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

Work Group 1.3

Urban Public Transit ITS Research and Development

DISCUSSION PAPER - DRAFT

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URBAN TRANSIT INTELLIGENT TRANSPORTATION SYSTEMS (ITS) RESEARCH AND DEVELOMENT (R&D) IN CANADA

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

1.1 Overview of Canadian Transit ITS

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) Needs 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 Johns, 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, 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 Priroity 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.

1.2 Canadian Transit ITS R&D Needs

As a result of this initial exploration, the following Transit ITS R&D needs have been identified as areas of significant interest to the Canadian transit ITS community.

Transit ITS 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:

1.2.1 Transit ITS 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 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. 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. Nigel Wilson of MIT and his students have conducted some research 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 PDAs, 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 farebox 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.

1.2.2. 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.

1.2.3. 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 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.

1.4 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 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 Needs 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. As a result, this topic has been chosen for more in-depth discussion in the following section.

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. 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 method for selectively detecting transit vehicles and communicating this 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 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 adhere 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 two types:

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

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 to meet variable control objectives, including minimization of vehicle delays or maximization of person throughput in the street network. 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 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.

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

Some advanced TSP strategies 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 is developed, with illustrative numerical examples provided.

2.3 <u>Overview of the Canadian State of the Practice</u>

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 19 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%, and auto delay decreased marginally. 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 and Developments

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

- Isolated deployments of intersection control activated by approaching buses typicsally 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 Rapid Bus system, a Bus Rapid Transit (BRT) system that involves the deployment of Transit ITS components in the form of real-time customer information system and TSP.

In addition, it should be noted that there are discussions underway in the U.S. to develop a **NTCIP Signal Control Priority Standard** 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

3. TSP R&D NEEDS

Through the consultations carried out with Canadian experts and discussion held during workshops held 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.

3.1 <u>Basic Research To Improve The Algorithms Used Or Develop New Approaches To TSP</u>

- **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: Application for Bus Arrival Predictions, Dwell Time Predictions, and Effective Conditional TSP**
  To explore the potential use and effectiveness of applying Artificial Intelligence techniques to various aspects of TSP (e.g. bus arrival predictions, dwell time prediction, cost-effective conditional priority, etc.)

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

- **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 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.

3.2 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.

4. SUMMARY AND CONCLUSIONS

TSP is an area of growing interest in the Canadian transit industry. However, there are significant R&D Needs. These fall into two categories:

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

Both areas will require attention to maximize the potential benefits from this cost-effective Transit ITS tool.

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