Using Context and Behavioral Patterns for Intelligent Traffic Management

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ABSTRACT
The integration of information and communications technologies across existing transportation infrastructure, systems and vehicles is fundamental to reducing traffic congestion, to improving driver safety, and to improving traveler experiences. Central to such intelligent traffic management are techniques and algorithms that are capable of analyzing the wealth of available contextual sensor data in "real time". Initial existing approaches tend to apply probability models and inference techniques to optimize traffic flow but fail to take into account certain aspects of human behavior that can affect the flow of traffic, such as patterns in human travel behavior. In this paper we explore how vehicle context information can be combined with the behavioral patterns of travelers to facilitate and improve intelligent traffic management. We present services for deriving reports on vehicle journeys that assist in the analysis of route performance, for enabling passengers to have remote access to real-time route performance information, and for the observation, learning, and utilization of human travel behavior patterns. These services provide essential traffic analysis information that is ultimately expected to lead to further improvements in intelligent traffic management, which aims at easing the flow of traffic in urban and suburban environments.

Categories and Subject Descriptors
D.2.8 [**Metrics**]: *Process metrics;* D.2.10 [**Design**]: *Methodologies*; D.2.11 [**Software Architectures**]: *Data abstraction, Domain-specific architectures*; E.1 [**Data Structures**]: *Distributed data structures*; H.1.2 [**User/Machine Systems**]: *Human factors, Human information processing;* H.3.4 [**Systems and Software**]: *Distributed systems*

General Terms
Design, Algorithms, Human Factors.

Keywords
Context-Based Intelligent Traffic Management, Context-Aware Services, Travel Behavior Patterns.

1. INTRODUCTION
Within all modern industrialized economies we can see evidence of the importance of road transportation. As the number of vehicles to be accommodated increases and the scope to build new and bigger roads and motorways decreases we witness an increase in traffic congestion despite the current efforts to free the flow of traffic. Congestion costs within the European Union could rise to 1% of its total Gross Domestic Product by the year 2010. Between the years 1991 and 1999 the number of cars per thousand persons increased by over 38% from 247 to 342 in Dublin alone [6]. Over the past 30 years the total distance travelled by road vehicles has tripled, while between 1993 and 2003 alone the amount of road freight in Europe increased by more than 40% [2].

To this end a proliferation of Intelligent Transportation Systems (ITS) have been developed and deployed throughout transport networks often with individual systems heavily tailored for their respective application-specific purpose. The integration and correlation of information and technologies across existing transportation infrastructure, systems and vehicles is fundamental not only to reducing traffic congestion but also to improving driver safety and traveler experiences. Central to such intelligent traffic management are concepts, techniques and algorithms that are capable of analyzing the myriads of contextual sensor data available in the transportation environments of cities or countries. Existing approaches tend to apply probability models and inference techniques on contextual traffic information to optimize traffic flow but fail to consider aspects and the context of human behavior that can affect the flow of traffic, such as the patterns in human travel behavior.

This paper explores how vehicle context information, such as vehicle identification, activity, location and time, can be combined with the behavioral patterns of travelers to facilitate and improve intelligent traffic management. We present services for enabling passengers to have remote access to real-time route performance information, for deriving reports on vehicle journeys that assist in the analysis of route performance, and for the observation, learning, and utilization of human travel behavior patterns. These services provide essential traffic analysis information that is expected to help increase the amount of people who opt to take public transport, to observe the performance of these public transport vehicles and of their scheduled routes, and to utilize commuter travel behavior to alert intelligently managed junctions of a vehicle's imminent approach. This analysis information is ultimately expected to lead to further improvements in intelligent traffic management.

While similar services have been proposed in the past, we argue that our approach is unique in a number of aspects. Our Real-Time Passenger Information Service provides real time access to information which is relevant to passengers, such as the location of the next bus to arrive at a certain bus stop and the estimated time of arrival to that particular stop. This service can be regarded as an implementation of a "view" in a MVC (Model View Controller) system, which can be accessed remotely by mobile devices as well as by web-sites. Supporting mobile devices and specifically, mobile phones provides commuters with convenient and pervasive access to real-time travel information almost on a global scale. Our Statistical Operator Report Service provides the operator of a number of vehicles, for example, of a fleet of coaches or buses, with detailed statistical analysis reports of the performance of the operator's vehicles, which may run over a number of different scheduled routes. Diagrams and charts are provided in these reports to enable a more comprehensive overview of this analysis. This service takes into account vehicles context as well as their schedules in order to perform an analysis of their actual and expected performance. Our proposed traffic management service acknowledges and utilises the fact that many travellers will choose to take the routes that they are most familiar with, and that they usually take, even when confronted with prevailing traffic conditions where an alternative route might be more suited, for example due to lower congestion levels. This aspect of human travel behaviour has been largely ignored by many ITS, not least because such behaviour is inherently difficult to model. Our approach enables the learning and analysis of the routes on which a vehicle is usually taken, and then uses this information to alert intelligently managed junctions of the vehicles imminent approach. This service is based on real-time location awareness provided by GPS but can in principle be applied to any ITS that provide some form of real-time location aware services.

The remainder of the paper is structured as follows. Section 2 compares our approach with related work. Section 3 presents our services for improved intelligent traffic management. Section 4 presents concluding remarks as well as research that remain for future work.

2. RELATED WORK

This section compares our work with related research in the area of real-time passenger information, and destination prediction.

There are many examples of services that provide real time passenger information for various forms of public transport. One such example is STREAMS [13], which is a real time passenger information service that provides information for transportation services such as busses, ferries, trains, light rail, and tram. The real time information is displayed to the passengers via websites, text messages to mobile phones, bus stop displays, and emails. One particular method of presenting information to passengers which is not provided is a native application on a mobile device such as a mobile phone. One benefit that this has over emails and websites is that it can be more easily accessed when the passenger needs it the most, for example when waiting at a bus stop. A benefit that a native application has over text messages is that it tends to be cheaper and is much easier to use. To request bus information in text message form, with its limits in length, the passenger would usually be required to send the service a number of codes representing the route and bus stop, in a text message. This severely limits the amount of information the passenger can request and receive and also adds to the complexity of the task. In contrast, systems that display travel information at bus stops can be extremely expressive and helpful as well as easy to use by passengers waiting at the bus stop, but are not helpful to passengers who have not yet arrived at the stop, who are wishing to plan their travels.

Krumm's research on real time destination prediction based on efficient routes [9] aims to accomplish a similar goal to our Intelligent Traffic Management Service in that it aims to predict the destination of a vehicle. However this research does not take into account an individual's travel behavior. This implies that this approach is capable of working without the need of any initial route learning, but also makes locations that are not as important to the individual just as likely to be predicted as the destination as those locations that the individual visits regularly. Froehlich and Krumm's research on "route prediction from trip observations" [7] does take into account an individual's travel behavior and it uses this to predict that individual's destination. This study focuses on the prediction of complete routes and final destinations as opposed to a probability-based approach with a focus on key points along a partial route, such as bus stops and traffic lights, with increasing probability of prediction as the vehicle approaches these points. As a result of Froehlich and Krumm's approach, the time until a prediction can be made is inappropriately high for our purposes. The work of Lin Liao [11] also focuses on the prediction of ultimate destinations but illustrates more robust methods of using probability models that may reduce the time for predicting a destination. Liao's Opportunity Knocks service [12] aims at improving independence, efficiency and safety of individuals with mild cognitive disabilities. As a result, his individual-centric service not only faces the challenge of predicting destinations but also faces challenges such as the importance of recognizing types of places and users activities at those places [10], the labeling of places, recognizing different modes of transportation, detecting user error, and also challenges related to its graphical user interface. In contrast, we have taken a vehicle-centric approach that does not require specific knowledge about destinations, beyond an understanding of the key points to be passed en-route to these destinations. The Intelligent Traffic Management Service is designed to be a ubiquitous service that the user remains unaware of and as such, there is no requirement for any explicit user interaction.

3. INTELLIGENT TRAFFIC MANAGEMENT SERVICES

This section describes the services that we propose for the improvement of intelligent traffic management and outlines how they contribute to achieving this goal. Initially, it describes the underlying workings and architecture that make these services possible.

3.1 Schedule Management Service

Figure 1 illustrates the architecture of the Schedule Management Service underlying our user services, namely, the Real-Time Passenger Information Service, the Statistical Operator Report Service, and the Intelligent Traffic Management Service. While this service architecture and the user service have been developed for urban and sub-urban travel in the greater Dublin area in the Republic of Ireland, they can be applied to any metropolitan transportation environment.

The Schedule Management Service uses real-time location information of vehicles, route schedule information, and road overlay information, such as a trace of GPS points along the road taken by the route, to match currently active vehicles with currently scheduled routes, and to analyze the performance of both vehicle and schedule. This service operates in the form of a microscopic transportation simulator as each individual vehicle is simulated using live location and context information. This enables the inference of information such as the status of vehicles (including "early", "late", and "on time") and the estimated time of arrivals at a given bus stop. The information that is inferred by this service is then displayed to the user via the Real-Time Passenger Information Service and is further analyzed and displayed via the Statistical Operator Report Service. The Intelligent Traffic Management Service also uses an extended version of the Schedule Management Service in order to infer vehicle destinations.

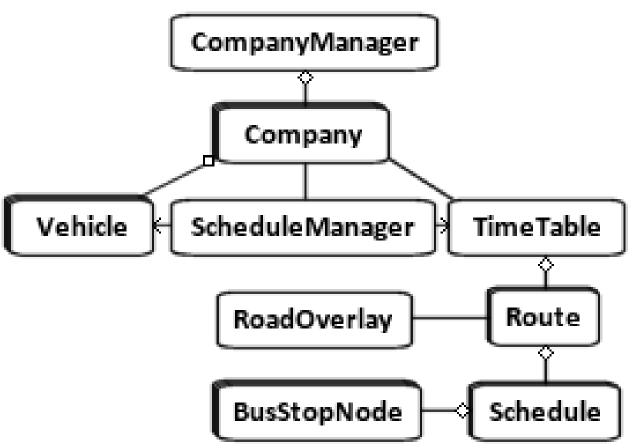

Figure 1. Schedule Management Service architecture.

The CompanyManager component can be queried by user services to discover relationships between companies, vehicles, routes, schedules, and bus stops. It manages a number of different companies, for example, bus or coach operators as well as tram, train, ferry, and flight operators. Each company manages a number of uniquely identifiable vehicle objects that are regularly updated with real-time location information (such as GPS coordinates and a text label describing the vehicle's general vicinity, for example, "Hawkins Street"). This information is archived in a separate database, which enables the system to maintain only the most recent updates in memory, thus, ensuring the system's scalability and continuation over time, as well as a means by which the Statistical Operator Report Service can be run on historic data to provide a report for any requested date. Each company also contains a timetable component that stores all possible routes that the vehicle can travel on. The routes consist of a source and destination location, as well as a list of locations which mark out the exact geographical path along this route, which are compressed and stored in the road overlay component. Each route also contains a list of all of the days and times that a vehicle is scheduled to run a particular route, and the locations of each bus stop to be visited as well as the times that the vehicle is supposed to arrive at each stop. The system thus has the context of each vehicle. The definition of context which we use is that which is presented by Dey and Abowd [3] as "any information that can be used to characterize the situation of entities (i.e. whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity and state of people, groups and computational and physical objects". They thus introduce the essential categories of context as identity, location, activity, and time, each of which is represented in this architecture. The schedule manager of each company regularly examines each vehicle and its context and compares this to the vehicle context that is expected of a vehicle running on each of the currently scheduled routes. The vehicle whose context best matches that expected by a currently scheduled route is assigned to that route. The system can thus deduce the progression of each vehicle along its assigned route, and can further deduce the estimated time of arrival at each bus stop along the route. As a result, the company manager becomes a knowledge base of the real-time status of each vehicle and each schedule, allowing services and ultimately passengers to make queries such as "what is the estimated time of arrival of any vehicle running on a given route, at a given bus stop?"

3.2 Real-Time Passenger Information Service

The Schedule Management Service described in the previous section acts as a foundation upon which we have built a number of separate transportation services. The first of these services is the Real-Time Passenger Information Service illustrated in Figure 2.

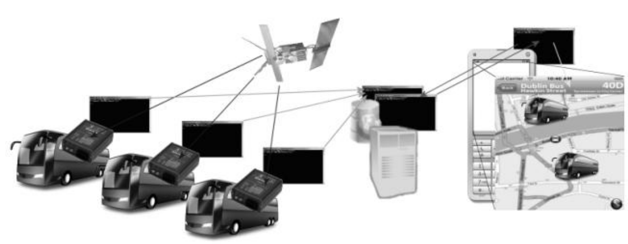

Figure 2. Real-Time Passenger Information Service.

This service aims to address the requirements for a real time passenger information service as laid out by the Department of Transport in Ireland [8]. Passengers wishing to use the service install a simple implementation of the client application onto a given mobile device. The client application will initially contain no information on any of the operator companies, routes, or bus stops captured in the schedule management service, but it will save to non-volatile memory any route information that has been queried or downloaded. This implies that only routes that are used by the individual passenger will be stored on the mobile device. The client application uses a http connection to connect to an adapter servlet, which is used as an interface between the client application and the Schedule Management Service. This overcomes any issues with accessing the Schedule Management Service using port numbers other than port 8080 from a cellular network (as the cellular network provider is likely to block access to ports other than port 8080, which is used for the web). The client application queries the Schedule Management Service with the name of the company, the desired route, and the desired bus stop, and is returned information about the location of the next vehicle to arrive at that particular bus stop, on that route. The client application is also informed as to whether the vehicle is running according to schedule or not, and if not then how far off schedule it is running as well as an estimated time of arrival. The client is also provided with a text description of the street or place where the vehicle is currently located. This information is initially displayed in a table format and when the passenger chooses to view the location of the vehicle and bus stop the coordinates are passed to Google maps and a map is returned with both vehicle and bus stop pinpointed.

The Real-Time Passenger Information Service is aimed at easing one of the annoyances of public transport namely, passengers being unaware of the actual time of arrival of a vehicle at their particular stop. This is expected to encourage a greater use of public transport, thus reducing the number of private vehicles within the traffic network.

3.3 Statistical Operator Report Service

The Statistical Operator Report Service is founded upon the Schedule Management Service and its purpose is to perform an analysis of the performance of a number of vehicles that run over a number of different scheduled routes and to provide detailed statistical reports, including diagrams and charts, to enable a more comprehensive overview of this analysis. As the microscopically simulated vehicles progress through their scheduled routes, important aspects of their context are stored, including assigned schedule, expected and actual time of departure from each bus stop, and distance traveled, and then used at a later point in time for analysis of the performance of the vehicle and the route. A statistical report is scheduled to be produced once a day (daily report) and then again once a week (weekly report). The daily report gives a breakdown of the percentage of scheduled runs of a route that were completed correctly in accordance with their given schedule (within a given tolerance). It also outlines the percentage of scheduled runs of a route that were completed, identifying discrepancies to their given schedule. Such discrepancies arise, for example, if a bus stop was skipped due to lack of passenger boarding or disembarking at that stop or when the final run of a day was aborted due to lack of passengers. Making this kind of information explicitly available to the operator of a bus route is of significant importance for strategic route planning and to uphold and improve the quality of the transportation provided to travelers.

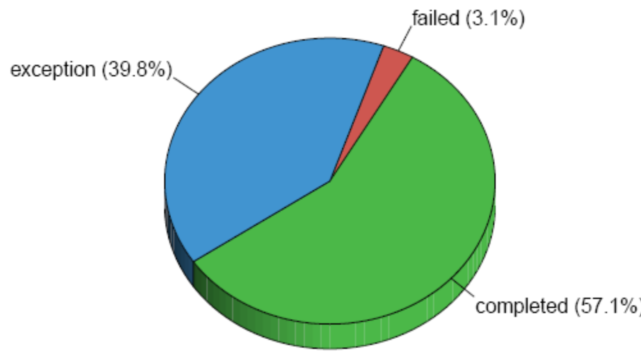

Figure 3. Daily completed schedules.

Figure 3 shows the breakdown provided in a daily report illustrating the percentage of completed and exceptional runs. Exceptional stops also include very early and very late departures at stops. In addition and as shown in Figure 4, a graph is provided which allows the operator to observe how long each vehicle stops at each bus stop giving an indication of which bus stops are the busiest.

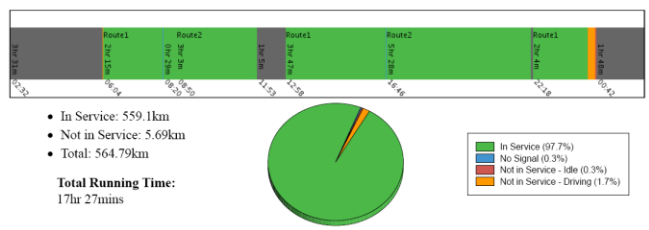

Figure 4. Daily vehicle timeline.

The daily report concludes by providing a detailed timeline of each of the vehicles activities throughout the day. This timeline not only displays the distance traveled by each vehicle throughout the day, but also whether or not the vehicle was assigned to a particular schedule at the time. This helps to identify vehicle misuse by drivers and other forms of inefficient use of vehicles. The timeline also identifies the amount of time the vehicle has its engine turned on, but is not in motion or assigned to a schedule. This might occur, for example, when the vehicle has its engine turned on but is just sitting in the garage, which, of course, is bad for the environment and is also a waste of fuel, and thus money. The general aim of the vehicle timeline is to assist in analysis of the efficiency of vehicle use.

As shown in Figure 5, the weekly report provides a view of scheduled departure times from each bus stop over the course of the week. This assists in the analysis of efficiency of schedules. If a vehicle is constantly leaving late from a particular stop, but leaves the others on time, then the timetable might have to be modified to reflect this.

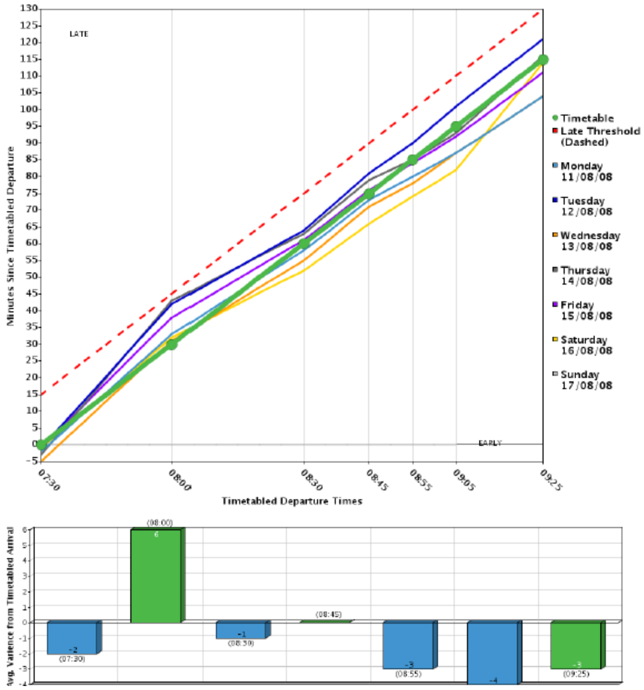

Figure 5. Weekly report charts.

The weekly operator report is then concluded with a recommended timetable based on the performance of each schedule over a given number of weeks or months. If the operator's vehicles usually run on time according to the timetable then the recommended timetable will be the same as the original. This information is important as the vehicles' schedule can be regarded as a list of traffic weights along a particular route at a given time of day, day of week and month of year. If a change is recommended in the timetable then this reflects a change in traffic patterns over time along the given route, for example, the traffic along Hawkins street might become heavier at midday during summer months, so, during these months, the Statistical Operator Report Service recommends a timetable that reflects the fact that it takes longer to drive from one stop to another. The timetables are thus automatically optimized to suite the varying traffic levels. This information may also be applied to the Intelligent Traffic Management Service where public transport vehicles can act as probe vehicles that measure traffic levels along given routes [1].

The purpose of the Statistical Operator Report Service is to assist bus and coach operators in evaluating the efficiency of their fleet of vehicles and the efficiency of their timetables. It also helps to identify the aspects that can be changed in order to increase fleet and timetable efficiency.

3.4 Intelligent Traffic Management Service

Both the Real-Time Passenger Information Service and the Statistical Operator Report Service have been implemented based upon the Schedule Management Service. These services provide the foundation for an Intelligent Traffic Management Service that can handle vehicles of individual drivers that do not run according to strict schedules like those of busses and coaches. Vehicles, such as those used by private transport commuters typically run on a more flexible schedule depending of the regularity of the commuters travel routine. The majority of commuters take the same route every day (as we are creatures of habit) with little variation in times or geographical paths taken, as shown by the research carried out by Froehlich and Krumm [7], which was also aimed at observing commuters travel behavior and using this information to predict the vehicles destination. In these situations the commuters travel behavior, i.e., the users timetable, is learned over time. The service records each road taken as well as the times and days on which they are taken. The areas in which the vehicle is left static over a period of time can be recorded as a source or destination (or stop) node. This context information is thus gathered over time and is analyzed regularly. The output of the analysis of the vehicle context information is a timetable that the service has learned and that can be modified and refined over time, while ensuring to remain flexible to handle expected exceptions that are part of regular behavior, such as holidays and business trips. The timetable can be viewed as a list of the users travel behavior patterns, identifying where the user travels to, what time the user travels, and how long it takes the user to get to her destination. This location predictive knowledge can then be used to improve intelligent traffic management by having each vehicle inform any ITS managing the traffic lights at junctions of their pending arrival so that junction managers can optimize their respective traffic flows. We expect such a service to significantly reduce the amount of time spent waiting for a traffic light to change while there is no or little opposing traffic especially in off peak or sub-urban traffic environments. This service may also support other ITS that depend on knowledge of approaching vehicles [4][5].

Capturing such sensitive context information raises serious privacy issues and in practice, access to this information must be restricted. To alleviate this, we propose to maintain each vehicle's context information within an onboard mobile computing device. This approach enables each vehicle to analyze its own context while restricting the results of this analysis to "private" use. However, we consider a further discussion of privacy issues typically associated with this kind of pervasive intelligent traffic management services beyond the scope of this paper.

4. CONCLUSION AND FUTURE WORK

This paper presented a service architecture for analyzing and utilizing the contextual information derived from public and private transport vehicles in order to increase the efficiency of these vehicles and to foster improvements in managing intelligent traffic systems. Furthermore, we propose a means for observing and analyzing unscheduled (or loosely scheduled) commuter travel behavior that we expect to lead to further improvements to the flow of traffic in urban and sub-urban environments. We are currently extending the existing implementations of the Schedule Management Service and the Statistical Operator Report Service as a test bed for an in-depth evaluation of the proposed Intelligent Traffic Management Service. We are also extending our system in order to improve the current structure. These modifications include the possible execution of each company entity on a separate machine, thus providing a more scalable solution. We are also introducing additional graphs, which will be provided by the Statistical Operator Report Service. These include individual driver performance graphs as well as graphs depicting the requests made by users of the Real-Time Passenger Information Service, allowing the Statistical Operator Report Service to detail the popularity and use of the Real-Time Passenger Information Service.

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