A Digital Ecosystem For Optimizing Service Reliability In Public Transport

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A DIGITAL ECOSYSTEM FOR OPTIMIZING SERVICE RELIABILITY IN PUBLIC TRANSPORT

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Abstract

Automatic vehicle location (AVL) and automatic passenger counting (APC) systems can generate a huge quantity and variety of operational, spatial, and temporal data. This potentially allows the discovery of new ways to enhance service quality and transport efficiency by utilizing AVL-APC inputs. There is currently no framework for implementing full service quality improvement cycles from automated data (Boyle 2008) and this motivates our case study. The objective of this research is to apply a digital ecosystem metaphor that extends the use of AVL and APC data for the benefit of transit agencies. It is intended that this framework will capture relevant data for stakeholders and enable the discovery of otherwise hidden trends that help explain irregularities in operations and suggest new avenues for service improvement. The framework is divided into two components: proactive adaptation and reactive adaptation.

Keywords: Digital ecosystems, transit service reliability, context-aware applications, connected mobility, location-based systems, real-time decision making.
1 INTRODUCTION

Automatic vehicle location (AVL) and Automatic passenger counting (APC) systems can handle the collection of a huge quantity and variety of operational, spatial, and temporal data. Traditionally these kind of data have not been utilized to maximize their full potential in terms of optimizing a transport network. Some AVL systems, designed mainly for real-time applications, fail to capture and/or store data items that might be useful in off-line evaluation. In a real-time mode, AVL and APC data provides operational control and current information to customers and transport managers. In an off-line mode, AVL and APC data can be used to help transit companies analyze performance and enhance operations. Five trends in data use have emerged from the paradigm shift from data poor to data rich, so called “big data”. These focus on extreme values; customer-oriented service standards; scheduling, planning for operational control; solutions to roadway congestion; and the discovery of hidden trends (Furth 2006).

APCs produce an abundant ridership and travel-time database with finer levels of detail compared to fare-based or manual passenger counts, even for agencies with just a few APCs. The increased number of observations provides greater confidence in decision-making regarding changes in service levels. There is also a need to discover new ways to enhance profitability by using AVL-APC data (Boyle 2008).

However, currently there is no framework allowing the implementation of a full service quality improvement cycle. Problems with successful implementation and operation include guaranteeing that bus assignments are completed, new demands for reports, priority for APC equipment in the maintenance department, and unrealistic expectations regarding turnaround time and data quality (Boyle 2008).

This research proposes a digital ecosystem framework that is generic, and hence can be readily applied to various aspects of bus (and other transport modalities) operational strategies over their whole-of-life-cycles. With data collection from AVL and APC, the framework focuses on providing bus service reliability in terms of improving headway, minimizing passenger wait time, and maintaining passenger comfort as well as supporting real-time proactive and reactive schedule and resource adaptation. Proactive adaptation allows the system to anticipate demand and behave optimally, and reactive adaptation is the ability of the system to assimilate historical data and improve its performance over time. Another result is expected to be control strategies to guide bus drivers toward optimal scheduling decisions.

A simulation will be developed to demonstrate the interaction among buses, passengers and the transit environment. The final purpose – and overall objective - is to discover hidden trends that help explain irregularities in operations and suggest new avenues for service improvement.

2 RESEARCH QUESTIONS

This research will answer the following questions:

1. What are the factors affecting transit service reliability?
2. How much impact do transit factors have on service reliability?
3. What cost-effective real-time control strategies can be developed to improve service reliability?
4. How can prior knowledge and historical data be used to support real-time decision-making and enhance operational planning?
5. How can the characteristics of a digital ecosystem for the framework be designed and implemented?

6. What are the general features of a transport-based digital ecosystem and how can these be re-used in other jurisdictions?

3 KEY BACKGROUND LITERATURE

In this section we review the background, existing work and systems that are relevant to our work. In particular, the review focuses on the following three broad areas: (1) Automatic vehicle location (AVL) and automatic passenger counting (APC), (2) Service reliability, and (3) Modeling and Simulation;

(1) involves reviews on AVL, APC technologies, benefits and pitfalls associated with various passenger counting technologies. Also a review of the kinds of decision-making required by bus agencies is encountered. These reviews help to decide business needs as well as issues or gaps in implementing and using AVL and APC in bus companies/agencies.

(2) includes reviews on the social effects of the problems and effects of service reliability in public transportation. This review will help efficiently design and implement our algorithms and models. In other words, our solution is supported and strengthened by social science-based research about service reliability.

(3) surveys algorithms, techniques and strategies to build models and simulations for bus operational strategies. This will lead to the building of innovative algorithms and models for our framework and simulations. 

A wide-variety of uses for archived AVL-APC data were identified in the literature. One of the richest application areas for archived AVL data involves run-time analysis, including designing scheduled running times and monitoring schedule adherence. Moreover, AVL data can be applied to schedule adherence, headway regularity, and passenger waiting time. Discovering archived AVL-APC data can allow “transit agencies to find hidden trends that help explain irregularities in operations and suggest new avenues for improvement” (Furth 2006). A significant move in AVL system development for collecting archived data appeared in the mid-1990s, when Tri-Met with an AVL vendor designed a hybrid AVL-APC system presenting on-board event recording and radio-based communication. The on-board computer is used to store stop and other event data, while messages useful for real-time monitoring are transmitted. However, regardless of what functions a data collection system may have, there is a common demand for archived data analysis. The transit industry is amid a revolutionary shift from a data poor to data rich state. Traditional analysis and decision support tools needed little data, “not because the data has little value, but because traditional management methods had to accommodate a scarcity of data” (Furth 2006). Automatic data gathering systems not only do more than meet traditional data needs, but also open up opportunities for new analysis methods that can be used to enhance monitoring, planning, performance, and management (Furth 2006).

Strengths associated with APC implementation included improved communication among departments and organisational units, enhanced decision-making capabilities, greater responsiveness, and the capacity to give the required data to end-users. Among other positive effects were noted, better relationships along with external agencies and improved management reaction to better reporting. As data systems are integrated new uses of APC data and innovative analytical strategies can be expected to emerge as users become more knowledgeable. This will affect data needs or the priority afforded to the APC system (Boyle 2008).

Bus service unreliability affects passengers because it causes passengers to wait longer. Particularly, on high frequency routes, headway regularity is important to passengers because of its impact on waiting time and overcrowding. Overcrowding is key to passengers – for their comfort - and to operations – because it can slow the boarding and alighting. The number of passengers is also important in planning because it is a measure of transport network efficiency. For transit services with
short headways, passengers can be assumed to randomly arrive independently of the schedule. The variability of headway makes passengers feel that the service is unreliable, especially when “bunching” of buses occurs. The transit industry has lacked a measure of service reliability that is measured in terms of its impact on customers. In other words, traditional measures do not express how much reliability impacts on passengers’ perceptions. In this proposal, service reliability is measured based on passenger wait time, comfort, and even headway (Furth 2006).

Models/simulations for transit operations have been studied for many years. Chen and Chen propose the stochastic simulation method to analyse the route-level transit service reliability for high frequency bus route services. The method describes the process of bus services, headway variation, and average passenger waiting time under different passenger demand and running time fluctuations (Chen and Chen 2009). A model for optimizing bus route headway has been developed for a given network configuration and demand matrix (Yu et al. 2011). This aims to find an acceptable balance between passenger and operator costs to maximize service quality and reduce operational costs. Zolfaghari, Azizi, and Jaber have developed a mathematical model for a holding control strategy based on real-time data of bus position to minimize the waiting time of passengers at all stops on the route (Zolfaghari, Azizi, and Jaber 2004).

The main drawback of earlier work is that they ignore the uncertainty of transit operation that are caused by the transit environment and randomness of passenger arrivals. There is also no framework for implementing full service quality improvement cycles. These are the main motivations for our case study.

4 THEORETICAL BASIS

![Figure 1. Information Systems research methodologies applied in the development of an AVL/APC digital ecosystem.](image)

*Original figure from (Hevner et al. 2004)*

Figure 1 presents our conceptual framework for understanding, executing, and evaluating the case study. For Information System (IS) research, the environment is composed of people, organizations, and their existing or planned technologies. The organisations are bus agencies and the stakeholders in this research are passengers, managers, station supervisors and drivers. Automatic vehicle tracking and
automatic passenger counting technology are employed in bus agencies. “Business needs are assessed and evaluated within the context of organizational strategies, structure, culture, and existing business processes. They are positioned relative to existing technology infrastructure, applications, communication architectures, and development capabilities. Together these define the business need or “problem” as perceived by the researcher. Framing research activities to address business needs assures research relevance” (Hevner et al. 2004).

The model being developed here addresses research through the building and evaluation of artefacts designed to meet the identified business need. There are three identifiable artefacts produced in this research: proactive adaptation component, reactive adaptation component, and framework itself. “Research assessment using justify/evaluate activities can result in the identification of weaknesses in the theory or artefact and the need to refine and reassessed. The refinement and reassessment process is typically described in future research directions” (Hevner et al. 2004).

“The knowledge base provides the raw materials from and through which IS research is accomplished. The knowledge base is composed of foundations and methodologies” (Hevner et al. 2004). The foundational theories in this research are transit operations research, data mining and machine learning. “Methodologies provide guidelines used in the justification/evaluation phase” (Hevner et al. 2004). Validation criteria, data analysis techniques and measures are the methodologies used in the study. “Rigor is achieved by appropriately applying existing foundations and methodologies” (Hevner et al. 2004). Analytical, simulation, and computational and mathematical methods are primarily used to evaluate the quality and effectiveness of artefacts.

5 RESEARCH MODEL

![Figure 2. Information Systems Research Model for analysis of AVL/APC digital ecosystem](image)

Figure 2. Information Systems Research Model for analysis of AVL/APC digital ecosystem
Figure 2 shows the conceptual model for this study. In the real-time mode, a supervisor will receive evaluations of a current scenario which combines previous experience, real-time data including real-time travel demand, transit demand, transit network and assignment data to give optimal proactive adaptation including guidance for drivers leading to optimizing the bus network operations. In the offline mode, historical data is used to study the impacts, namely the relationship between factors and to evaluate proactive decision/control decision to re-plan the strategies.

Rational decision-making in the context of this research model depends on “both the relative importance of various goals and the likelihood that, and degree to which, they will be achieved” (Russell and Norvig 2010). Probability offers a means of summarizing the uncertainty that originates from “laziness” and “ignorance”. “Laziness” here means there is too much work in listing the complete set of antecedents and consequents needed to ensure an exception-less ruleset. The term “ignorance” splits in meaning between theoretical and practical. In theoretical terms “ignorance” here means there maybe no complete theory so the point at which a complete coverage of rules for the problem domain can never be adequately determined. In terms of practical “ignorance”, even though we know all the rules, we might be uncertain about specific circumstances because not all the necessary deterministic tests have been (or can be) run (Russell and Norvig 2010).

6 PROPOSED METHODOLOGY

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<th>Method</th>
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<td>Phase 4: Findings validation</td>
<td>Interpretation of findings</td>
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*Figure 3. Research Design*

Based on the research questions specified earlier, the research design proposed for this study is depicted in Figure 3. The study is divided into four phases.
Phase 1 defines the research context through a literature review on relevant topics. Then AVL and APC equipment will be installed on the Shuttle bus in Wollongong, Australia. The simulation environment of the framework will also be developed. Validation criteria will be used to evaluate data modelling from real world data for simulation.

Phase 2 involves developing a proactive adaptation component to help answer Research Questions 1-3 above. The intention is to find strategies to guide drivers towards optimizing the overall bus network, not strategies solely for an individual bus. This component also is used to study the relationship between factors that affect service reliability and their interactions and interdependencies. Algorithms will be developed to: maintain/restore service reliability for passengers; reduce passenger waiting time; reduce in-vehicle travel time; reduce passenger overcrowding; and for operations, to keep buses on schedule, to maintaining uniform headway, to find out the main causes of unreliability. Data analysis techniques, computational and mathematical methods are used to justify/evaluate for Phase 2 outcomes.

Phase 3 involves developing active adaptation components as part of addressing Research Questions 1, 2, 4. This phase will evaluate proactive decision making methods to re-plan the strategies, which in turn will improve the real-time control strategies. It will also help to evaluate driving and travel behavior. There is an interaction between the driver and the system; the driver not only is a user of the system, but also a part of the system itself. The feedback/lessons that they have received from their interaction with the system will help them to adjust their behavior. Data analysis techniques, computational and mathematical method are used to justify/evaluate phase 3 outcomes.

In Phase 4, it is expected that all research questions 1-6 will be answered and findings will be validated.

7 CURRENT STAGE OF THE RESEARCH

The candidate has been writing a literature review, has developed simulation environments for the framework, which is the first phase of this research. The candidate is currently developing the second phase of the research.

8 PLANS FOR COMPLETION

This research commenced on 10th October 2011 and is expected to be completed in June 2015. Below is the research plan.

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9  RESEARCH CONTRIBUTIONS

Body of knowledge

This study will contribute towards the body of knowledge in the following ways:

1. The study introduces new approaches for control strategies that can deal with decision making in a multi-criteria environment with uncertainty.

2. An innovative digital ecosystem framework for real-time bus control strategies and operation planning will be developed to better understand the impact and relationship of transit factors, travelers, and drivers: that affect bus service reliability. This research will develop a framework to implement full service quality improvement cycles.

3. The use of AVL-APC data in the organisation will be extended.

Practical Contributions

This research provides clear and practical useful information to both technical and managerial audiences:

1. For technical audiences: new approaches to decision support using methodologies of machine learning, data mining, and digital ecosystem design will be provided.

2. For managerial audiences: a new framework will be provided that helps managers and planners understand factors that influence service reliability and extend the capability and cost-effectiveness of transit operations. Transit agencies will be able to provide and analyze service operations, find hidden trends that help explain irregularities in operations and suggest new avenues for improvement. Exploratory analysis might also reveal relationships that can lead to better end-of-line identification, or to better understanding terminal circulation needs.

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