frequency of post-launch reviews	5-point scale	≤1 (per year)	2 (per year)	3 (per year)	>4 (per year)	105 firms (Cooper & Edgett, 2014a)
	Coordination	(PM-E2)	[PM31] Communication within projects	Discrete time-scale	≤25%	25%<value<43%	43%<value<75%	≥75%	32 firms (Kivimäki et al., 2000)

APPENDICES

Table VI.2 'Hard' characterisation of the performance levels for each dimension (continued).

Performance dimension	Sub-dimension (requirement)		Performance indicator	Scale	Level 1	Level 2	Level 3	Level 4	Sample reference
Technology management	Technology potential	(TM-TO1 and TM-TO2)	[TM2] Level of new technologies monitoring	Discrete time-scale	≤12%	12%<value<50%	50%<value<67%	≥67%	453 firms (Markham & Lee, 2013)
		(TM-P1)	[TM13] Degree of technology tools used in items 6	Discrete time-scale	≤19%	19%<value<50%	50%<value<75%	≥75%	453 firms (Markham & Lee, 2013)
	R&D Efficiency	(TM-R&D1)	[TM12] Importance of intellectual property (IP) for protecting technology development	5-point scale	≤25%	31%<value≤50%	50%<value<66%	≥66%	42 funded ideas (Lilien et al., 2002)
		(TM-R&D2)	[TM22] R&D intensity (analysed in conjunction with the percentage of total expending R&D in relation to total turnover)	Open	<10% or >90%	10%<value<30% or >80%	30%<value<40%	40%<value<70%	1.540 firms (Ebersberger & Herstad, 2011)
Team management	Team cross-functionality	(TEAM-Cr1)	[TEAM1] Cross-functional team	Discrete time-scale	≤24%	24%<value<50%	50%<value<67%	≥67%	453 firms (Markham & Lee, 2013)
		(TEAM-Cr2)	[TEAM3] Cross-functional training	Discrete time-scale	≤31%	31%<value<60%	60%<value<80%	≥80%	453 firms (Markham & Lee, 2013)
	Team stability	(TEAM-St1)	[TEAM2] Identifiable project team leader	Discrete time-scale	≤35%	35%<value<64%	64%<value<80%	≥80%	105 firms (Cooper et al., 2004)
			[TEAM5] Dedicated innovation group	Discrete time-scale	≤50%	50%<value<55%	55%<value<68%	≥68%	135 firms (Cooper & Kleinschmidt, 1995)

APPENDICES

Table VI.2 'Hard' characterisation of the performance levels for each dimension (continued).

Performance dimension	Sub-dimension (requirement)		Performance indicator	Scale	Level 1	Level 2	Level 3	Level 4	Sample reference
		(TEAM-St2)	[TEAM17] Team innovative behaviour	Discrete time-scale	≤25%	24%<value<50%	50%<value<75%	≥75%	29 firms (Post, 2012)
Market	Market research and testing	MA-RT1	[MA1] Use of market research tools	Discrete time-scale	≤25%	25%<value<44%	44%<value<50%	≥50%	453 firms (Markham & Lee, 2013)
		MA-RT2	[MA11] Product testing proficiency	Discrete time-scale	≤30%	30%<value<44%	44%<value<60%	60%	453 firms (Markham & Lee, 2013)
	Marketing monitoring	MA-MgS1	[MA15] Market monitoring proficiency	5-point scale	≤2.0	2.0<value<2.5	2.5<value<3.5	≥3.5	28 firms (M. X. Song & Parry, 1996)

Legend for the encoding used in Table VI.2.

Dimensions: **IS**- innovation strategy; **KM**- knowledge management; **OC**-organisation and culture; **PFM**-portfolio management; **PM**-project management; **TM**-technology management; **TEAM**-team management; **MA**-market and **IE**-innovation environment.

Sub-dimensions: **IO**-innovation orientation and **Le**-leadership; **IdM**-idea management, **Inf**-informational flows and **R**-knowledge repository; **C**-organisational culture and **S**-organisational structure; **B**-portfolio balance and **EvT**-portfolio evaluation tools; **E**-project management efficiency and **T**-project management tools; **TO**-technology orientation, **P**-technology potential and **R&D**: R&D efficiency; **Cr**: team cross-functionality and **St**: team stability; **RT**: market research and testing and **MgS**: marketing and sales; **Op**: openness, **Ser**: servitisation and **Sus**: sustainability.

APPENDIX VII. IMPROVEMENT ACTIONS FROM THE LITERATURE

In order to avoid repetition of the context among the three versions of the PF (conceptual, ‘intermediary’ after AR first case, consolidated and final version case 1), this appendix presents the final consolidated version of the innovation practices. Table VII.2 presents the simplified domain mapping matrix relating the performance levels with practices, showing where the practices can be applied. This matrix was built by the researcher and validated with the practitioners of the AR.

Table VII.1. Compilation of innovation practices for the literature.

Code	Performance indicator	Practice title	Practice goal	Reference
P01-IS-IO	[IS2] Spending reflects the innovation strategy	Development of guidelines for the continuity of the innovation strategy	To establish a better balance between day-to-day execution and future development by setting up strategic objectives to ensure that at least some amount of time and resources on future activities	(Lakiza & Deschamps, 2019; Nilsson & Ritzén, 2014)
P02-IS-IO	[IS3] Innovation long-term planning	Scorecard for business planning	To introduce the discipline of creating a scorecard forces companies to integrate the strategic planning and budgeting, thereby ensuring that financial budgets do indeed support long-term strategic goals.	(Kaplan & Norton, 2007)
P03-IS-IO		Delphi method for innovation planning	To plan for a great deal of uncertainty or long time horizons by a surveying experts opinion on what the future key issues will be, and the likelihood of the developments. The responses are analysed, and the same sample of experts resurveyed with a new, more focused questionnaire. This is repeated until some convergence is observed, or conversely if no consensus is reached.	(Tidd et al., 2005)
P04-IS-IO	[IS16] Top management support for innovation	Management statements for innovation	To show that top management formally committed itself to this strategic change in various presentations and occasions, internally and externally.	(Melnik et al., 2010)

APPENDICES

Table VII.1. Compilation of innovation practices for the literature (continued).

Code	Performance indicator	Practice title	Practice goal	Reference
P05-IE-Op	[IE1] Recognition of open innovation opportunities	Lead user method	To systematically facilitate the involvement of customers in the innovation process.	(Erkens et al., 2014; Lilien et al., 2002).
P06-IE-Op		Customer potential of lead users	To increase the heterogeneity of lead users involved.	(Erkens et al., 2014; Lilien et al., 2002)
P07-IE-Op		Roadmap for partnerships	To introduce a technology roadmap methodology for mapping external partnerships.	(Zobel, 2017)
P08-IE-Op	[IE2] Promotion of open innovation	Ideation contest	To create an environment for idea suggestions.	(Erkens et al., 2014; Schemmann, Herrmann, Chappin, & Heimeriks, 2016)
P09-IE-Op		Broadcast search	To facilitate the identification of technical solutions for current project problems.	(Erkens et al., 2014; Schemmann et al., 2016)
P10-IE-Ser		Screen for PSS	The focus is on incorporating a screening for PSS opportunities in the IFE (with tools such as user activity cycle, offering cards, product life gallery and service blueprint)	(Barquet, 2015; D. Mourtzis, Boli, & Fotia, 2017)
P11-IE-Ser	[IE12] Servitisation diversification strategy	Networks for enabling PSSs	To enable the visualisation of the PPS network to facilitate its modularisation.	(Barquet, 2015; Lim, Kim, Hong, & Park, 2012)
P12-IE-Ser		Simulation of PSS offers	To assist in the selection of services within the PSS offers.	(Alfian, Rhee, & Yoon, 2014; Barquet, 2015).
P13-IE-Sus		Reward for ecodesign implementation	To introduce an update to the reward system to encourage the ecodesign application.	(Rodrigues, Pigosso, & McAloone, 2017)
P14-IE-Sus	[IE21] Sustainability criteria for innovation in new product development	Integration of environmental issues	To integrate environmental issues in the company ideas' portfolio.	(J. Hall & Wagner, 2012; Pigosso, 2012).
P15-IE-Sus		Coherency of environmental goals	To ensure coherency of environmental goals and the company strategic planning.	(Gallego-Álvarez, Manuel Prado-Lorenzo, & García-Sánchez, 2011; Pigosso, 2012).

APPENDICES

Table VII.1. Compilation of innovation practices for the literature (continued).

Code	Performance indicator	Practice title	Practice goal	Reference
P16-KM-IdM	[KM1] Percentage of ideas actively generated by formal/informal activities	Idea management system	To establish an idea management system that addresses the influential success factors: i) all-inclusive suggestion policy, ii) proper name of the idea management; iii) proactive gathering of ideas; iv) call for ideas to specific topic/issue; v) simple electronic suggestion form; iv) group ideas and v) equitable award structure.	(Boeddrich, 2004)
P17-KM-IdM	[KM2] Rate of product ideas reviewed or approved (per phase)	Consistency in the criteria of both radical and incremental ideas/projects	To develop a predetermined set of criteria to select ideas, including complementary and distinguishing criteria for incremental and radical ideas to ensure that no important criteria are overlooked.	(Eling et al., 2016)
P18-KM-IF	[KM16] Diversity of knowledge sources	Communities of practice (CoP) for the innovation process	To stimulate collective communities of practice (CoP) that develop their knowledge by drawing upon several sources of knowledge in the innovation process.	(Prencipe & Tell, 2001)
P19-KM-R	[KM27] Time-off for creative things and generation of tacit knowledge	Development of a knowledge repository and management strategies	To develop a knowledge repository and its management strategies to form and nurture communities of practice within the BU and at the institutional level.	(Bose, 2004; Prencipe & Tell, 2001).
P20-OC-C	[OC1] Organisational climate for innovation	'Skunkworks' and unofficial projects	To promote a culture of experimentation with 'skunkworks' and unofficial projects.	(Cooper & Kleinschmidt, 2007).
P21-OC-C		Fostering intrapreneurship	To promote intrapreneurship culture within the organisation.	(Cooper & Kleinschmidt, 2007).
P22-OC-S	[OC9] Work environment support for innovation	Suitable 'spatials'	To warranty dedicated physical resources, ranging from inputs such as computers to buildings, including physical proximity if possible, of the people involved, should be considered into the innovation process.	(Adams et al., 2006).
P23-PFM-B	[PFM1] Formalised portfolio management	Decentralisation of the innovation portfolio management (IPM)	To establish moderate levels of decentralisation in the IPM to facilitate and speed-up the portfolio management.	(Carbonell & Rodriguez Escudero, 2016).
P24-PFM-B		Innovation portfolio management	To apply portfolio management tools (bubble diagram), and make room in the project portfolio for innovation projects – including a multicriteria score using the strategic importance; degree of innovation (new to the company, improvement, extension) and market risk, besides profitability PIs, implementation time and cost.	(Tolonen et al., 2015)

APPENDICES

Table VII.1. Compilation of innovation practices for the literature (continued).

Code	Performance indicator	Practice title	Practice goal	Reference
P25-PFM-B	[PFM11] Innovation portfolio strategic alignment	Innovation portfolio management connection to other business processes	To warranty alignment between the IPM across the business processes.	(Tolonen et al., 2015).
P26-PFM-EvT	[PFM10] Portfolio balance	Hybrid approaches for innovation portfolio management (IPM)	To combine complementary portfolio management methods.	(Beringer et al., 2013; Cooper, Edgett, & Kleinschmidt, 1999).
P27-PFM-EvT		Real options for IPM under high uncertainty environment	To introduce options pricing analysis into the IPM when high uncertainty is involved.	(Cooper et al., 1999; de Castro Rodrigues, Nappi, & Rozenfeld, 2014).
P28-PM-T	[PM23] Degree of use of project management tools	Evaluation strategy for PM tools	To assess the appropriateness of existing technologies, tools and techniques for applying in the project management (this extends to the selection, acquisition and application of appropriate tools).	(Rogers et al., 2005)
P29-PM-T	[PM24] Frequency of post-launch reviews	Life cycle thinking for post-implementation reviews (PIRs).	To promote inter-project learning for PIRs.	(Killen & Hunt, 2013; Prencipe & Tell, 2001).
P30-PM-PE		Gates 'with teeth'	To enable the termination of poor performing projects.	(Cooper, 2008; Killen & Hunt, 2013).
P31-PM-T	[PM31] Communication within projects	Active encouragement of communication zones	To create distinct physical areas to facilitate and enable communication between development teams.	(Berg et al., 2008; Haner, 2005).
P32-PM-T	[PM32] Time-to-market management	Increase innovation speed	To have more agile and focused work: encourage faster development projects requiring more focus and more dedicated resources.	(Lakiza et al., 2018)
P33-TM-P	[TM13] Degree of technology tools used	Small update cycles of technology	To enable small update cycles of technology plans during the year instead of annually.	(Atuahene-Gima, 2005; Gurtner & Reinhardt, 2016)
P34-TM-TO		Dedicated force for studying artificial intelligence and machine learning	To build expertise and capacity in these areas across the organisation.	(Markham & Lee, 2013).

APPENDICES

Table VII.1. Compilation of innovation practices for the literature (continued).

Code	Performance indicator	Practice title	Practice goal	Reference
P35-TM-P	[TM2] Level of new technologies monitoring	Idea splitters for technology monitoring	To identify idea splitters by means of strategic technology and market monitoring	(Brem & Voigt, 2009).
P36-TM-R&D	[TM12] Importance of intellectual property (IP) for protecting technology development	Inter-organisational agreement on performance measurement for IP strategies	To establish an integrated performance measurement system with strategic partners, within open innovation projects.	(Bititci, Garengo, Dörfler, & Nudurupati, 2012).
P37-TM-R&D	[TM22] R&D intensity	In-house R&D monitoring	To align in-house R&D development with a well-informed and active monitoring of outside opportunities (it could be mergers and acquisitions department).	(Spithoven, Frantzen, & Clarysse, 2010)
P38-TEAM-Cr	[TEAM1] Cross-functional team	Maintain functional diversity core team	To keep the level of cross-functionality (functional diversity) and team longevity at a moderate level.	(Dayan & Di Benedetto, 2009)
P39-TEAM-Cr	[TEAM3] Cross-functional training	Performance measurement introduction to cross-functional training	To integrate performance measurement issues into cross-functional training.	(Hertenstein & Platt, 2000).
P40-TEAM-St	[TEAM2] Identifiable project team leader	Clearly identifiable project leader for all projects	To create a clear human-resources structure to have project team leaders.	(Howell & Shea, 2006; Kahn et al., 2006).
P41-TEAM-St	[TEAM5] Innovation dedicated group	"Ambidextrous teams"	To establish dedicated resources, which entails a core team and ad hoc team members that are brought in on project basis, to perform exploitation activities of existing competencies, the current projects being developed ('business as usual') and further dedicated technical resources to perform exploration activities considering the long-term horizon to develop new skills/technical capabilities to be applied in future developments	(Birchall & Tovstiga, 2006; Cooper & Kleinschmidt, 1995).

APPENDICES

Table VII.1. Compilation of innovation practices for the literature (continued).

Code	Performance indicator	Practice title	Practice goal	Reference
P42-TEAM-St	[TEAM17] Team innovative behaviour	Creation of shared mental models	To enable teams to create shared knowledge structures in terms of mental models in paper/online.	(Acur, Kandemir, & Boer, 2012; Hertenstein & Platt, 2000).
P43-MA-RT	[MA1] Use of market research tools	Development and maintenance of a market monitoring process	To implement customer-oriented analysis with feedback cycles for better cross-functional communication concerning innovation.	(Gurtner & Reinhardt, 2016)
P44-MA-RT	[MA11] Product testing proficiency	Pre-test proficiency support	To surveying the capacity of the department to develop and analyse testing (to interpret the findings and incorporating those into product design).	(M. X. Song & Parry, 1996)
P45-MA-RT	[MA14] Market monitoring proficiency	More focus on market launch and marketing-oriented activities	To prioritise the development of projects in the pipeline showing value for the customer (explicitly analysed with users).	(Lakiza et al., 2018)

Table VII.2. Simplified domain mapping matrix relating levels with the practices.

	Levels \ Practices	P01-IS-IO	P02-IS-IO	P03-IS-IO	P04-IS-IO	P05-IE-Op	P06-IE-Op	P07-IE-Op	P08-IE-Op	P09-IE-Op	P10-IE-Ser	P11-IE-Ser	P12-IE-Ser	P13-IE-Sus	P14-IE-Sus	P15-IE-Sus	P16-KM-IdM	P17-KM-IdM	P18-KM-IdM	P19-KM-IF	P20-KM-R	P21-OC-C	P22-OC-C	P23-OC-S	P24-PFM-B	P25-PFM-B	P26-PFM-EvT	P27-PFM-EvT	P28-PM-T	P29-PM4-T	P30-PM-PE	P31-PM-T	P32-PM-T	P33-TM-P	P34-TM-TO	P35-TM-P	P36-TM-R&D	P37-TM-R&D	P38-TEAM-Cr	P39-TEAM-Cr	P40-TEAM-St	P41-TEAM-St	P42-TEAM-St	P43-MA-RT	P44-MA-RT	P45-MA-RT	
2				X	X			X			X						X	X	X		X			X					X																		
3	X	X					X				X			X	X	X					X								X					X	X								X	X	X		
4					X	X	X	X	X	X		X	X							X		X	X		X	X	X	X		X	X	X		X													

APPENDIX VIII. QUESTIONNAIRE S1 FOR CONTEXTUAL VARIABLES

This appendix presents the questionnaire S1 developed to identify the characteristic of the innovation process, called here 'contextual variables'. It is designed for semi-structured interviews, where more information can be asked depending on the interviewee's responses.

GENERAL INFORMATION

i) How many employees does the Company have?

- ☐ 1 – 9
- ☐ 10 - 49
- ☐ 50 - 249
- ☐ > 250

ii) How much revenue does the Company have in the last period (in millions of euros)?

- ☐ < €2 m turnover or < €2 (balance sheet total)
- ☐ < €10 m turnover or < €10 m (balance sheet total)
- ☐ < €50 m turnover or < €43 m (balance sheet total)
- ☐ ≥ €50 m turnover or ≥ €43 m (balance sheet total)

iii) Which manufacturing sector(s) is the Company involved?

- ☐ 10 – Manufacture of food products
- ☐ 11 – Manufacture of beverages
- ☐ 12 – Manufacture of tobacco products
- ☐ 13 – Manufacture of textiles
- ☐ 14 – Manufacture of wearing apparel
- ☐ 15 – Manufacture of leather and related products
- ☐ 16 – Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
- ☐ 17 – Manufacture of paper and paper products
- ☐ 18 – Printing and reproduction of recorded media
- ☐ 19 – Manufacture of coke and refined petroleum products
- ☐ 20 – Manufacture of chemicals and chemical products
- ☐ 21 – Manufacture of pharmaceuticals, medicinal chemical and botanical products
- ☐ 22 – Manufacture of rubber and plastics products
- ☐ 23 – Manufacture of other non-metallic mineral products
- ☐ 24 – Manufacture of basic metals
- ☐ 25 – Manufacture of fabricated metal products, except machinery and equipment
- ☐ 26 – Manufacture of computer, electronic and optical products
- ☐ 27 – Manufacture of electrical equipment

- ☐ 28 – Manufacture of machinery and equipment n.e.c.
- ☐ 29 – Manufacture of motor vehicles, trailers and semi-trailers
- ☐ 30 – Manufacture of other transport equipment
- ☐ 31 – Manufacture of furniture
- ☐ 32 – Other manufacturing
- ☐ 33 – Repair and installation of machinery and equipment

LEVEL OF FORMALISATION OF ACTIVITIES

iv) What is the level of formalisation of the innovation process?

- ☐ High formalisation
- ☐ Medium formalisation
- ☐ Lack of formalisation

v) Is the formalisation (model/guidelines) used for every innovation project?

vi) Does the Company use a typology to differentiate the projects? E.g., radical projects and new platforms, incremental or line extensions, sourcing, engineering to order, laws and regulations projects, etc.

vii) What is the typical length of a special/customised order for a customer?

viii) Does the Company use any information technology and communication system (software) to support the idea management process? Which one?

ix) How many ideas did you generate in the last period of the Company (per program)?

x) What rate of ideas implemented in the last period by the Company?

xi) Thinking about a typical project that would navigate the Company's model/guideline, what areas would the development team be composed of? Or what areas navigate this process?

Areas	Participation
...	
...	
....	
...	

xii) How is the structure of the Company organised?

APPENDICES

- ☐ Functional/Divisional
- ☐ Matrix
- ☐ Projectized

DRIVERS OF THE INNOVATION PROCESS

xiii) Has the Company received any innovation awards in the last period?

- ☐ No;
- ☐ Yes. Describe:

xiv) How many lines of products does the Company have a portfolio at the moment? What is the distribution of orders in a month/week?

xv) Does the customer maintain ownership of the product, or are there other models like sharing, leasing?

xvi) Number of final products per day/month or year?

xvii) How many/what percentage of those are customised or special orders?

xviii) Characterise the degree of novelty of the main product/PSS or process:

Specify examples of projects:_____.

- ☐ New to the company, but already existing in the domestic market
- ☐ New to the domestic market, but already existing in the international market
- ☐ New to the world

xix) Characterise the type of product developed:

Added value	High			
	Medium			
	Low			
		Low	Medium	High

Novelty

xx) What is the approximate number of components for a typical product? What is the total number of SKUs?

xxi) What percentage of the company's turnover is the result of new products launched by the Company in the last period?

xxii) Does the Company sell its products to another industry or an end customer?

- ☐ Business to Business (B2B)
- ☐ Business to Customer (B2C)

xxiii) Does the Company put to use patent information? How many patents applications were made in the last period?

xxiv) What type of innovation driver is the Company? What is the participation of each type?

- ☐ **Technology push:** the stimulus for new products comes (internally or externally) from R&D, with the aim of making commercial use of newly developed technical knowledge.
- ☐ **Market pull:** the source of innovation is a response to customer needs and satisfaction, resulting in new demands for the resolution of these requests.
- ☐ **Both.**

CLOSED AND OPEN INNOVATION PARADIGM

xxv) Does the Company use the open innovation strategy during the idea management process?

- ☐ No
- ☐ Yes. Describe (who is responsible):

xxvi) Does the Company use customer relationship management (CRM) software collect feedback from customers? How often would you say that the company retro feeds these insights into the innovation process as a requirement?

SURROUNDING ENVIRONMENT

xxvii) What type of strategic orientation does the Company adopt?

- ☐ **Reactor:** companies that do not have a coherent relationship between strategy and structure, and do not have a definitive innovation strategy.
- ☐ **Defender:** companies that have dominion over a specific market segment and seek to avoid the entry of competitors acting aggressively in quality and price.
- ☐ **Analyser:** a hybrid of the prospecting and defending strategies, since at the same time as they look for new markets and opportunities for new products, these are concerned to maintain their traditional segments and clients.

☐ **Prospector:** companies characterised by the high search for innovations, that is, they can generate new products that will originate new market segments.

xxviii) Does the Company have strategic objectives related to innovation and the launch of new products?

- ☐ No
☐ Yes. Describe:

xxix) Does the Company use technology roadmapping ('T-Plan'), or scenario creation or else, for planning new products or new technologies?

xxx) Characterise the innovation cycle related to the main products of the Company.

- A. ☐ **Fluid pattern:** product change is associated with identifying an emerging need or a new way of meeting an existing need, i.e. it is an enterprising act.
B. ☐ **Transitional phase:** important innovations in processes necessary to increase the volume of production and in which the main products are used more widely.
C. ☐ **Specific phase:** The competitive emphasis is on cost reduction stimulated by pressure for price reduction and quality improvement by generating predominantly incremental innovations in products and processes, with a cumulative improvement in productivity and quality.

APPENDIX IX. QUESTIONNAIRE S2 FOR PERFORMANCE ASSESSMENT

This appendix presents the questionnaire S2 developed to compile information for measuring the 34 rapid assessment PIs adapted to their application into structured interviews. The comments justifying and providing evidence on the reason why the answer to an indicator was given are also documented here (shown in shades of yellow: from light yellow illustrating evidence for the top of the scale, e.g., 5 or 4 and 100% or 75%; 'average' shade of yellow for evidence for the medium of the scale, e.g., 3 or 2 and 0% or 25%; and stronger yellow for lack of evidence, e.g., 1 or 0%).

INNOVATION STRATEGY (IS)

[IS1]. What is the level of awareness and clarity of innovation goals among everyone who is involved in the innovation process, considering the following qualitative scale? Adapted from (Cooper & Kleinschmidt, 1995, 2007; Cormican & O'Sullivan, 2004).

1 = Innovation strategy is known and shared only among top management.

5 = Innovation strategy is clearly defined and communicated to all employees.

Evidence (to be selected by the facilitator):



☐ Innovation goals in the company's intranet or the interviewee's own Objectives and Key Results (OKR).

☐ Yearly strategic planning and subsequent meetings.

☐ No inclusion of innovation in strategic planning.

What would be an estimate of the percentage of time the employees aware of, sharing the innovation goals, policies and values, according to your own perspective?

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ Interviewee answers with a strategic goal for the year and the long-term goal.

☐ Interviewee answers with a strategic goal for the year.

☐ No innovation strategic goal is known by the interviewees.

[IS2]. Does the breakdown of spending (or budget) in the Company's projects portfolio truly reflect the innovation strategy? Adapted from (Killen et al., 2008).

1 = No, spending breakdown is inconsistent with the Company's innovation strategy.

5 = Spending consistent with the innovation strategy established.

Evidence (to be selected by the facilitator):



- ☐ There is a budget for the innovation/R&D projects for the next year.
- ☐ At least one or more innovation/R&D projects are underway.
- ☐ No budget allocated for innovation/R&D projects.

[IS3]. About the planning horizon for new products (product generations), what best reflects what the Company has been practising so far, considering the following qualitative scale:

Adapted from (Chiesa et al., 1996; Cooper & Kleinschmidt, 1995).

1 = The Company focus on our current product lines planning.

5 = The product innovation programme has a long term thrust and focus (5 to 15 years).

Evidence (to be selected by the facilitator):



- ☐ At least 5-year plan is known beyond the innovation/R&D area.
- ☐ There is at least one person responsible that knows the plan.
- ☐ Lack of 5-year planning.

[IS16]. About the top management support for innovative ideas/solutions, what best reflects what the Company has been practising so far, considering the following qualitative scale:

Adapted from (Cormican & O'Sullivan, 2004).

1 = Leaders do not address innovation visibly.

5 = Leaders visibly drive innovation. Top management actively encourages the submission of new ideas.

Evidence (to be selected by the facilitator):



- ☐ More than innovation/R&D contributes with to ideas (more than incremental).
- ☐ More than innovation/R&D contributes with ideas (mostly incremental).
- ☐ Do not know what areas can suggest ideas.

INNOVATION ENVIRONMENT (IE)

[IE1]. For the Company, what percentage of time do innovation projects involve the following statement:

Adapted from (Dubiel et al., 2016; Markham & Lee, 2013).

Find that key problems that must be solved with skills that reside outside the Company.

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



APPENDICES

- ☐ Developed or purchased open platform to collaborate with external entities for developing.
- ☐ Partnership with universities/colleges or suppliers for developing innovation/R&D projects.
- ☐ Lack of external parties involved in the innovation front-end.

[IE2]. For the Company, what percentage of time do innovation projects involve the following:

Adapted from (Markham & Lee, 2013).

External collaboration with a supplier of component parts.

External collaboration with a firm much smaller than the Company.

Facilitate collaboration internally through an internal focused open innovation system (inside-out), i.e., meaning internal company knowledge to be developed externally.

Facilitate collaboration externally through an externally focused open innovation system (outside-in), i.e., meaning external knowledge acquired to be developed by the Company.

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ A project with an open platform in the last two years was cited.
- ☐ A project with partnerships, suppliers and universities/colleges, in the last two years was cited.
- ☐ No projects in the last two years in the cited circumstances were recalled.

[IE12]. What is the Company's new product diversification strategy in terms of goods, service or a combination of both? Choose the number of products, sales or profit as a base:

Adapted from (Markham & Lee, 2013).

	Goods	Service	Mix	Total
Number of new products commercialised	_____ %	_____ %	_____ %	100%
New product sales	_____ %	_____ %	_____ %	100%
New product profits	_____ %	_____ %	_____ %	100%

References: (Markham & Lee, 2013).

Evidence (to be selected by the facilitator):



- ☐ Servicing people participate in innovation and R&D projects.
- ☐ They know about product service systems - PSS (training/networking, etc.)
- ☐ Lack of involvement of servicing and service consideration in the innovation front-end.

[IE21]. For the Company, what percentage of time do innovation projects involve the following sustainability practices? Adapted from (Markham & Lee, 2013).

Environmental sustainability (carbon-footprint, Life Cycle Assessment - LCA)

Social sustainability (e.g., compliance with ethical guidelines; community affairs; minority purchases)

Sustainability criteria for New Product Development

Measuring New Product progress on Sustainability

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ The company performs Life Cycle Assessment for strategic products.
- ☐ The company measures carbon footprint for strategic products.
- ☐ The company only measures environmental impact or similar for the buildings/facilities.

KNOWLEDGE MANAGEMENT (KM)

[KM1]. About how ideas are generated in the Company, what percentage of time best reflects what the Company has been practising so far? Adapted from (Markham & Lee, 2013).

Actively generated by formally planned activities (including brainstorming sessions, competitor analysis, trend analysis, customer observation, roadmapping, etc.) to fill identified gaps in our existing product portfolio

Actively generated by informal activities (e.g. time provided for ideation to recognises "idea" people) to fill identified gaps in our existing product portfolio

Actively generated by informal activities because in general, we need more ideas

Ideas come without specific prompting from a wide variety of people

Other methods not specified

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

Evidence (to be selected by the facilitator):



- ☐ Frequent (2x year) conduction of formal idea generation activities (roadmapping, scenarios, personas, etc.).
- ☐ Innovation committee to analyse ideas.
- ☐ Lack of formalised ideas generation activities.

[KM2]. What is the percentage of new product ideas in relation to the total (also including improvements and incremental) that the Company generates? Adapted from (Markham & Lee, 2013).

Evidence (to be selected by the facilitator):



- ☐ Ideas are capture in software for idea management and analysed once a semester at least.
- ☐ Ideas in a database and frequency to analyse ideas more than twice a year.
- ☐ Lack of ideas collection database.

[KM16]. About collecting data and information for the development of innovation projects, what percentage of time best reflects what the Company has been practising so far?

Adapted from (Markham & Lee, 2013; Wang et al., 2010).

Techniques/products from competitors

Techniques/products from academic research institutions

Published patents in the industry

Technical publications academic databases

The required R&D knowledge and experiences are documented in our organisation

Our organisation has a standardised administration process in managing and acquiring knowledge for R&D processes and techniques

Our organisation has a well-established knowledge system in saving the R&D outcomes

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ There is an area/department responsible for knowledge management.
- ☐ There are employee(s) within areas that are responsible for KM (search products/patents/scientific papers more than once a year).
- ☐ Lack of resources to monitor products and scientific knowledge.

[KM27]. About the time-off for creative things, what best reflects what the Company has been practising so far, considering the following qualitative scale:

Adapted from (Cooper & Kleinschmidt, 1995, 2007).

1 = Employees carry out their regular duties, and after that, they can begin creativity-related activities.

5 = We provide time and resources for employees to generate, share/exchange and experiment with innovative ideas/solutions.

Evidence (to be selected by the facilitator):



- ☐ Free time once a week to research for skunk or pet projects.
- ☐ Time and resources to research for projects not only on reducing cost or improving process efficiency.

☐ Time and resources to research for projects focused on reducing cost or improving process efficiency.

ORGANISATION AND CULTURE (OC)

[OC1]. Thinking about the culture within the Company, what percentage of time does the Company reflects these values?

Adapted from (Markham & Lee, 2013).

Open to the constructive conflict that occurs within the innovation process

Failure is understood to be a natural part of the innovation process

Both innovation and risk-taking are valued for career development

Recruitment parameters include consideration for innovation potential

Managers establish objectives in the areas of innovation including training, measures and results

These established objectives are used in the performance review process

Our organisation is a learning organisation

Effectively communicates its innovation values internally

Effectively communicates its innovation values externally

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ Interviewee gives an example of experimentation culture and failure acceptance

☐ Interviewee gives an example of experimentation culture with prototypes.

☐ Lack of examples.

[OC9]. About the work environment for innovation, what best reflects what the Company has been practising so far, considering the following qualitative scale?

Adapted from (Prajogo & Ahmed, 2006).

1 = At the moment, the Company does not have incentives/rewards for development teams.

5 = Employees are recognised and rewarded for creativity and innovative ideas, and there is a structured reward system in place.

Evidence (to be selected by the facilitator):



☐ Reward considering the impact with distinct criteria not only cost-saving or efficiency.

☐ Reward considering the impact on cost-saving or efficiency.

☐ Lack of reward system.

PORTFOLIO MANAGEMENT (PFM)

[PFM1]. What the percentage of innovation projects does the Company review as part of the portfolio management process?

Adapted (Markham & Lee, 2013).

Per cent of total radical innovation projects reviewed.

Per cent of total more innovative projects reviewed.

Per cent of total incremental project reviewed.

Per cent of all firm's project reviewed

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ There is a typology to classify the ideas and distinct routes may be taken.
- ☐ Ideas are classified according to financial criteria.
- ☐ Lack of differentiation for the ideas.

[PFM10]. What percentage of the time does the Company use a defined innovation strategy in the portfolio selection to? Adapted from (Killen et al., 2008; Markham & Lee, 2013).

Formulate investment decisions

Formulate platform decisions

Formulate project selection decisions

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ Portfolio selection is based not only cost-saving, but more criteria are also used.
- ☐ Portfolio selection based on only cost-saving.
- ☐ No criteria for selecting new projects in the portfolio.

[PFM11]. What percentage of the time does the Company use a defined innovation strategy in the portfolio selection to? Adapted from (Killen et al., 2008; Markham & Lee, 2013).

Formulate project continuation decisions

Formulate decisions within active projects

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ More than 1 project were cancelled/postponed due to market/technology changes in the last three years.
- ☐ One project was cancelled/postponed due to market/technology changes in the last three years.
- ☐ Once initiated projects are not terminated/cancelled.

PROJECT MANAGEMENT (PM)

[PM1]. What percentage of time is the following statement true for development teams in the Company? Adapted from (Markham & Lee, 2013).

Teams are given the needed resources to be effective in the development of innovation projects.

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ Projects are not cancelled due to the lack of resources in the last 3 years.
- ☐ One or two projects were cancelled due to the lack of resources in the last 3 years.
- ☐ Three or more projects were terminated due to the lack of resources in the last 3 years.

[PM23]. What percentage of time are the following project management related practices employed in the Company? Adapted from (Markham & Lee, 2013).

A distinct Division or Venture with its own Profit & Loss statement

A separate New Product Department with permanent multifunctional staff

Project management is treated as a separate function ("Project office") with a "New Product Committee" of functional resource owners is assembled

A "New Product Committee" of functional resource owners is assembled

Marketing drives development of new products

Engineering drives development of new products

R&D drives development of new products

Production drives development of new products

Other department drives development of new products, if so, which department

The structure is a sequential workflow through each function

Other structure not mentioned above

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ PM Office for new products and/or someone responsible for innovation/R&D projects.
- ☐ People/resources to manage all (innovation and business as usual projects); might be someone borrowed from a functional position.
- ☐ No one is specifically responsible for managing the projects.

[PM24]. About the frequency of projects post-reviews, what best reflects what the Company has been practising so far? Adapted from (Atuahene-Gima, 1995).

- ☐ More often than monthly review
- ☐ Monthly review
- ☐ Quarterly review
- ☐ Semi-annually review
- ☐ Annually review
- ☐ Not specified

Evidence (to be selected by the facilitator):



- ☐ Every project, considered strategic, once finished has a post-review (lessons learned), and results are review from time to time.
- ☐ *Ad hoc* post-reviews on innovation/R&D projects.
- ☐ No review is done after the projects are finished.

[PM31]. About the quality of communication within projects, what best reflects what the Company has been practising so far? Adapted from (Kivimäki et al., 2000).

There was frequent communication within the team.

The team members often communicate in spontaneous meeting, phone conversation, etc.

Important information was kept away from other team members in a certain situation.

In our team, there were conflicts regarding the openness of the information flow.

The team members were happy with the timeliness in which they received information from other team members.

The team members were happy with the precision of the information received from other team members.

The team members were happy with the usefulness of the information received from other team members

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ All project teams are able to use PM supporting tools (MS projects, scrum, XP, etc.)
- ☐ Project teams need more support of PM than what they have.
- ☐ Lack of PM supporting tools.

[PM32]. For a typical project, what is the typical length of time (in weeks) spent on each of these activities in the Company? Adapted from (Markham & Lee, 2013).

Project Scoping: lays out the foundation for the project (weeks)

Technical assessment: demonstrates the lab or technical feasibility under ideal circumstances (months)

Detailed investigation: implements the full experimental plan. Technology feasibility is proven (years)

Product Line Planning: Analyse the Business Unit's product portfolio vis-a-vis the competitive arena

Project Strategy Development: Determine this project's place in the product line, delineate the target market, determine market need and attractiveness

Idea/Concept Generation: Identify opportunities and generation of possible solutions

Idea Screening: Sort and rank solutions, eliminate unsuitable and unattractive options

Business Analysis: Evaluate the concept financially, write business case, prepare protocol/development contract

Design & Development: Convert concept into a working product

Test and Validation: Product use, field, market and regulatory testing with customers

Manufacturing Development: Develop and pilot the manufacturing process

Commercialisation: Launch the new product or service into full-scale production and sales

Process Review: Post-launch review and evaluation of the development process

Results Monitoring: Implement a process for ongoing measurement of selected outcomes

Evidence (to be selected by the facilitator):



- ☐ Strategies to deal with time-to-market or lead time are applied to manage.
- ☐ Time-to-market or lead time is known but not managed.
- ☐ Time-to-market or lead time is not known.

TECHNOLOGY MANAGEMENT (TM)

[TM2]. Is technology an important part of the Company? Which statement below best describes the Company? Adapted from (Markham & Lee, 2013).

Technology is not a major issue for our Company.

We follow up, from time to time, on technological advancements that may impact our current products and/or services.

We regularly follow up on technological advancements that may impact our current products and/or services.

We regularly follow up on technological advancements that may improve our current products and/or services, and markets and adjacent technologies that may bring about a complete breakthrough in our activities.

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ There are dedicated resources/people responsible for following up technological advancements.

☐ People, who have other functions, monitor technological advancements (once or twice a year).

☐ Lack of resources/people to keep up with technological advancements.

[TM12]. Intellectual property is defined as Patents, Trademarks, Trade secrets, and copyrights. Adapted from (Lilien et al., 2002; Markham & Lee, 2013).

How effective is the Company at developing the needed intellectual property strategies for protecting technology development?

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

How often intellectual property is a major component of the Company's technology development?

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ Dedicated resource/person/department to deal with IP (more than patents).

☐ Procedure to manage IP in the company (only patents)

☐ No strategy in place; no one manages IP.

[TM13]. For the Company, what percentage of time do innovation projects involve the following technology tools/technique? Adapted from (Markham & Lee, 2013).

Lean New Product Development

Design for Manufacturing, Assembly, Testing, DFX

Failure Mode & Effect Analysis (FMEA)

Six Sigma Analysis

TRIZ (Theory of Inventive Problem Solving)

Theory of Constraints

Rapid Prototyping Systems

Performance Modelling & Simulation Systems

Virtual Reality/Virtual Design/Cave Technology

Remote Collaborative Design Systems

Product Data Management Systems

Product Portfolio Management Software

Customer Needs/Requirements Analysis Software

Project Management Systems

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ More than ten distinct tools from the list are applied in the company.

☐ Up to 5 tools from the list are applied in the company.

☐ One or no tools from the list are applied.

[TM22]. How much do you agree that the following statements describe the Company? Adapted from (Markham & Lee, 2013).

Our R&D personnel are capable of learning and assimilating new techniques.

Our organisation not only focuses on R&D related to our main product but also on research indirect to our main product.

Compare to other division, R&D division is highly valued in our organisation.

We have acquired significantly more patents than competitors.

We have developed significantly more new products than competitors.

☐ 1: Not at all ☐ 2: slightly ☐ 3: Somewhat ☐ 4: Moderately ☐ 5: Extremely

R&D intensity.

Budget or investments for R&D activities = _____ money | _____ people

Or Total = _____ money | _____ people

Evidence (to be selected by the facilitator):



- ☐ At least one of the interviewees know by heart (and the value is around 40%).
- ☐ The value is about 40% (but none of the interviewees knows by heart - they have to check).
- ☐ No interviewee knows.

TEAM MANAGEMENT (TEAM)

[TEAM1]. What percentage of time are the following cross-functional team practices employed in the Company? Adapted from (Cooper et al., 2004; Markham & Lee, 2013).

Good cross-functional cooperation on the team (e.g. representatives not too much time and effort wasted on politics, conflicts, interdepartmental prejudices, etc.)

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ Cross-functional (multidisciplinary) composition with technical people and commercial/marketing/ business development and service (or similar).
- ☐ Cross-functional (multidisciplinary) composition with technical people and commercial/marketing/ business development.
- ☐ The team composed only by technical people.

[TEAM2]. What percentage of time are the following team leadership practices employed for the development teams in the Company? Adapted (Markham & Lee, 2013).

A professional project/program manager whose only job is project management

A full-time project leader borrowed from a full-time position for a single project

A part-time project leader who has other duties

The project team is self-directed

A process owner serves as leader

A project champion who could reside anywhere in the organisation moves the project along

Other, please specify:

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ Full-time project leader (either traditional PM or agile).

APPENDICES

- ☐ Project leader borrowed from functional areas.
- ☐ No team leader or agile management (self-management).

[TEAM3]. What percentage of time are the following cross-functional practices employed for the development teams in the Company? Adapted from (Markham & Lee, 2013).

Cross-functional team training occurs

Cross-functional/Multidisciplinary goals and objectives are established for teams

Team goals and objectives are related to the company strategy

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ More than one team goals or Objectives and Key Results (OKR) deployed from the company's strategy were cited/provided.
- ☐ One team goals or Objectives and Key Results (OKR) deployed from the company's strategy were cited/provided.
- ☐ No team goals are used.

[TEAM5]. What percentage of time are the following dedicated project group practices employed for the development teams in the Company? Adapted from (Markham & Lee, 2013).

Teams have the skill set needed to be effective

Teams are given the needed resources to be effective

Teams are 100% co-located

Teams are a virtual team and only meet electronically

Teams are made up of people that are globally dispersed

Overall, how often are your teams effective

- ☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time
- ☐ Virtually always

Evidence (to be selected by the facilitator):



- ☐ At least a few members are co-located and have a space to work; easy access to collaborative tools (messaging/sharing screen devices).
- ☐ Teams that are co-located have functional space to work, or remote teams have some tools to collaborate if necessary.
- ☐ Teams that are co-located have no clear space to work, or remote teams have limited tools (personal) to collaborate.

[TEAM17]. About the team's innovative behaviour, what percentage of time the following statements best reflect what the Company has been practising so far? Adapted from (Markham & Lee, 2013; Post, 2012).

Our team creates new ideas which are transformed into useful applications

In our company, we tolerate individuals who do things in a different way

We are willing to try new ways of doing things and seek unusual, novel solutions

We encourage people to think and behave in original and novel ways

When we see new ways of doing things, we are last at adopting them

When we cannot solve a problem using conventional methods, we improvise on new methods

☐ Never ☐ About 25% of the time ☐ About 50% of the time ☐ About 75% of the time

☐ Virtually always

Evidence (to be selected by the facilitator):



☐ There is an institutional satisfaction survey for employees on a frequent basis (at least every year) used to inform improvements.

☐ At the discretion of the team leader/manager, there are satisfaction surveys/indicators.

☐ No satisfaction measurements.

MARKET (MA)

[MA1]. For each market research tools/technique presented, what best reflects what the Company has been practising so far? Adapted from (Markham & Lee, 2013).

Focus Groups (interview as a group for needs)

Customer Site Visits (observe and interview at their workplace)

Ethnography (observe customers and their environment for needs)

Lead Users (analysis and/or inclusion)

Voice of the Customer (1-on-1 in-depth interviews for needs)

Creativity Sessions (professionally moderated)

Online focus groups, online surveys etc.

Online communities, net ethnography, virtual shopping, semiotics

☐ 1=Not applied ☐ 2=Slightly applied ☐ 3=Partially applied ☐ 4=Applied ☐ 5=Applied and collaborative (not only technical staff apply it)

Evidence (to be selected by the facilitator):



APPENDICES

- ☐ Practices for identifying needs/requirements (needfinding) are applied in more than one stage/phase of the innovation process.
- ☐ Practices for identifying needs/requirements (needfinding) are applied in only one stage/phase of the innovation process.
- ☐ Lack of application of the mentioned practices in the innovation process.

[MA11]. For each customer testing tools/technique presented, what best reflects what the Company has been practising so far. Adapted from (Markham & Lee, 2013).

Alpha Testing (early tests with users)

Beta Testing (tests of working models by users)

Gamma Testing (testing with the ideal product)

Pre-test Markets (including Simulated Testing Marketing, information acceleration)

Test Markets or pilot product releases

Concept Engineering (formal method for concept development)

Concept Tests (customer evaluation of concept statements)

Trade-off Analysis (conjoint, discrete choice modelling)

Fusing qualitative and quantitative or qualiquant methods

☐ 1=Not applied ☐ 2=Slightly applied ☐ 3=Partially applied ☐ 4=Applied ☐ 5=Applied and collaborative (not only technical staff apply it)

Evidence (to be selected by the facilitator):



- ☐ More than one stage/phase of the innovation process applied the practices for testing.
- ☐ One stage/phase of the innovation process applied the practices for testing.
- ☐ Lack of application of the mentioned practices in the innovation process.

[MA15]. Which indicators are most important to the Company to monitor results after launch? Adapted from (Markham & Lee, 2013; M. X. Song & Parry, 1996).

New Product sales as a per cent of total sales

Profit from New Product sales

Total cost of New Product effort as a per cent of revenue

Project cost vs budget

Percentage of R&D budget allocated to Radical Innovations

Number of Innovative products achieved within the last N years

Number of projects/products at each stage of their life cycle

Measure of the importance of patents

Net Margin return on innovation investment (ROI)

Market share trends

Technical (level of service)

Environmental impact (carbon footprint)

Social impact (community complaints)

☐ 1=Not applied ☐ 2=Slightly applied ☐ 3=Partially applied ☐ 4=Applied ☐ 5=Applied and collaborative (not only technical staff apply it)

Evidence (to be selected by the facilitator):	
☐ Last time these indicators were discussed was within a month.	
☐ Last time these indicators were discussed was last six months.	
☐ Lack of application of the mentioned indicators to monitor the innovation process or more than a year.	

APPENDIX X. IMPROVEMENT PROJECT EXAMPLE

Project to implement guidelines for building and maintaining the innovation strategy

PERFORMANCE DIMENSION TACKLED

This improvement project acts upon the innovation strategy performance dimension, and tackles the following undesirable effects from level 2 of performance (initiated innovation) of the performance framework:

- [REDACTED]
- [REDACTED]
- [REDACTED].

PROJECT GOALS

To develop guidelines for the construction and continued maintenance of the innovation strategy in [REDACTED] also including guidelines for measuring innovation and with the integrated involvement of the technical and sales/commercial areas (avoiding [REDACTED] [REDACTED])

PROJECT CHARACTERISTICS

Complexity		Implementation capacity	
Importance		Risks	
Implementation time	<i>Medium-term – up to 6 months</i> [REDACTED]		
Sponsor	[REDACTED]		
Project owners	[REDACTED]		
Involved areas	<i>R&D, technology radar, product development, business development, commercial (mandatory participation); service, tendering, project management (suggested participation).</i>		
CAPTION	LOW 	MEDIUM 	HIGH  VERY HIGH 

DESCRIPTION

The development of guidelines for the continuous construction of the innovation strategy in the [REDACTED] requires:

- i) Establishment of an innovation committee composed of champions from business development, commercial and R&D ([REDACTED]).
- ii) Periodic meetings to coordinate and monitor actions and measure the performance of the innovation strategy.
- iii) Indicators and goals identified by the innovation committee under the supervision of champions for follow-up meetings.
- iv) Presentation of the results to the [REDACTED] directors and further dissemination in the quarterly reviews (to middle and lower management).

MAIN DELIVERABLES

- Presentation of concepts on performance measurement in a workshop session.
- Elaboration of meeting procedures and follow-ups.
- Creation of an indicator registration plan.
- Training of representatives to use the procedures and the indicator registration plan.

BENEFITS

- Better balance between day-to-day execution and future development.
- More engaged and 'less passive' management in established companies to improve their capacity for innovation.
- Expected increase of [REDACTED]
[REDACTED]

IN-DEPTH INDICATORS FOR MONITORING

Suggestion of performance indicators to be measured and to support monthly innovation committee meetings and follow-up interdepartmental meetings:

- Time spent on activities related to innovation outside formal projects;
- Number of innovation initiatives/workshops started, in progress and concluded;
- Number of projects started, in progress and completed;
- Number of new external collaborations initiated, in progress and concluded;
- Number of and quality of new ideas related to products collected in the system;

- Percentage of all product-related ideas generated (including external parties);
- Number of new patents filed;
- Number of organisational process improvement ideas generated, under implementation and implemented.

PREMISES AND REQUIREMENTS FOR IMPLEMENTATION

- Premise: [REDACTED]
[REDACTED].
- Requirement: [REDACTED].

EXAMPLE

Whirlpool is an example of a company that implemented this practice systematically. In a 5-year plan, Dave Whitwam, then president and CEO of Whirlpool, launched a challenge to his leadership team; turn Whirlpool into a source of innovation for customers, with the slogan “innovation from everyone, everywhere”. Main changes implemented in this plan:

- Make innovation a central topic in Whirlpool's leadership development programs;
- Require that every strategic product development plan contains a considerable component of innovation in the new market;
- Set aside time in the quarterly business analysis meetings for an in-depth discussion of each unit's innovation performance;
- Deployment of the strategy and development of a set of indicators to track innovation inputs, internal processes, and products;
- Allocate a substantial part of capital expenditures each year to projects that meet a certain rigid standard of innovation;
- Train innovation mentors charged with encouraging innovation across the company;
- Enrol all employees in an online course on business innovation;
- Build an innovation portal that allows Whirlpool employees to access a compendium of tools and innovation data in the company's global innovation pipeline.

REFERENCES

(Nilsson & Ritzén, 2014; Thuriaux, 2006).

APPENDIX XI. SPREADSHEET FOR INNOVATION PROFILE CONSTRUCTION

This appendix presents three main screens captured in the spreadsheet developed for tabulating the data from the interviews, comparing and analysing in order to create the innovation capability profile for the companies. This spreadsheet is to be used only by the facilitator.

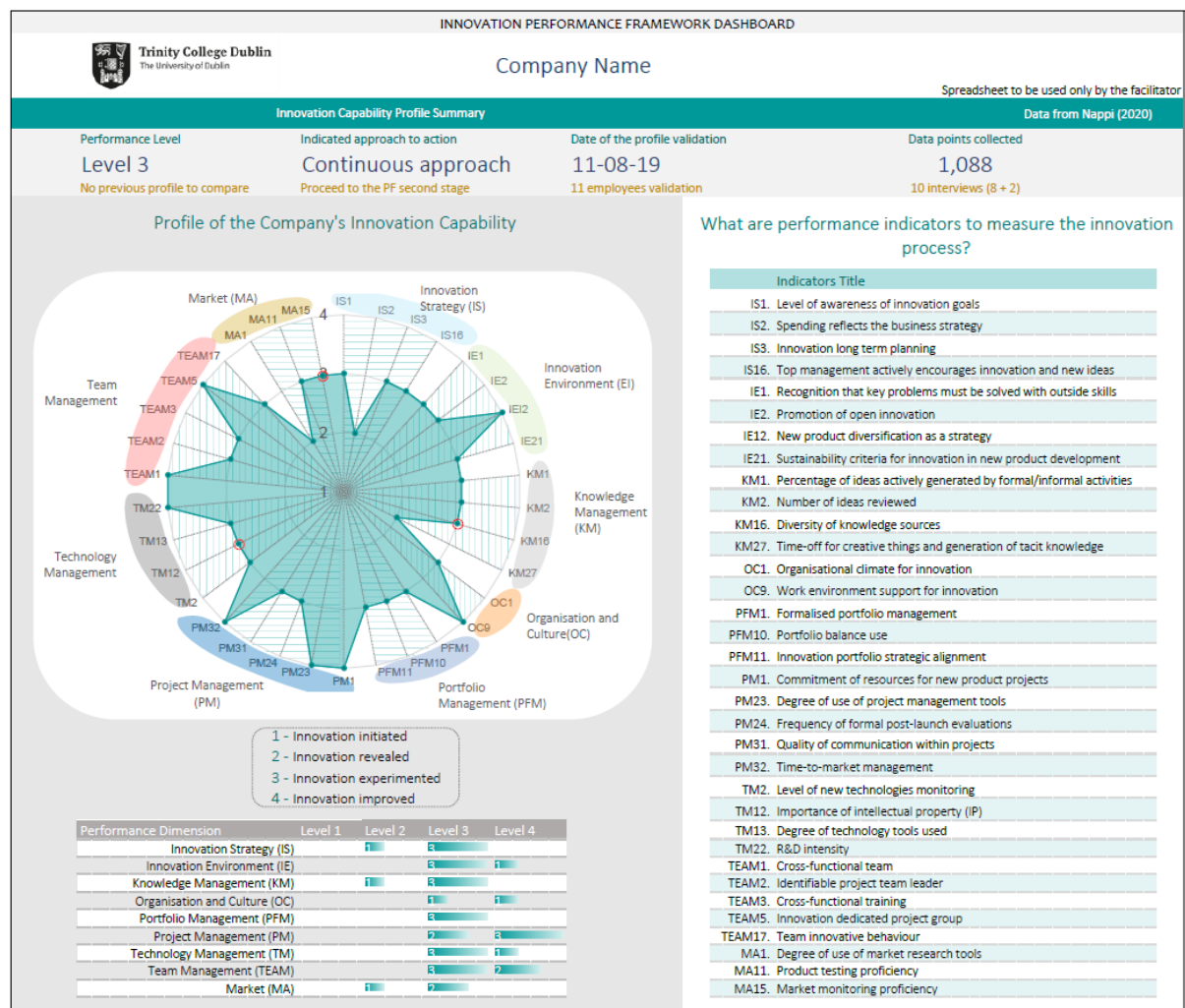


Figure XI.1. Initial screen of the spreadsheet for the profile construction.

APPENDICES

[1]	[2]	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S		
		TABULATION OF INTERVIEW RESPONSES																				
		Number of data points: 1088																				
		D (Quest. • Cod • Sec • EIT technology/R&D • E2 (Operation Support/Support) • E3 (Business Develop) • E4 (Engineer) • E5 (Tender) • E6 (Service) • E7 (PMC) • E8 (R&D) • Average • Var • Std • Avg • Level • Evidence provided																				
1	Year	ID1	IS1	15	4	4	4	4	4	3	2	4	4	4	3.75	0.63	2.00	0.91	3	Innovation goals in the company's intranet or interviewee's own Objectives and Key Results (OKRs)		
2	Experience	ID2	IS2	15	4	4	4	4	4	3	2	4	4	4	3.75	0.63	2.00	0.91	3	Interviewee proposed a strategic goal for the year and the long-term goal		
3		ID3	IS3	15	3	2	3	3	3	3	3	4	3	3	3.00	2.00	0.88	2	At least one or more innovation/R&D projects are underway			
4		ID4	IS4	15	4	4	4	4	4	4	4	4	4	4	4.00	0.00	0.00	3	5 star project known beyond innovation/R&D areas			
5		ID5	IS5	15	4	4	4	4	4	4	4	4	4	4	4.00	0.00	0.00	3	More than innovation/R&D contributors with ideas (monthly incremental)			
6		ID6	IS6	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3	Partnering with universities/colleges for innovation/R&D projects		
7		ID7	IS7	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3	Named the last project done with partnerships with universities/colleges		
8		ID8	IS8	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
9		ID9	IS9	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
10		ID10	IS10	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
11		ID11	IS11	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
12		ID12	IS12	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
13		ID13	IS13	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
14		ID14	IS14	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
15		ID15	IS15	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
16		ID16	IS16	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
17		ID17	IS17	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
18		ID18	IS18	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
19		ID19	IS19	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
20		ID20	IS20	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
21		ID21	IS21	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
22		ID22	IS22	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
23		ID23	IS23	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
24		ID24	IS24	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
25		ID25	IS25	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
26		ID26	IS26	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
27		ID27	IS27	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
28		ID28	IS28	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
29		ID29	IS29	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
30		ID30	IS30	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
31		ID31	IS31	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
32		ID32	IS32	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
33		ID33	IS33	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
34		ID34	IS34	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
35		ID35	IS35	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
36		ID36	IS36	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
37		ID37	IS37	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
38		ID38	IS38	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
39		ID39	IS39	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
40		ID40	IS40	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
41		ID41	IS41	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
42		ID42	IS42	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
43		ID43	IS43	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
44		ID44	IS44	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
45		ID45	IS45	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
46		ID46	IS46	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
47		ID47	IS47	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
48		ID48	IS48	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
49		ID49	IS49	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
50		ID50	IS50	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
51		ID51	IS51	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
52		ID52	IS52	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
53		ID53	IS53	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
54		ID54	IS54	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
55		ID55	IS55	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
56		ID56	IS56	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
57		ID57	IS57	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
58		ID58	IS58	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
59		ID59	IS59	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
60		ID60	IS60	15	25%	50%	50%	50%	50%	75%	75%	50%	50%	50%	50%	0.50	0.50	0.59	3			
Dashboard		Summary of Inputs		Measurements		Evidence Lists															4	

Figure XI.2. Tabulating the data from the interviews.

LIST OF EVIDENCE TO CORROBORATE INDICATORS MEASUREMENTS	
Legend Evidence for top of the scale (5 or 4); (100% or 75%) Evidence for medium of the scale (3 or 2); (50% or 25%) Lack of evidence (1); (0%)	
Innovation Strategy (IS) ID11 Innovation goals in the company's intranet or interviewee's own Objectives and Key Results (OKR) Yearly strategic planning and subsequent meetings No inclusion of innovation in the strategic planning. ID12 Interviewee responds a strategic goal for the year and the long term goal Interviewee responds a strategic goal for the year No innovation strategic goal known by the interviewees. ID2 There is a budget for the innovation/R&D projects for the year. At least one or more innovation/R&D projects are underway. No budget allocated for innovation/R&D projects. ID3 5 year plan is known beyond innovation/R&D area. There is at least one person responsible that knows the plan. Lack of 5-year planning. ID4 More than innovation/R&D contributes with ideas (more than incremental). More than innovation/R&D contributes with ideas (mostly incremental). Do not know what areas can suggest ideas.	Innovation Environment (IE) ID5 Developed or purchased open platform to collaborate with external entities for developing. Partnership with universities/colleges or suppliers for developing innovation/R&D projects. Lack of external parties involved in the innovation front-end. The project done with partnerships with the open platform to collaborate in the last 2 years was cited. The project done with partnerships with suppliers or universities/colleges in the last 2 years was cited. No projects in the last 2 years in the cited circumstances were recalled. ID7 Servicing people participate in innovation and R&D projects. They know about product service systems - PSS (training/networking, etc.) Lack of involvement of servicing and service consideration in the innovation front-end. ID8 Company performs Life Cycle Assessment for strategic products. Company measures carbon footprint for strategic products. Company only measures environmental impact in the facilities.
Knowledge Management (KM) ID9 Frequent (2x year) conduction of formal idea generation activities (roadmapping, scenarios, personas, etc). Innovation committee to analyse ideas. Lack of formalised ideas generation activities. ID10 Ideas are capture in software for idea management and analysed once a semester at least. Ideas in a database and frequency to analyse ideas more than twice a year	Organisation and Culture (OC) ID13 Interviewee gives an example of experimentation culture and failure acceptance Interviewee gives an example of experimentation culture with prototypes. Lack of examples. ID14 Reward considering the impact with distinct criteria not only cost saving or efficiency. Reward considering the impact on cost saving or efficiency. Lack of reward system.
Project Management (PM)	

Figure XI.3. Corroborating the measurements with evidence from the company.

APPENDIX XII. SPREADSHEET FOR PROJECT PRIORITISATION

This appendix presents the main screens captured in the spreadsheet developed for project selection, using the AHP logic to prioritise the projects.

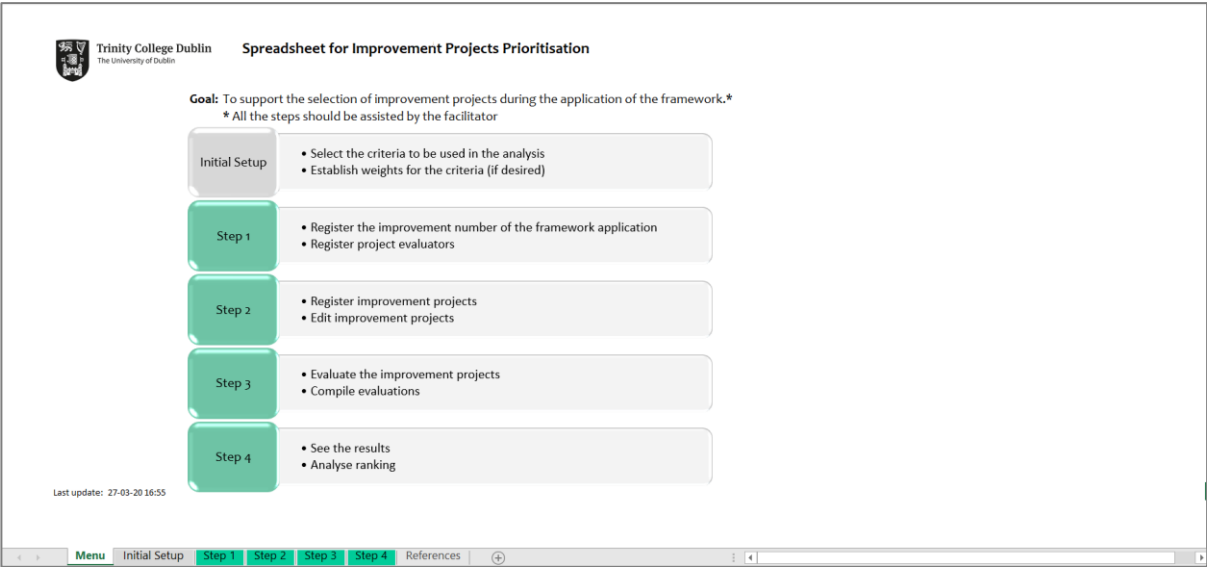


Figure XII.1. Initial menu of the prioritisation spreadsheet.

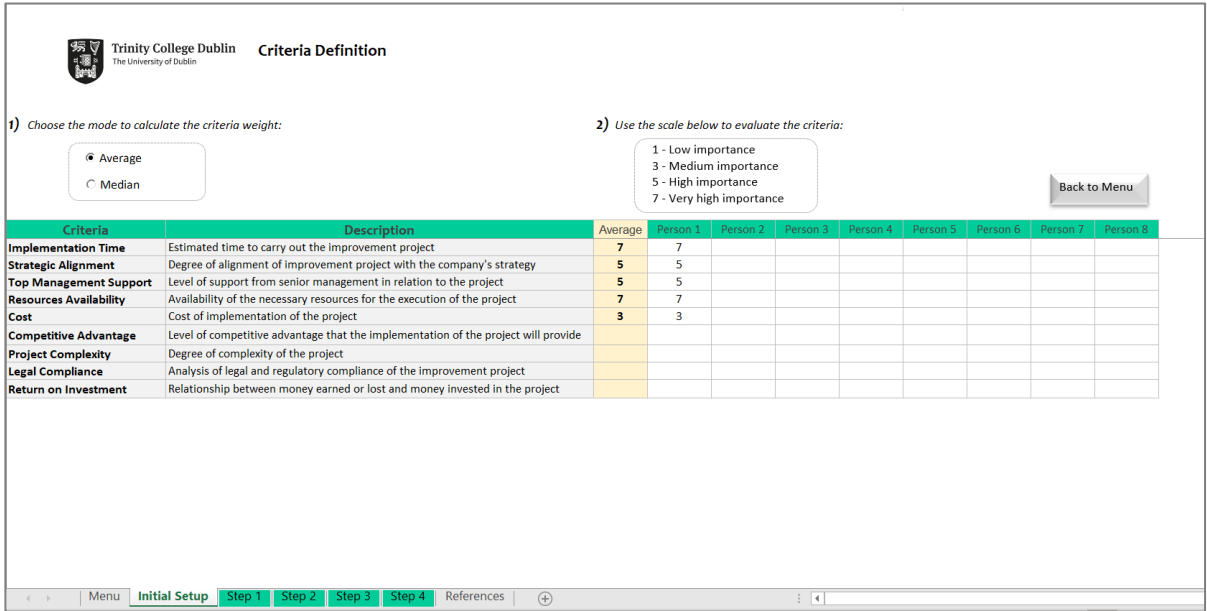


Figure XII.2. Weighting of the criteria for prioritisation.

APPENDICES

The screenshot displays the 'Framework Application' interface for Trinity College Dublin. It includes a header with the college's logo and name. The main content area is divided into two sections: '1) Entry the data about the framework application:' and '2) Register the evaluators for the improvement projects'. The first section contains four input fields: 'Improvement cycle number', 'Place', 'Date (dd-mm-yy)', and 'Facilitator(s)'. The second section features a 'Register Project Evaluators' button, a 'Clear' button, and a table with columns 'Name' and 'Area'. A modal window titled 'Register Evaluators' is open, showing fields for 'Name' and 'Area/Department' with 'Add' and 'Close' buttons. A 'Back to Menu' button is also present. The bottom navigation bar includes 'Menu', 'Initial Setup', 'Step 1', 'Step 2', 'Step 3', 'Step 4', and 'References'.

Figure XII.3. Registration of evaluators of the prioritisation spreadsheet.

The screenshot displays the 'Entry Improvement Projects' interface for Trinity College Dublin. It includes a header with the college's logo and name. The main content area is divided into two sections: '1) Add the title of the projects and a short description.' and 'Number of Projects:'. The first section contains an 'Add Project' button, a 'Clear' button, and a table with columns 'Title' and 'Short Description'. The table lists five project examples. A modal window titled 'Entry Projects' is open, showing fields for 'Project Name' and 'Short Description' with 'Add' and 'Close' buttons. A 'Back to Menu' button is also present. The bottom navigation bar includes 'Menu', 'Initial Setup', 'Step 1', 'Step 2', 'Step 3', 'Step 4', and 'References'.

Figure XII.4. Registration of the projects to be prioritised.

Trinity College Dublin
The University of Dublin

Evaluate Projects

1) Analyse each project against each other using the scale provided.

Projects

Project	Project Example 1	Project Example 2	Project Example 3	Project Example 4	Project Example 5
Project Example 1	0.5				
Project Example 2	2.0	1.0			
Project Example 3	2.0	1.0	1.0		
Project Example 4	9.0	8.0	7.0	6.0	
Project Example 5					

Implementation Time

Project Example 1
Project Example 2
Project Example 3
Project Example 4
Project Example 5

Strategic Alignment

Project Example 1
Project Example 2
Project Example 3
Project Example 4
Project Example 5

Scale

- 1 - Equal importance
- 3 - Moderate importance
- 5 - Strong importance
- 7 - Very strong importance
- 9 - Extreme importance
- 2,4,6,8 - Intermediate values

In the white cells of the matrix, select the preference value number (see scale):

a) If "i" preference is higher than "j", select the integer, or

b) If "i" is lower than "j", select the reciprocal (e.g., 1/9; 1/7; 1/5; 1/3).

Buttons: Load Projects, Clear All, Back to Menu

Navigation: Menu, Initial Setup, Step 1, Step 2, Step 3, Step 4, References

Figure XII.5. Evaluation of the projects according to the AHP method.

Trinity College Dublin
The University of Dublin

Ranking of Projects

Projects	Implementation Time	Strategic Alignment	Top Management Support	Resource Availability	Cost	Competitive Advantage	Project Complexity	Legal Compliance	Return on Investment	Points	Ranking
Project Example 1	0.28	0.35								0.63	4.00
Project Example 2	0.27	0.24								0.51	5.00
Project Example 3	0.36	0.30								0.66	3.00
Project Example 4	0.37	0.48								0.84	2.00
Project Example 5	2.23	1.13								3.36	1.00

Buttons: Back to Menu, Check for Consistency, OK, OK

Navigation: Menu, Initial Setup, Step 1, Step 2, Step 3, Step 4, References

Figure XII.6. Results of the evaluation, showing a ranking of the projects.

Further clarification on AHP

Analytical Hierarchy Process (AHP) is an approach used where decision-makers are faced with a problem with several criteria to be judged and distinct alternatives. It is based on the creation of a problem statement, for example, the selection of improvement projects. The approach is built upon on a hierarchy from the problem statement, broke down into different criteria, and possibly sub-criteria, aggregating the assessment of the possible alternatives into a ranking or prioritisation. It relies on the stakeholders involved knowing enough about the decision that requires a decision to develop a complete structure of relations between the alternatives against the criteria (Saaty, 1990).

With the criteria defined, the principles which guide problem-solving using AHP are comparative or pairwise judgements and synthesis of priorities. In using comparative judgements, pairwise comparisons of the relative importance of elements within a given a shared criterion or property in the level above. This creates a matrix of judgements A and its corresponding principal eigenvector. The matrix A is a $n \times n$ judgement matrix, where n is the number of alternatives (the projects in this case). Each entry a_{ij} of the matrix A represents the importance of the i^{th} alternative relative to the j^{th} criterion. Thus, the relative preference between the two alternatives is measured according to a numerical scale from 1 to 9 (see Figure XII.5). It is also possible to assign intermediate values which do not correspond to a precise interpretation.

1= i and j are equally preferable/important

3= i is slightly more preferable/important than j

5= i is more preferable/important than j

7= i is strongly more preferable/important than j

9= i is absolutely more preferable/important than j

The entries a_{ij} and a_{ji} of matrix A satisfy the following constrain, where:

$$a_{ji} = 1/a_{ij}$$

Clearly, $a_{ij} = 1$ for the same alternatives being compared, and therefore, the diagonal of matrix A is composed of 1.

$$A = \begin{bmatrix} 1 & 1/a_{12} & \dots & 1/a_{1n} \\ a_{12} & 1 & \dots & 1/a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1n} & a_{2n} & \dots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = cw$$

This homogeneous system of linear equations $Aw = cw$ has a solution w if c is the principal eigenvalue of A , or the characteristic value of the matrix A (c = a proportionally constant).

Therefore, once the matrix A is built, it is possible to derive from A the normalised pairwise comparison matrix A_{norm} by making equal to 1 the sum of the entries on each column, i.e. each entry a_{ij} of the matrix A_{norm} is computed as:

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{l=1}^n a_{lj}}$$

After the matrix A_{norm} is complete, the method prescribes the calculation of a vector that expresses the priority of each alternative (this is the eigenvector). The vector, w_j , that is an n -dimensional column vector is built by averaging the entries on each row of A_{norm} , i.e.,

$$w_i = \frac{\sum_{l=1}^n a_{il}}{n}$$

The final global score for each alternative is given by multiplying w and the weight. If there are different weights for the criteria used (the spreadsheet default is equal weight, but this can be changed by the decision-makers):

$$Global\ score = w_i \times weight$$

The final step to prioritise the analysed alternatives is to rank the alternatives. It is accomplished by ordering the global scores in decreasing order. This ranking is presented as a result of this spreadsheet (see Figure XII.6).

The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision-maker when building each of the pairwise comparisons. The Consistency Index (CI) is obtained by first computing the scalar average x of the elements of the vector whose i^{th} element of A is the ratio of the i^{th} element of the vector $A \times w$ to the corresponding element of the vector x_i :

$$CI = \frac{x - n}{n - 1}$$

A perfectly consistent decision-maker should always obtain $CI=0$, but small values of inconsistency may be tolerated. In particular, if:

$$\frac{CI}{RI} < 0.1$$

the inconsistencies are tolerable, and a reliable result may be expected from the AHP. RI is the Random Index, i.e. the consistency index when the entries of A are completely random (Saaty, 1990). The values of RI for small problems ($n \leq 10$) are shown below:

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

APPENDIX XIII. EVALUATION QUESTIONNAIRE RESULTS

This appendix presents the results of the evaluation questionnaire conducted after the application of the PF (Table XIII.1) in each participating company (TRFR, TRPT, and DFED).

Table XIII.1. Results of the PF evaluation in each participating company.

	Respondents	Questions											
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Company TRFR	1	4.00	4.00	4.00	3.00	4.00	3.00	4.00	3.00	4.00	4.00	4.00	3.00
	2	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	3	4.00	4.00	3.00	3.00	3.00	2.00	3.00	2.00	2.00	2.00	2.00	3.00
	4	4.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	4.00	3.00
	5	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	6	4.00	4.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	4.00	4.00	3.00
	7	4.00	4.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00
	Indexes												
	$\mu_{(i)}$	4.00	3.86	3.14	3.00	3.14	3.00	3.14	2.57	3.00	3.00	3.29	3.00
	$SD_{(i)}$	0.00	0.35	0.35	0.00	0.35	0.53	0.35	0.49	0.53	0.76	0.70	0.00
	$SD_{(i)}^2$	0.00	0.12	0.12	0.00	0.12	0.29	0.12	0.24	0.29	0.57	0.49	0.00
Company TRPT	8	4.00	3.00	3.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	4.00	3.00
	9	3.00	4.00	4.00	3.00	3.00	3.00	4.00	3.00	4.00	4.00	4.00	4.00
	10	4.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	3.00	4.00	4.00
	11	4.00	4.00	3.00	4.00	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00
	12	3.00	3.00	3.00	3.00	3.00	4.00	3.00	2.00	3.00	2.00	3.00	2.00
	13	3.00	3.00	3.00	4.00	2.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00
	14	4.00	4.00	3.00	4.00	3.00	4.00	3.00	3.00	4.00	4.00	3.00	3.00
	Indexes												
	$\mu_{(i)}$	3.57	3.57	3.29	3.71	3.00	3.86	3.43	3.00	3.57	3.14	3.43	3.14
	$SD_{(i)}$	0.49	0.49	0.45	0.45	0.53	0.35	0.49	0.53	0.49	0.64	0.49	0.64
	$SD_{(i)}^2$	0.24	0.24	0.20	0.20	0.29	0.12	0.24	0.29	0.24	0.41	0.24	0.41
Company DFED	15	3.00	3.00	4.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	3.00
	16	3.00	3.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	4.00	3.00
	17	4.00	4.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00
	18	4.00	3.00	3.00	4.00	3.00	3.00	3.00	4.00	3.00	3.00	4.00	3.00
	Indexes												
	$\mu_{(i)}$	3.50	3.25	3.50	3.50	3.00	3.00	3.50	3.75	3.25	3.25	3.75	3.25
	$SD_{(i)}$	0.50	0.43	0.50	0.50	0.00	0.00	0.50	0.43	0.43	0.43	0.43	0.43
	$SD_{(i)}^2$	0.25	0.19	0.25	0.25	0.00	0.00	0.25	0.19	0.19	0.19	0.19	0.19
	σ_i^2	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
	$r_{wg(i)}$	0.80	0.85	0.80	0.80	1.00	1.00	0.80	0.85	0.85	0.85	0.85	0.85