ATLANTIC

A Thematic Long-term Approach to Networking for the Telematics and ITS Community

A Partnership of ITS Communities in Europe and
North America

DISCUSSION PAPER

URBAN PUBLIC TRANSIT ITS RESEARCH AND DEVELOPMENT IN CANADA

Prepared by

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IN COLLABORATION WITH PARTICIPATING PARTNERS AND SPONSORS

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PREFACE

ATLANTIC (A Thematic Long-term Approach to Networking for the Telematics and ITS Community) is an international cooperative undertaking that aims to foster information exchange and policy debate related to the application and development of Intelligent Transport Systems (ITS). ATLANTIC originated as a project sponsored by the European Union under the 5th Research Framework with self-sustaining partners in Canada and the United States. ATLANTIC is organized into 8 work groups focused on different topics related to Telematics and ITS. This document is the product of one of the Canadian work groups to benchmark and assess the state of ITS practice and research and development in Canada.

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The ATLANTIC Canada network node is sponsored by Transport Canada, Ministry of Transportation Ontario and Ministère des Transports du Québec and jointly managed by the ITS Centre and Testbed, University of Toronto and the Centre de recherché sur les transports, Université de Montréal. The core team providing overall leadership for ATLANTIC Canada includes Professor Baher Abdulhai (Toronto), Professor Teodor Gabriel Crainic (Montréal) and Dr. William Johnson (Ottawa).

The Canadian Work Group 1.3 "Intermodal Collective Transport Information" is jointly managed by Professor Amer Shalaby, University of Toronto and Dr. Brendon Hemily, Hemily and Associates. They provided the intellectual leadership and writing skills to assemble and document this discussion paper with inputs and contributions from a network of Work Group members. The names of Work Group 1.3 members and contributors appear in Annex A. Special recognition is extended to Dr. Liping Fu, University of Waterloo for his extensive contribution.

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1. OVERVIEW OF PUBLIC TRANSPORT ITS R&D NEEDS IN CANADA

1.1 Introduction: Overview of Transit ITS and Scope of Discussion Paper

"Public Transport Services" is one of the User Services Bundles defined in the *Intelligent Transportation Systems Architecture for Canada*. It includes and defines the related User Services as follows:

Public Transportation Management (User Service 3.1)

The Public Transportation Management user service applies advanced vehicle electronic systems to various public transportation modes and uses the data generated by these modes to improve service to the public. It includes operation of vehicles and facilities, planning and scheduling, and personnel management.

En-Route Transit Information (User Service 3.2)

The En-Route Transit Information user service provides travelers with real-time transit and high-occupancy vehicle information allowing travel alternatives to be chosen once the traveller is en-route. The single sub-service of the En-Route Transit Information user service provides three major functions, which are (1) Information Receipt, (2) Information Processing, and (3) Information Distribution. This capability integrates information from different transit modes and presents it to travelers for decision making.

Demand Responsive Transit (User Service 3.3)

The Demand Responsive Transit user service involves the use of flexibly routed transit vehicles offering more convenient service to customers. These transit vehicles include small buses, taxicabs, or fixed-route transit buses that are detoured from their pre-established route to pick up or discharge passengers.

Public Travel Security (User Service 3.4)

The Public Travel Security user service supports innovative applications of technology to improve the security of public transportation. Security concerns include protecting transit patrons and employees from street crime, maintaining an environment of actual and perceived security, and developing innovative technical measures to respond to incidents.

The Canadian ITS Architecture defines *Public Transit Management* as including six sub-services:

- Transit Vehicle Tracking
- Transit Fixed-Route Operations
- Passenger and Fare management
- Transit Maintenance
- Multi-Modal Co-ordination
- Multi-Modal Connection Protection

In addition, the effective and efficient delivery of transit service may also be enhanced through the integrated deployment of several other ITS User Services defined in the ITS Architecture, including;

- Traveller Information
- Traffic Control Services
- Electronic Payment Services, and
- Archived Data Management

In simple terms, the basic components of Transit ITS include:

- Intelligent / smart vehicles, with on-board computers / data storage capability,
- Mobile communication systems,
- Location tracking system (typically using GPS),
- Transit management control centres,
- Call centres and station/stop systems for customer information,
- Maintenance garage systems, and
- Archived data from the various Transit Intelligent Transportation Systems.

These basic components are used and integrated to provide potentially a number of powerful functionalities that make fixed-route transit more effective or efficient. These include the enhancement of communications, the provision of Computer Aided Dispatch (CAD), provision of continuous Automatic Vehicle Location (AVL) monitoring, enhanced and responsive security measures, provision of continuous schedule adherence monitoring, enhanced data collection through Automatic Passenger Counting (APC), provision of Transit Signal Priority (TSP) in the traffic control system, continuous monitoring of vehicle performance data through on-board sensors, enhanced customer information (pre-trip and/or en-route), and the potential for electronic fare payment.

In addition, transit ITS offers the potential to enhance demand responsive transit services, through real-time scheduling / dispatching of paratransit vehicles or route-deviation vehicles, and the potential for dynamic rideshare matching.

The potential of Transit ITS to enhance or create the above functionalities has promoted considerable interest in the Canadian transit industry. In light of this interest, the ATLANTIC Work Group (WG) 1.3 provided a forum for exploring **Public Transportation ITS Research and Development Needs.** This forum served to:

- identify experts interested in this issue (see the list of WG 1.3 experts in the Appendix),
- solicit feedback on related R&D activities that are underway, or on R&D needs in the area of urban transit ITS, and
- to provide a basis for the development of a discussion paper.

The objective of this discussion paper was to build on the interactions with practitioner and research experts in order to identify R&D needs in public transport R&D in general, focusing on a limited number of higher priority areas. However, given the existing state of ITS activities in public transportation in Canada, and the modest financial resources available for support in preparing this discussion paper, the Work Group concentrated the scope of its efforts to **Urban**

Public Transit ITS Research and Development, focusing in particular on the areas of transit signal priority and demand responsive transit.

1.2 Overview of Transit ITS in Canada

The first step in the workings of Work group 1.3 was to assess the state-of-the art and of the practice in the Canadian context. The leaders of Working Group 1.3 have conducted, through interviews and a review of existing documents, a scan of Transit Intelligent Transportation Systems (ITS) Research and Development (R&D) in Canada. There is considerable interest in the Canadian transit industry in the application of ITS technologies in order to improve operational efficiency and/or the attractiveness of transit service to existing or potential customers. Interest in the potential role of Transit ITS takes several forms.

A few transit systems deployed in the 1985-1992 period multi-function Transit ITS systems, built on an Automatic Vehicle Location (AVL) system, including: Toronto, Outaouais Region, Halifax, Hamilton, and Ottawa. More recently, AVL systems have been deployed, or are being deployed, in London, St John's, Newfoundland and for the Vancouver TransLink Richmond Rapid Bus. In addition, several other transit systems have deployed stand-alone Transit ITS systems such as Automatic Passenger Counting (APC), Transit Signal Priority (TSP), etc., including: Longueil, Montreal, Quebec City Region, Victoria and Winnipeg.

There has also been considerable interest across Canada in Transport Canada's ITS deployment grant program, and several transit systems have received ITS deployment grants for transit-related initiatives. Projects include:

- Calgary-Traffic Signal Priority and Automatic Vehicle Tracking System
- Go Transit-Rail Operations Information Systems
- Ottawa-Deployment of Intelligent Transit Vehicle Subsystem
- Outaouais-Dynamic Message Signs at Bus Stops
- Peterborough-Integrated Traffic Signal Control and Bus Priority System
- Richmond-Vancouver Rapid Transit Evaluation
- St John's, Newfoundland-Metrobus GPS-based AVL System
- Toronto Integrated Mobility Systems: A Multi-Modal Multi-Application Smart Card Initiative
- Waterloo-Transportation Demand Management Initiative
- York Region-Transit Priority System Integration and deployment

Many systems are also actively planning for Transit ITS. For example, a few regional or transit systems have conducted, or are conducting, formal ITS Strategic Plans in the last 2 years (e.g. TransLink in Vancouver, Edmonton, AMT in Montreal, City of Calgary, etc). In addition, several municipal transit systems are currently exploring the range of ITS applications that use the potential offered by a common core GPS-based location system (e.g. Ottawa, Mississauga, Winnipeg, etc.). Other transit systems are evaluating individual applications of local interest, such as TSP, Customer Information systems. There is clearly much interest in ITS in the Canadian transit community. Municipalities operate in a **highly constrained fiscal environment**, and the lack of funding is the greatest challenge at the municipal level impeding

ITS deployment. It should be noted that in this context, transit systems are not surprisingly generally less interested in fundamental research, than in applied research, developments, and demonstrations that help them move closer to deployment.

1.3 Comparison of Transit ITS in Canada and Abroad

Canada was an international leader in the 1980's in the development and deployment of advanced technology in public transportation, especially in the areas of AVL, with several new systems being introduced in the late 1980's. This was highlighted during an International Conference on AVL Systems, organized by the Canadian Urban Transit Association (CUTA) in 1988 in Ottawa. Although countries such as France and Germany were slightly more advanced than Canada in the development and deployment of AVL systems, Canada was not far behind, and certainly on par with developments in the U.S.A. In fact, Canada was more advanced at the time in the deployment of schedule-based telephone customer information systems.

By 1992, the situation had totally changed. As a result of the disinvestments that started to occur as of 1992 in all public sector areas in an effort to reduce budgetary deficits, at both the federal and Provincial levels, investment in terms of both research and deployment in advanced transit technology gradually disappeared. This situation continued for a period of 6 to 8 years, and was characterized by:

- The wrapping up of all existing technology projects, such as the London AVL system, and the TSP study conducted by CUTA [O'Brien, 2000] with no new projects being initiated;
- The elimination of federal and most provincial R&D programs that could be used by the transit industry;
- The reduction or elimination of provincial capital transit subsidy programs, forcing transit systems to focus more on immediate priorities such as vehicle replacement to the detriment of Transit ITS;
- The dearth of academic research on transit technology for lack of funding; and
- The loss of Canadian manufacturing capability in the area of transit ITS for lack of domestic demand.

In contrast, during this period, massive investment in Transit ITS research and deployment were made in both Europe and the U.S.A. In Europe:

- Transit ITS has been systematically deployed in all large and medium-sized transit systems;
- Research, development, and demonstration of Transit ITS has been systematically pursued across Europe through successive European DRIVE and Telematics Framework R&D programs, with dozens of major multi-partner, multi-city R&D projects exploring all aspects of transit ITS; and
- Supplementary national programs, such as the PREDIT in France, and projects, such as the VdV project in Germany, were initiated to pursue research and deployment of Transit ITS at the national level.

In the U.S.:

- 46 transit systems have equipped 14,619 buses with AVL, and an additional 32 transit systems are planning to do so;
- 24 transit systems have equipped 3,433 buses with on-board customer information systems, and 40 other transit systems are planning to do so;
- 12 transit systems have installed APC systems on 895 buses, and 16 other transit systems are planning to do so;
- The FTA has sponsored since 1994 the production of a bi-annual comprehensive inventory of all Transit ITS-related developments and deployments in the U.S.A., entitled "*Advanced Public Transportation Systems: The State of the Art*";
- The U.S. DOT Joint Program Office sponsors a web site containing a database of all known ITS deployments by technology, including Transit ITS;
- An entire research program has been underway over the past few years in the U.S. to develop *transit-specific* ITS standards through the Transit Communications Interface Profiles (TCIP) program;
- Major research projects, involving millions of dollars, have been conducted in the U.S. on issues related to Transit ITS, by various organizations, including: the Transportation Research Board's Transit Cooperative Research Program (TCRP), ITS America, MitreTek, Battelle, the Center for Urban Transportation Research (CUTR), the California PATH Program, and the University Transportation Centers (UTC) Program; these often involve direct or indirect funding from the U.S. Federal Transit Administration; and
- The library on Transit ITS, available from the US DOT web site contains dozens of reports specifically on Transit ITS-related topics.

During this period, there has been the development of an enormous gap between Canada and Europe and the U.S., in terms of both deployment, and especially R&D related to transit ITS.

However, more recently, in particular since 2000, one is observing a slight reinvestment in transit ITS in Canada. This is illustrated by the ten or so transit systems that have benefited from the limited federal ITS deployment grant program, as well as the several Transit ITS strategic planning efforts underway, as discussed above. The investment in the ITS laboratories at the University of Toronto and the University of Montreal have opened some possibilities for Transit ITS research, but to date, participation by transit systems remains limited. Interest by the Canadian transit industry in Transit ITS will remain extremely limited until larger issues of sustainable capital funding for transit are resolved, and without the interest of the transit industry itself, the potential for synergy between academic research, supplier development, and transit industry deployment remains problematic.

1.4 Canadian Transit ITS R&D Needs

Through consultations with experts across Canada in the area of Transit ITS concerning R&D needs, the following Transit ITS R&D needs have been identified as areas of significant interest to the Canadian transit ITS community.

R&D Needs Related to Specific Applications:

- Transit Signal Priority (TSP): technical and institutional issues, and potential benefits
- Development of models and algorithms for real-time transit operations control based on AVL and APC systems
- Needs, related issues, and benefits of transit automated customer information systems, including "511"
- Institutional and technical barriers to deployment of transit contactless smart card automatic fare collection systems
- Dynamic routing and scheduling of demand responsive transit

Data-Related Issues and Applications:

- The role of Geographic Information Systems (GIS) and location-based data in Transit ITS applications
- The use of GPS-based location data from Automatic Passenger Counting (APC) and Automatic Vehicle Location (AVL) systems to enhance transit management, planning, and customer information
- Integrating ITS with standard transit planning methodologies and practice

R&D Needs Related to the Deployment of Transit ITS in General:

- Benefits and cost-effectiveness of Transit ITS applications
- Transit ITS and the Canadian ITS Architecture
- Inventory of Transit ITS deployments
- Development of transit system requirements in municipal trunk radio systems in new / reorganized municipalities

A brief discussion of each of these R&D Needs follows:

1.4.1 R&D Needs Related to Specific Applications:

- **Transit Signal Priority as a critical tool to increase the effectiveness and efficiency of Canadian transit; feasibility, benefits, and obstacles**
  Of the various ITS technologies, transit signal priority (TSP) offers one of the most cost-effective approaches to enhancing the effectiveness and efficiency of transit, and encouraging a modal shift to transit. Recent initiatives have demonstrated new "conditional" priority strategies and significant benefits. Conditional priority, providing priority only when the bus is late, may be more acceptable to the traffic engineering community, and thus more likely for deployment. There is a need to explore technical and institutional issues, and potential benefits of TSP. There is also a need to explore new TSP traffic control strategies as well as functional requirements for TSP systems and traffic controller equipment that might be used in specifying new systems.

- **Development of models and algorithms for real-time transit operations control based on AVL and APC systems**.
  Transit operations monitoring and control have long been a major focus of transit operations. The current state of practice is however mainly limited to service monitoring and manual supervision. This is true even for transit agencies that are using ITS

technologies such as AVL and APC. Most transit managers are aware of potential real-time operations control strategies, such as short turning, expressing, and holding. However, in practice, these control strategies are only used in simple forms, which do not consider system-wide effects and optimization. Mathematical models and algorithms are needed to realize the full-scale benefits of these control strategies by identifying optimal combinations of different control strategies based on real-time information. Several research efforts have been made in this area, and other efforts are being pursued by MitreTech in the U.S. However, no workable systems have been developed to date for real applications.

- **Needs, related issues, and benefits of transit automated customer information systems including "511"**
  Canada was one of the earliest implementers of telephone-based customer information, but has lagged more recently in the deployment of ITS-based transit customer information systems. These include national efforts such as the "511" telephone information system in the U.S. or equivalent systems in the U.K. or the Netherlands. They also include a wide range of local initiatives, involving real-time transit information or trip planning systems on web sites or PDA's, at terminal/stop displays, or the use of Cellular Data Packet Communications (CDPD) or wireless communications. There is a need to explore the range of transit ITS customer information developments, their potential application in Canada, and benefits in terms of enhanced customer information.

- **Institutional and technical barriers to deployment of transit contactless smart card automatic fare collection systems**
  Smart cards offer a significant strategic ITS technology for the transit industry. However, deployment of smart cards has remained limited as a result of several practical barriers, including: difficulties in integrating or transitioning from current fare box technologies, a lack of understanding and uncertainty with respect to current smart card strategies by financial institutions, a lack of understanding of potential fare strategies using smart cards, issues of distribution and support, etc. There is a need to explore and better understand institutional and technical barriers to the deployment of transit smart cards.

- **Dynamic routing and scheduling of demand responsive transit**.
  ITS technologies make it convenient to adjust existing demand-responsive trips in real time in response to changes in demand and traffic conditions. For example, one of the major issues that many paratransit agencies are currently facing is high cancellation and no-show, which often render many pre-optimized routes and schedules sub-optimal or useless. A key question is how to design routes and schedules so that they are not only efficient at the time of planning, but also robust, being able to adapt to changing conditions and take advantage of the availability of real-time information and communication ability due to ITS technologies.

1.4.2. Data-Related Issues and Applications:

- **The role of Geographic Information Systems (GIS) and location-based data in Transit ITS applications**
  ITS applications in transit rely not only on geographic positioning, typically through GPS, but also rely on the collection, storage, and processing of location-based data. Current GIS software provides a powerful tool in this respect, but is not well understood or extensively used by transit systems in Canada. There is a need to explore the potential uses of GIS or location-based data in Transit ITS applications (from real-time control functions to data analysis for service planning to real-time web-based customer information systems, etc.), and to define transit system requirements with respect to GIS tools.

- **The use of GPS-based location data from Automatic Passenger Counting (APC) and Automatic Vehicle Location (AVL) systems to enhance transit management, planning, and customer information**
  GPS, with its ability to provide accurate location information on vehicles, has become a mature technology and a basic building block for ITS systems. There is a need to explore the variety of potential applications that can be made of GPS-based location information for transit systems. These include both its use in real-time systems such as AVL and real-time customer information displays on-board vehicles or at stops, but also "off-line" applications related to collecting and using location-based information.

- **Integrating ITS with standard transit planning methodologies and practice**
  ITS has steadily become more prevalent in the transit industry. There is a need to explore how transit planning methodologies and practice should be modified to reflect the availability of new ITS tools and information.

1.4.3. R&D Needs Related to the Deployment of Transit ITS in General:

- **Benefits and cost-effectiveness of Transit ITS applications**
  Canadian transit systems operate in a highly constrained fiscal environment, and the lack of funding at the municipal level is the greatest challenge impeding ITS deployment. ITS must compete with many other capital and operating needs of the municipality. Deployment of Transit ITS has to be sold based on a solid business case. There is a need to explore the benefits and cost-effectiveness of ITS applications in transit.

- **Transit ITS and the Canadian ITS Architecture**
  There is a need to assess to what extent existing and planned Transit ITS projects are consistent with the Canadian ITS Architecture, and to develop any related recommendations that would help encourage a better integration within the ITS Architecture.

- **Inventory of Transit ITS**
  There is a need to inventory all fully integrated Transit ITS systems, as well as all stand-alone systems that might be considered as building blocks for Transit ITS, in use in Canadian transit agencies for planning, operations, fare collection, and customer information. This assessment would also determine what linkages might be developed between exisitng legacy systems to enhance their effectiveness, and to move towards the implementation of fully integrated Transit ITS systems.

- **Transit system requirements in municipal trunk radio systems: identifying functional requirements for computer-assisted radio and AVL**
  Recent institutional developments have led to increased integration of transit in the municipal organization across Canada (including Edmonton, Calgary, Winnipeg, Hamilton, Ottawa, Montreal, Hamilton, etc.). Increasingly, transit radio communications are no longer stand-alone systems, but being integrated into municipal trunk radio systems. This has serious consequences for transit and especially with respect to their ability to deploy ITS technologies. There is a need to clarify the specific requirements of transit systems for computer-assisted radio communications and Automatic Vehicle Location within the context of municipal trunk radio systems, and would help to protect the future deployment of ITS in Canadian transit systems.

1.5. Conclusion

There is significant interest in the Canadian transit industry in pursuing the development and deployment of ITS systems to improve service to transit customers or to improve operational efficiency. However, the reality is that Canadian transit systems operate in one of the most financially constrained environments among the G7 countries. As a result, ITS deployment has, and will likely continue to be for the foreseeable future, piecemeal and limited. It will be guided overwhelmingly by cost-effectiveness considerations and the requirement for a strong business case.

Among the potential Transit ITS technologies and R&D topics identified above, Transit Signal Priority (TSP) represents the highest potential benefits for Canadian transit from a cost-effective point of view. For relatively minor levels of investment (and far less than other ITS technologies such as Automatic Vehicle Location or Smart Cards), TSP offers the potential to enhance service reliability and reduce transit travel times. This can translate into simultaneous cost savings and improved service to transit customers, a win-win application. However, TSP deployment has been spotty to date, and there remain a number of technical and institutional challenges that have hindered deployment. Another important transit ITS area is Intelligent Demand Responsive Transit. Both topics have been chosen for more in-depth discussion in the next 2 sections. It should be noted that other significant areas of transit ITS are covered by other workgroups of the ATLANTIC project, such as transit customer information systems (Workgroup 1.1) and smart card systems (Workgroup 2.3)

2. TRANSIT SIGNAL PRIORITY (TSP)

2.1 Primer on TSP

TSP is a control strategy that provides preferential treatment to surface transit vehicles (buses and streetcars) operating in mixed traffic along urban corridors. The objective of TSP measures is mainly to reduce transit vehicle delays at signalized intersections through the modification of signal time settings, thus improving transit operational efficiency and level of service. TSP treatments can be classified into three types, which also roughly represent the evolution of TSP and its level of sophistication over the years. These types are described briefly below.

Passive TSP

Under Passive TSP, signal timing plans are designed off-line based on transit vehicle frequency and speed. The timing plans are then deployed at the corresponding intersections, where they are executed continuously without regard to the presence of transit vehicles. As such, no vehicle detection technology is required for Passive TSP, reducing the cost involved. Passive TSP is most effective under conditions of high transit vehicle volumes. However, they may incur unnecessarily significant delays to cross-street traffic, if transit vehicle arrivals are not highly regular and predictable (which is often the case). Passive priority may include one or more of the following treatments: (i) signal coordination based on transit travel times, (ii) phase splitting, and (iii) cycle length adjustment. Studies have shown that this is not a very effective way to provide priority to transit vehicles in the traffic stream.

Active TSP

Under this scheme, priority is only granted when transit vehicles are approaching intersections, and as such, a technology for selectively detecting transit vehicles and communicating this information to the traffic controller is necessary. Extension of the priority phase (i.e. green extension), early truncation of the non-priority phase (i.e. red truncation), and transit-exclusive phase, are common strategies of active transit signal priority. Phase omission and rotation are also sometimes used, though there is a perception among many traffic engineers that this creates confusion among motorists.

There are two operational concepts for Active TSP. The first, *Unconditional TSP*, grants priority to any transit vehicle once it is detected upstream of the intersection. The priority is provided typically *via* green extension or red truncation, with offset transitioning implemented after the transit vehicle clears the intersection in order to recover signal coordination and to compensate the non-priority phases. Unconditional TSP has been successful in speeding up transit vehicles along arterial corridors. However, in some instances, transit vehicles may be granted priority when not needed (e.g. vehicle is ahead of schedule, or carrying few passengers), incurring significant delays to non-priority traffic (e.g. cross traffic).

The second type, *Conditional TSP*, grants priority selectively to transit vehicles that meet certain conditions based on deviation of vehicle from the schedule, or time elapsed since last awarded priority. The possibility of granting priority based on some threshold number of passengers on board the vehicle has also been discussed, but has not been applied in the North American context, due to the lack of accurate *real-time* passenger load counting systems.

Conditional TSP requires in addition to the vehicle detection system other systems or mechanisms for measuring whether the approaching vehicle meets the criteria for granting priority. These may involve an AVL (Automated Vehicle Location) system for measuring schedule adherence and possibly in the future APC (Automatic Passenger Counting) systems. Conditional TSP has the potential of limiting buses running ahead of schedule and of mitigating the impacts of Unconditional TSP on non-priority traffic. It, however, also limits the absolute travel time benefit that might be achieved in the corridor.

Adaptive TSP

Adaptive TSP refers to a relatively new generation of priority schemes, which attempt to achieve advanced operational objectives by means of adaptive signal control. Examples of operational objectives include improving transit headway regularity, reducing total vehicle delay in the corridor, and maximizing person throughput. Under Adaptive TSP, the traffic signal controller adapts its plan dynamically according to the criteria reflecting the desired objective. Adaptive signal control is increasingly common in Europe but has not been widely deployed yet in North America to date, but offers considerable promise for maximizing benefits for both transit vehicles and the general traffic.

2.2 Review of Recent Canadian TSP R&D Activities

The recent Canadian research efforts in the area of TSP can be classified into the following three types:

- Development of advanced TSP systems,
- Development of models/algorithms supporting advanced TSP systems (e.g. travel time prediction models and real-time bus performance measurement), and
- Development of simulation tools for evaluation of TSP systems.

2.2.1 The SPPORT Model – University of Waterloo

SPPORT (Signal Priority Procedure for Optimization in Real Time) is a rule-based traffic-responsive signal control model that was primarily developed to incorporate methods of traffic responsive signal control and operational control of transit vehicles. By integrating traffic and transit movements in optimizing traffic signal timing, the SPPORT model is able to provide preferential treatment to approaching transit vehicles while maintaining reasonable levels of operational quality to non-transit traffic. In the SPPORT model, the signal timing plans are updated based on real-time traffic data from detector stations and on traffic events. The SPPORT model uses a heuristic decision-making process in generating the signal timing plans. It creates a priority list of important events in order to allocate green times. The higher an event is on the list, the more likely it is to receive a green phase. Thus, high-ranked events such as a transit vehicle approaching the intersection triggers signal priority. The initial development efforts for the SPPORT model were limited to individual intersection control with simple two-phase signal operation. The model was later improved to be applicable to other intersection types. In addition, enhanced heuristic rules were added for isolated intersection control. Recently, several modifications have been made for the model particularly in the signal optimization module to consider explicitly signal coordination.

2.2.2 Integrated System of Adaptive Traffic Signal Control and TSP – University of Toronto

Similar to several efforts worldwide, this ongoing research seeks to develop a unified and integrated system for adaptive signal control of traffic and transit flows. The system is being designed based on multivariate optimization; for example, minimization of vehicle delay while providing fastest travel time to transit vehicles or minimization of transit vehicle delay while maintaining passenger vehicle's delay at some pre-specified level. The system is also being built to accommodate various control objectives including maximization of person throughput or maximization of vehicle throughput at only strategic routes. The key feature of the system is its simulation-based signal timing optimization using Genetic Algorithms. The current implementation of the system includes the component of adaptive traffic signal control, which has shown superior performance over the TRANSYT-7F model when tested on a network of three intersections. The integration of the TSP component into the overall system is underway.

2.2.3 Adaptive Signal Priority for Automated Transit Headway Control – University of Toronto

This study developed an adaptive TSP strategy that controls transit operations of high frequency routes using traffic signals, thus automating the operations control task and relieving transit agencies of this burden. The TSP of this study is adaptive in the sense that the signal controller adapts its plan according to the status of the approaching transit vehicle with respect to headway and traffic signal conditions. It finds the optimal phase duration for each approaching transit vehicle given specific values of headway deviation (i.e. observed headway minus scheduled headway) and phase time elapsed at the instance of detection. The objective of the strategy is to maximize headway regularity along the route and to break a "bunch" of transit vehicles if one is detected. The algorithm also addresses complications presented by near sided stops, which are typical of transit routes. The method used to develop the algorithm is based on Reinforcement Learning (RL). A case study was carried out by employing the microscopic traffic microsimulation software Paramics to simulate transit and traffic operations at a series of intersections along the King Streetcar route in downtown Toronto. The results show that the control policy learned by the RL agent could effectively reduce the transit headway deviation and cause smaller disruption to cross street traffic compared with unconditional transit signal priority. In addition the agent was effective in breaking up transit vehicle bunches and restoring a reasonable headway over a succession of intersections.

2.2.4 Simulation Study of the Impacts of Environmental Parameters on the Effectiveness of Transit Signal Priority – University of British Columbia

This research investigated the impacts of a number of traffic and transit parameters on the Transit Signal Priority application based on a microscopic simulation approach. The 98 B-Line rapid bus transit line along the Granville Street corridor, Vancouver, was modeled in VISSIM, a microscopic simulation software. A total of 7 parameters were analyzed including bus approach volume, cross street volume/capacity ratio, bus headway, bus stop location, bus check-in detector location, left turn condition, and signal coordination. On the basis of the simulation results, this study proposed several generic guidelines and recommendations for TSP applications such as, i) TSP is more effective where the traffic condition on the bus approach is moderate-to-heavy, ii) exclusive left-turn lane and protected left turn signal should be considered where the left turn flow and the opposing through traffic flow are heavy, iii) consider far-sided bus stop rather than near-sided stop, iv) maintain signal coordination on the bus route, v) the implementation of TSP should be carefully considered where the cross street has a high v/c ratio, vi) the bus performance was sensitive to the location of check-in detectors when a far-sided bus stop is placed, and vii) check-in detectors placed further upstream improves the effectiveness of TSP.

2.2.5 Prediction Model of Bus Arrival and Departure Times Using AVL and APC Data – University of Toronto

Most advanced TSP strategies require accurate prediction of the arrival of the approaching transit vehicle at the subject signalized intersection, and where transit stops are located near sided the departure time from the stop (i.e. following dwell time) is required. This research effort developed a model for dynamic bus arrival and departure time prediction using AVL and APC data. The model is based on two Kalman filter algorithms for the prediction of running times and dwell times alternately in an integrated framework. As such, the model can capture the interaction between the 2 variables (i.e. the effect of one on the other). The model was shown to outperform other traditional models (regression and Neural Network models) in terms of predictive ability when tested on a "hold out" real-world data. More importantly, the superiority of the model was even more prominent when tested on two simulated scenarios representing passenger demand surge (for example because of a special event) and lane closure (for example because of an incident). This is primarily due to the continuous updating of the model parameters based on dynamic real-time data, as opposed to traditional models, which are typically calibrated using historical data, with infrequent recalibration of the model.

2.2.6 A Multi-Attribute Performance Measurement Model for Advanced Public Transit Systems – Ryerson University

Some advanced TSP systems implemented on a network/corridor basis (as opposed to isolated intersections) require a real-time measure of operational performance as input to the TSP algorithm. This study presents a new approach to measuring the performance of services in advanced public transit systems. The novelty of the work lies in integrating two operation control tools, which are schedule and headway adherences applicable respectively to low and high frequency services. These tools help identify deviations in schedules. A new mathematical model was developed, with illustrative numerical examples provided.

2.2.7 SimTransit - University of Waterloo

SimTransit is an advanced simulation model recently developed at the University of Waterloo specifically for the purpose of developing and evaluating advanced transit control and operating strategies under real-time information. The model has been used to evaluate several sophisticated computer-aided dispatching algorithms including holding control and mathematical programming based stop skipping rules. Compared to some existing models, SimTransit features a unique component-based structure, in which individual components for transit vehicle performance monitoring/prediction and operations optimization and simulation are implemented in separate programs that can be executed on different computers over a computer network and synchronized through a central database. This model structure brings in three main advantages. First, the users of the system can use the simulation program to evaluate a wide range of control and prediction models, developed either by their own or by a third party, in addition to those that are provided as part of the simulation model. Second, it supports on-line evaluation of transit control and prediction models with the human dispatcher as part of the simulation loop. Third, the control and prediction models can be readily extracted for field deployment. Efforts are currently under way to incorporate the SPPORT functionality into SimTransit to form a comprehensive optimization and evaluation platform for evaluating various hybrid control strategies including holding, short turn, stop skipping as well as TSP.

2.3 Overview of the Canadian State of the Practice

2.3.1 Transit Signal Priority in Toronto

The Toronto Transit Commission (TTC) was one of the first transit systems to explore the use of TSP. After a first study that assessed the potential application of passive TSP, a demonstration was conducted in 1990, involving six intersections. The findings of this first demonstration were that delay reductions of 5 to 9 seconds at each intersection were attained, contributing up to a 20% reduction in total transit travel time. Other traffic was not significantly affected. Following this success, an incremental program was undertaken to equip over 150 intersections on seven streetcar routes. This resulted in the need for 10 fewer streetcars, and saved over $1 million a year in operating costs. The payback period was less than 5 years.

In 1997, a demonstration of bus TSP was undertaken, and the results were: bus delay decreased up to 46%, auto delay decreased marginally, and cross street traffic not significantly affected. The detection system, however, caused some reliability problems. Since then, a program has equipped over 110 intersections on bus routes. The program is currently under evaluation to assess further deployment.

TSP strategies are implemented in several corridors in Toronto such as the King and St. Clair Streetcar routes. All TSP implementations are of the “Unconditional” type. They work mostly as follows. At an intersection with transit signal priority, if a streetcar has been detected at the upstream ‘request’ loop (approximately 80 m from the stop line), and has not yet crossed the ‘cancel’ loop at the stop line, the controller considers the “zone” to be “active” for this transit route direction. Two basic algorithms are used to provide signal priority for transit vehicles: transit-corridor green extension, and cross-street green truncation. In case of any disruption to the offsets (in reference to the master system clock) by the provision of signal priority an offset recovery routine is initiated.

For transit-corridor green extension, a decision point is defined. It may refer to the number of seconds before the end of the transit-corridor green (e.g. 12 seconds). Alternately, the decision point may be defined based on an interval number (e.g. react at the start of interval #3).

If either of the “zones is active” (i.e., for either transit route direction) at the time of the decision point for transit-corridor green extension, the green extension algorithm will begin with an initial fixed green time period for the transit corridor. This is followed by demand-dependant extensions (1 or 2 seconds depending on the controller type) for the transit-corridor green. The extensions are served consecutively until the zone is cleared (i.e., streetcar passes the cancel loop) or until a maximum number of extensions are provided.

An additional decision point is defined for the truncation. If the zone is active at the time of this decision point, the signal will also switch to local control. The signal timing will be altered to shorten the cross-street green time, and hasten the provision of green to the transit corridor. The amount of green time that will be subtracted from the cross street is a set value defined per intersection, ranging from 2 to 6 seconds after minimum walking time in the study area.

Those decision points for transit-corridor green extension and cross-street green truncation are defined for each intersection after pedestrian walking time and signal priority can be provided in successive cycles if the “zone” is still active.

2.3.2 Other Canadian Developments and Comparison with International Experience

There have been a few other deployments in Canada, including:

- Isolated deployments of intersection control activated by approaching buses typically for buses entering an arterial from off-street terminals or subdivision secondary streets (e.g. Eglinton Bus Station, Edmonton)

- Recent corridor deployments, involving a limited number of TSP-equipped intersections in Quebec City, Longueil, and Calgary.

- Recent or ongoing deployments of new sophisticated municipal traffic control systems that include TSP in Peterborough and York Region, both partially funded through Transport Canada ITS deployment grants.

- Deployment of TSP for the TransLink's Richmond and Granville Street Rapid Bus lines that involve the deployment of Transit ITS components in the form of real-time customer information system and TSP.

Most deployments of TSP in Canadian cities have been of the "unconditional" type, where priority is granted to any transit vehicle once detected upstream of the intersection[1]. Although many TSP deployments in the US, Europe and Japan are also of the "unconditional" type, there have been recent implementations of "conditional" TSP and "adaptive" TSP. For example, conditional TSP has been implemented at 150 intersections in Portland, Oregon, where priority is granted based on the schedule adherence of the approaching bus (i.e. give priority if bus is late). In Japan, the UTMS 21, a "next generation" adaptive traffic management system, includes PTPS (Public Transport Priority System) as one of its subsystems. The PTPS/UTMS21 system has been applied to a number of Japanese cities including Tokyo, Nagoya, Hamamatsu, and Sapporo.

Another international development is the ongoing development of the **NTCIP Signal Control Priority Standard** in the U.S. that will cover Emergency Vehicles, Transit, and Light Rail. The NTCIP Standard contents include: concept of operations, functional requirements, dialogs and sequences (interface specifications), data dictionary, and test procedure.

2.4 TSP R&D Needs

Through the consultations carried out with Canadian experts and discussions held during workshops in the U.S., a number of TSP-related R&D needs have been identified. These fall into two general categories:

- Basic research to improve the algorithms used or develop new approaches to TSP, and
- Applied research to evaluate experience to date, assess issues, and encourage further deployment.

2.4.1 *Basic Research To Improve The Algorithms Used Or Develop New Approaches To TSP*

- **Designing TSP-Based Operational Control Strategies**
  To develop *operational control strategies* (e.g. deadheading, closed door runs, holding, short-turns, etc.) for surface transit, that maximize the potential benefit from TSP systems.

- **Artificial Intelligence and TSP**
  To explore the potential use and effectiveness of applying Artificial Intelligence techniques to various aspects of TSP (e.g. bus arrival prediction, dwell time prediction, cost-effective conditional priority, etc.)

[1] Some TSP systems in Canada may not provide priority to a transit vehicle if its priority request was too soon (based on some threshold value of elapsed time) since last priority request. One such system is the 98 B-Line rapid bus transit line along the Granville Street corridor in Vancouver.

- **Implications of Signal System Design and Traffic Parameters on TSP Request Activation Strategies**
  To explore the implications of signal system design and traffic parameters on different request activation strategies and their effectiveness (e.g. prediction accuracy, priority request success rates, etc.).

- **Integrated TSP With Traffic Adaptive Signal Control Systems, Involving Optimization-Based Priority**
  To develop optimization-based priority algorithms and systems in order to integrate TSP with traffic adaptive signal control.

- **Corridor-Based TSP**
  To develop TSP systems that attempt to minimize delays due to stop-and-go transit vehicle operation through activation of TSP strategies at a number of consecutive intersections upon detection of an approaching transit vehicle.

- **Technical Options for Conditional Priority: a Review of Approaches, and Technologies, and Evaluation Under Various Situations**
  To identify the range of technical options for *conditional priority* (involving schedule adherence monitoring and communication of requests for priority that fulfill conditions), to evaluate the effectiveness and implications of the various options, and to provide guidance for selection of the best option under various local scenarios.

- **Development of Differential Priority Algorithms and Systems**
  To develop methods and systems that would grant different levels of priority to transit vehicles based on real-time information concerning approaching vehicle's condition, with vehicles furthest behind schedule receive higher priority.

- **Hybrid Application of Unconditional and Conditional Control for TSP: Rationale, and Technical Feasibility**
  To develop a hybrid application involving both unconditional and conditional control, under different conditions, to evaluate its potential effectiveness, and to assess its technical feasibility.

2.4.2 *Applied Research To Evaluate Experience To Date, Assess Issues, And Encourage Further Deployment*

- **The Development of an Analytic Framework for Selecting Corridors and Intersections for TSP Treatment: Identification of Warrants and Sources of Data for Assessment**
  To develop an analytic framework and methodologies to assist transportation professionals in selecting corridors and/or intersections for TSP treatment, through a strategic approach to TSP that is based on corporate objectives.

- **TSP and Transit Scheduling: Best Practices for Maximizing the Benefits of TSP under Different Conditions.**
  To develop improved *transit scheduling* methodologies under different TSP conditions.

- **TSP and Automatic Vehicle Location (AVL): Factors Affecting the Transit Agency's Technology Development Strategy, Technical and Management Implications, and Cost-Effectiveness Considerations**
  To provide guidance to transit agency staff on the potential integration of TSP and AVL systems, and the various technical, management, and cost-related implications to be assessed as part of the TSP planning process.

- **Integrating Physical and Signal Priority Measures for Transit: Inventory, Best Practices, and Issues**
  To explore the inter-relationships between physical transit priority measures (e.g. queue jumps, bus / HOV lanes, bus bulbs, etc.) and transit signal priority strategies, and to provide guidance to maximize potential synergies.

- **Traffic Controllers and TSP: Technical Requirements for Alternative TSP Strategies and Inventory of Traffic Controllers and Technical Characteristics**
  To define technical capabilities required of traffic controller equipment under different TSP strategies, and to inventory and evaluate existing controller equipment according to these technical requirements.

- **The Role of TSP in BRT System Design, and in BRT-Specific Planning Tools**
  To isolate TSP among the many elements of BRT system design, to evaluate the specific contribution of TSP to BRT system performance, to explore the interactions between TSP and other BRT strategy elements, and to develop analytic approaches for incorporating TSP in BRT-specific planning tools (e.g. SmartBRT).

- **The Impact of Bus Operator Behavior on Transit Schedules Under TSP**
  To explore how bus operator behavior might affect transit schedules under different TSP deployment scenarios.

- **A Review of Major European TSP-Related Demonstration Programs, Identified Benefits, and Implications of Lessons Learned for Canadian Deployment of TSP**
  To review the findings from several major European Demonstration Programs (e.g. PRISCILLA, ROMANSE, INCOME, ROSETTA, TABASCO, etc.) where TSP played a prominent role, and to identify the benefits and implications of lessons learned with respect to the deployment of TSP in Canada.

3. INTELLIGENT DEMAND RESPONSIVE TRANSIT[2]

3.1 Introduction to Demand Responsive Transit (DRT)

Dial-a-ride paratransit, also called demand responsive transit (DRT), is a significant component of the public transportation system. It plays a vital role in providing equitable transportation services to special groups of population such as the elderly and persons with disabilities who have difficulties to access the regular public transit system. Different from regular fixed-route transit, DRT commonly uses small to medium sized vehicles to provide shared-ride, door-to-door services with flexible routes and schedules. Due to its taxi-like service approach with a fare scheme comparable to regular transit, most paratransit systems in North America are very costly, relying heavily on subsidization. According to the Canadian Urban Transit Association (CUTA), the total operating expenses of Canadian DRT agencies in 2002 amounted to over 215 million dollars, of which less than 10% was recovered from fare revenues and the rest was subsidized. Such strikingly unfavourable cost efficiency has been mainly attributed to low vehicle productivity of paratransit services.

In order to seek cost-effective solutions, many paratransit agencies are turning to applications of advanced information technologies such as automatic vehicle location and computer aided dispatch systems (AVL/CAD), digital telecommunication and computers. Intelligent DRT is the result of integrating these information technologies into the operations and management of DRT systems. With the ability to track vehicle locations, communicate with drivers and clients, and access traffic information on a continuous basis, intelligent DRT systems are expected to operate at a significantly improved level of productivity, reliability and quality of service.

3.2 Intelligent DRT: Technology Background

Operations of DRT are substantially different from regular fixed route transit, requiring a mesh of interrelated managerial functions such as reservation, vehicle scheduling, real-time dispatching, billing and business reporting. With various ITS technologies such as microcomputers, AVL and digital communication, these functions can be automated for potentially more cost-effective operations. The objective of this overview is to provide some operational and technological background of an intelligent DRT system.

In an intelligent DRT system, the reservation system provides the connection between the operation centre and the customers, responsible for recording information on each customer's request, including pickup and delivery locations, desired time window, person to be picked up/delivered and their special requirements, and, in the case of service cancellation and change of service time, for updating request information. This procedure is traditionally performed by a reservation clerk who receives the information over the telephone and then manually enters it into the computer. Under intelligent DRT, more advanced reservation methods, such as automated telephone systems and Internet based interactive reservation systems, would be used.

Each service vehicle is equipped with an in-vehicle computer or a mobile data terminal (MDT), to which operating schedules can be uploaded from the central computer through a wireless

[2] This section has been contributed by Dr. Liping Fu, University of Waterloo

communication channel. The MDT is integrated with an AVL system that provides the dispatch centre with real-time location information. Several alternative AVL technologies are available, different by positioning accuracy and updating frequency. The most popular technology is the Global Positioning System (GPS) that relies on radio signals from satellites to locate the vehicles. The location information is used for real-time monitoring and vehicle dispatching.

All related information is managed by a central database management system (DBMS) and a geographical information system (GIS) for effective data support to all associated functions. There commonly exist two categories of data that need to be treated differently. The first category of data, called static data, consists of those that are relatively stable and need not be updated frequently. Examples include road network topology, customer addresses, and fleet and driver information. The second category includes data such as vehicle location, traffic conditions, new requests and cancellation, which often change during the time of day and need to be updated on a continuous basis.

The scheduling component provides both off-line and on-line scheduling capabilities. The off-line scheduling function is used to assign the trips that are requested in advance and known before operation starts. The on-line scheduling component is essential to a computer-aided dispatch system (CAD) responsible for assigning the requests that arrive in real time and need to be serviced immediately.

The dispatcher monitors continuously any operational changes in the system such as vehicle breakdowns, service cancellations and new requests. These changes may justify modification of existing vehicle schedules such as diverting en-route an on-road vehicle to service a new request in the vicinity or re-assigning trips from one vehicle to another. Once a change is verified, the modified schedules are sent to the drivers and displayed in their in-vehicle computers or mobile data terminals (MDT).

3.3 Review of Recent Canadian R&D Activities on Intelligent DRT

Canada has played a leading role in providing software solutions for DRT. Examples include the two world renowned transit software solution providers: Trapeze Inc. of Mississauga, Ontario (www.trapezesoftware.com) and GIRO Inc. of Montreal, Quebec(www.giro.ca). Trapeze Inc. has developed a range of software solutions for the planning, scheduling and dispatching of DRT. GIRO is the developer of the scheduling software system GIRO/ACCES which has been successfully applied to the TTC's WheelTrans.

Recent development in technology is generating interest in developing new methodologies and optimization/evaluation tools that can be used to deploy Intelligent DRT. This section provides a summary of recent Canadian R&D in this area.

3.3.1 *The SimParatransit Model – University of Waterloo*

SimParatransit is a simulation model developed by a research team at the University of Waterloo specifically for the purpose of evaluating intelligent DRT systems under a variety of operating conditions, technology options and dispatching strategies. It simulates the detailed activities of individual vehicles in service, starting from accepting their assigned routes and schedules, to moving from street to street along the shortest path, to picking up or dropping off customers. The dynamic and stochastic impact of traffic congestion is explicitly simulated within the service area. SimParatransit also integrates mechanisms for simulating a variety of real-time events, including late vehicles, real-time requests, trip cancellation, and dispatcher-related events such as periodic schedule re-optimization. It provides interactive simulation (dispatching) ability under which a user can act as a dispatcher and make dispatching decisions in response to computer-generated real-time events during the course of simulation. It explicitly models automatic vehicle location and computer-aided dispatch systems (AVL/CAD) functionality by allowing a 'dispatcher' to access the coordinates of service vehicles and models CAD with a set of dynamic scheduling functions.

This SimParatransit model has been successfully applied to the evaluation of potential impacts of AVL/CAD technology on DRT performance. In this research, a large number of cases representing variations in operating environment such as service area, demand intensity and proportion of real-time demand trips were simulated for a sensitivity analysis under three operational improvements: *en-route diversion*, *dwell time reduction* and *periodic re-optimization*. The results indicate that while the effectiveness of AVL/CAD varies from case to case, on average, they can help achieve substantial improvement to paratransit performance.

3.3.2 *Development and Evaluation of Dynamic Scheduling Algorithms – University of Montreal*

Availability of advanced communication and information technologies has also generated a resurgent interest in the dynamic vehicle scheduling problems that often arise in not just DRT but also other application domains such as emergency services, courier services and trucking industry. In contrast to their static counterpart, the objective of dynamic scheduling is to revise in real time existing routes and schedules in response to changes in system conditions such as new demand, late vehicles and trip cancellations. Dynamic scheduling problems have several distinctive features: customers to be serviced are only partially known; information on the system conditions is incomplete; advance reservation customers and real-time requests need to be treated differently; service time windows may be relaxed.

A research team at the Centre for Research in Transportation (CRT) of the University of Montreal has recently investigated the problem of dynamic scheduling and various related issues within the application context of courier services. The problem was formulated mathematically and solved using a Tabu search heuristic. Simulations on the Tabu search heuristic, with and without the dynamic scheduling strategy, have demonstrated the potential savings that can be obtained through the application of the new approach. The research team also investigated several adaptive memory-based neighborhood search heuristics. Parallel implementations are also developed to increase the amount of computational work between the occurrences of new events. Their numerical results show the benefits of sophisticated procedures to optimize the planned routes in a real-time context.

A research team at the University of Waterloo has also investigated the dynamic scheduling problem. Two dynamic scheduling strategies were developed and evaluated: en-route diversion for real-time requests and periodic re-optimization of existing routes. Simulation results indicate that substantial improvements on paratransit performance can be achieved through the implementation of dynamic scheduling strategies.

3.3.3 *Planning and Scheduling of Advanced Flex-route Transit – University of Waterloo*

Flex-route transit is a hybrid of conventional fixed route transit and DRT service. It assimilates conventional transit in that its main route covers a service corridor with a set of fixed stops and schedule. Flex-route is also demand responsive as its service vehicles are allowed to deviate from the main route to provide door-to-door or checkpoint-to-checkpoint service to users who either have trip ends located out of the service coverage of the main route, or require accessible services such as paratransit. By integrating the regularity of conventional fixed schedule transit and the flexibility of demand-responsive, variable-route paratransit, flex-route transit has the potential to become a vital transit option, especially for low-density areas where demand for general public transit is too low to be efficiently serviced by conventional transit.

Research has been initiated at the University of Waterloo to investigate various issues involved in the planning and design of flex-route transit services. An analytical model has been developed for the relationship between the number of feasible deviations and various system parameters such as slack time, zone size and dwell time. The model has been evaluated by simulation for its validity in providing insights into various issues that may arise in designing a flex-route service. This research has also led to the proposal of a new Transit Cooperative Research Program (TCRP) synthesis project called "Operational Experiences with Flexible Transit Services".

3.4 R&D Needs for Intelligent DRT

Intelligent DRT systems have presented a unique opportunity for public transit agencies to improve the productivity, reliability and quality of their paratransit services. However, many issues need to be addressed before such technologically advanced systems can attain their full potential and gain broad acceptance by public transit agencies. This section summarizes future R&D needs related to intelligent DRT, including both basic and applied research.

- **Development of Dynamic Scheduling Algorithms for Intelligent DRT**
  The value of real-time information from ITS technologies can be realized only if it is used in service operations planning and scheduling. There is therefore an urgent need to develop new scheduling algorithms that can be used to adaptively adjust the existing routes and schedules in response to specific events such as vehicle breakdown, traffic incidents and congestion, trip cancellations and no shows, taking into account real-time information on vehicle location, traffic conditions and future travel demand. The research should explore the feasibility of extending several successful meta-heuristics, such as Tabu search and evolutionary computation, for dynamic scheduling.

- **Planning under Uncertainty and Real-time Information**
  DRT operations are inherently uncertain: incoming trip requests, trip cancellations and no shows, traffic congestion and incidents. While real-time information technologies have made it possible to swiftly and efficiently respond to these uncertain events, there is also

an important and challenging issue of how to plan the service (including both resource planning and service scheduling) in such a way that these uncertain events are strategically managed and their effects can thus be minimized.

- **Exploration of Distributed Computation Platform for Intelligent DRT**
  Most existing DRT operations systems are centralized with all managerial functions such as booking, scheduling and dispatching performed by dispatchers at a central office. DRT vehicles with in-vehicle computers could, however, form a parallel distributed computation platform that can perform some of these functions, such as directly taking calls from clients, scheduling using the in-vehicle computer, and directly communicating with other service vehicles for exchange of information and transferring of passengers. Further research is required to examine the vitality of this new operating concept and develop new scheduling models and algorithms.

- **Development of Data Fusion and Estimation Algorithms**
  DRT vehicles with AVL can be potentially used as massive traffic probes to provide real time data on traffic conditions and travel times. These data could be a valuable source of information for the planning, scheduling and operations of DRT as well as other transportation planning and management functions.

- **Development of Scheduling Algorithms for Integration of Fixed Route Transit and DRT**
  The operating costs of DRT could be greatly reduced if some portion of the DRT passengers' journeys can be covered by regular fixed route transit. The main challenge is however how to develop itineraries that seamlessly integrate DRT and regular transit services with effortless transfer and minimum waiting.

- **Planning and Scheduling of Advanced Flex-Route Transit**
  Flex-route, designed to combines the main operating features of regular transit and DRT, becomes increasingly popular among transit agencies because of their needs to provide service in low-demand areas and periods, its cost advantage comparing to DRT, and the availability of ITS technologies. Currently there is however no robust and efficient algorithms available for scheduling trips for this type of services.

- **Intelligent DRT: Inventory, Best Practices, and Issues**
  Intelligent DRT is not necessarily suitable or cost-effective for all communities. The applicability of ITS technologies and their potential benefits likely depend on the particular application environments. One way to identify the underlying relationships is to synthesize current practices and identify those unique features that have made some operators successful and others failed.

- **Development of an Operations Manual for Intelligent DRT**
  In order to promote and expedite the deployment of intelligent DRT, it is necessary to develop operations guidelines for implementing, managing and operating intelligent DRT.

- **Planning Tools for Intelligent DRT**
  Application of ITS technologies in DRT will have significant implications on resource requirements and system costing. It is important to have sound methodologies and tools for estimating various system performance measures (e.g. productivity, efficiency and effectiveness) as related to available resources.

- **A Review of International Programs on Intelligent DRT, Identified Benefits, and Implications of Lessons Learned for Canadian Deployment**
  To review the findings from several major international activities on intelligent DRT, and to identify the benefits and implications of lessons learned with respect to the deployment of intelligent DRT in Canada.

4. SUMMARY AND CONCLUSIONS

This discussion paper provides an overview of transit ITS in Canada and identifies research and development needs for several transit ITS areas. The paper focuses on two key areas, namely, TSP (Transit Signal Priority) and Intelligent DRT (Demand Responsive Transit), and elaborates on their R&D needs[3].

Numerous deployments of TSP systems have been made across Canada since the early nineties. For example, in Toronto alone, TSP has been implemented at 150 intersections on seven streetcar routes and at 110 intersections on several bus routes. Other Canadian cities that have deployed, or plan to deploy, TSP systems include Vancouver, Edmonton, Calgary, York Region, Peterborough, Ottawa and Quebec City. Most deployments of TSP in those cities have been of the "unconditional" type, where priority is granted to any transit vehicle once detected upstream of the intersection. The most common TSP strategies of those systems include green extension and/or red truncation, with offset transitioning implemented after the transit vehicle clears the intersection in order to recover signal coordination and to compensate the non-priority phases. Although many TSP deployments in the US, Europe and Japan are also of the "unconditional" type, there have been recent successful implementations of "conditional" TSP (e.g. 150 intersections in Portland, Oregon) and "adaptive" TSP (e.g. PTPS/UTMS21 system in 4 Japanese cities). Advancements of TSP deployments in those countries create a gap for Canada that requires serious attention and higher investments to fill.

On the research side, the paper shows that advanced research has been undertaken in Canada on various aspects of TSP. Examples include the development of advanced control algorithms (e.g. adaptive TSP) and models (e.g. prediction and performance models), the development of simulation tools for TSP evaluation (e.g. SimTransit) and the assessment of TSP systems. These research efforts are very important and vital to keep Canada on par with other countries in the area of TSP. In order to further the leading-edge TSP research already carried out and to improve the chances of deploying advanced TSP systems in Canada, a number of significant R&D needs have been identified. They fall into two categories:

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[3] Another two significant areas of transit ITS are addressed by other workgroups of the ATLANTIC project, namely transit customer information systems (Workgroup 1.1) and smart card systems (Workgroup 2.3)

- Basic research to improve the algorithms used or develop new approaches to TSP, and
- Applied research to evaluate experience to date, assess issues, and encourage further deployment

The first category includes the following topics: (1) Designing TSP-Based Operational Control Strategies, (2) Artificial Intelligence-Based TSP, (3) Implications of Signal System Design and Traffic Parameters on TSP Request Activation Strategies, (4) Integrated TSP With Traffic Adaptive Signal Control Systems, Involving Optimization-Based Priority, (5) Corridor-Based TSP, (6) Technical Options for Conditional Priority, (7) Development of Differential Priority Algorithms and Systems, and (8) Hybrid Application of Unconditional and Conditional Control for TSP.

The second category includes the following topics: (1) Development of an Analytic Framework for Selecting Corridors and Intersections for TSP Treatment, (2) TSP and Transit Scheduling: Best Practices for Maximizing the Benefits of TSP under Different Conditions, (3) TSP and Automatic Vehicle Location (AVL): Factors Affecting the Transit Agency's Technology Development Strategy, Technical and Management Implications, and Cost-Effectiveness Considerations, (4) Integrating Physical and Signal Priority Measures for Transit: Inventory, Best Practices, and Issues, (5) Traffic Controllers and TSP: Technical Requirements for Alternative TSP Strategies and Inventory of Traffic Controllers and Technical Characteristics, (6) The Role of TSP in BRT System Design, and in BRT-Specific Planning Tools, (7) Impact of Bus Operator Behavior on Transit Schedules Under TSP, (8) Review of Major European TSP-Related Demonstration Programs, Identified Benefits, and Implications of Lessons Learned for Canadian Deployment of TSP

Intelligent DRT (Demand Responsive Transit) is the second transit ITS area on which this paper focused. Paratransit agencies in Canada are increasingly turning to applications of advanced information technologies such as automatic vehicle location and computer aided dispatch systems (AVL/CAD), and digital telecommunications in order to improve the cost effectiveness of their operations. Intelligent DRT is the result of integrating these information technologies into the operations and management of DRT systems. With the ability to track vehicle locations, communicate with drivers and clients, and access traffic information on a continuous basis, intelligent DRT systems are expected to operate at a significantly improved level of productivity, reliability and quality of service.

Canada is a world leader in Intelligent DRT software, providing two world-renowned system providers, namely Trapeze Inc. of Mississauga, Ontario and GIRO Inc. of Montreal, Quebec. Both provide software solutions for planning, scheduling and dispatching of DRT operations. Also, advanced research has been undertaken including the development of dynamic scheduling algorithms and models, the development of simulation tools for the evaluation of intelligent DRT (SimParatransit) and the planning/scheduling of advanced flex-route transit.

In order to maintain Canada's leading position in this ITS area, ten R&D needs have been identified. These include: (1) Development of Dynamic Scheduling Algorithms for Intelligent DRT, (2) Planning under Uncertainty and Real-time Information, (3) Exploration of Distributed Computation Platform for Intelligent DRT, (4) Development of Data Fusion and Estimation

Algorithms, (5) Development of Scheduling Algorithms for Integration of Fixed Route Transit and DRT, (6) Planning and Scheduling of Advanced Flex-route Transit, (7) Intelligent DRT: Inventory, Best Practices, and Issues, (8) Development of Operations Manual for Intelligent DRT, (9) Planning Tools for Intelligent DRT, and (10) A Review of International Programs on Intelligent DRT, Identified Benefits, and Implications of Lessons Learned for Canadian Deployment.

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