RISK ANALYSIS OF INTELLIGENT TRANSPORTATION SYSTEMS IN PUBLIC TRANSIT

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Abstract
Improvements to public transit in terms of user service and cost-efficiency can be achieved through careful planning and application of intelligent transportation systems. Since public funds are used as investments in these systems and the results cannot be predicted with certainty, it is prudent to subject such investments to risk analysis. This paper reports a methodology for the risk analysis of investments in intelligent transportation system (ITS) applications to public transit. The role of advanced technology in shaping systems at the strategic, tactical and operational levels is acknowledged. Public transit system improvement requirements are outlined and the role of advanced technology in supporting such improvements is described. Mainstreaming of ITS in public transit is covered and selected applications are described. A Monte Carlo Simulation Model application is illustrated for assessing risk in ITS investments. Finally, conclusions are presented on ITS in public transit and the need for risk analysis of ITS investments is highlighted.

Keywords: Intelligent transportation systems; Public transit; Risk analysis; Investment; Monte Carlo simulation model
Topic Area: B2 Telecommunication and Advanced Information Systems

1. Introduction
Public transit is gaining much importance due to public policy emphasis on sustainable urban transportation (Dockendore et. al. 2000). Also, it is a goal of transportation planners to integrate public transit in the overall urban transportation network. Careful planning and applications of advanced technology can yield improvements to public transit in terms of user service and cost-efficiency (FTA, 1998,2000; TRB 1997; Weiland et al., 2000).

Planning and decision-making for public transit improvements are carried out at three stages (Khan, Rathwell, 1999). These are strategic, tactical and operational stages. Figure 1 shows the strategic level. Strategies cover transit service corridors, service concepts, infrastructure, workforce, and equipment. The tactical level is presented in Figure 2. At the tactical level, routes and schedules are established, workforce and equipment assignments are undertaken and traffic is assigned to infrastructure. The operational level is presented in Figure 3. Examples of operational level tasks include detailed assignments within a day, passenger counts, vehicle control, fleet management, fare collection, traveller (public) information, and maintenance schedules.

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Strategic Level Activities (Examples)
. Corridor & service concepts
. Infrastructure
. Workforce
. Equipment

Role of Advanced Technology

Strategic level activities assisted or made possible by ITS & related information technologies

Figure 1: Strategic Level

Tactical Level Activities (Examples)
. Routes & schedules
. Assignments of equipment
. Assignment of traffic to infrastructure

Role of Advanced Technology

Tactical level activities assisted or made possible by ITS and related information technologies

Figure 2: Tactical Level

Operational Level Activities (Examples)
. Detailed assignments within a day
. Passenger loads
. Vehicle control
. Public information
. Maintenance schedule

Role of Advanced Technology

Operational level activities assisted or made possible by ITS and related information technologies

Figure 3: Operational Level

There is a role for advanced technology in shaping options at all levels of planning and decision-making (Figures 1 to 3). The knowledge of potential applications of intelligent transportation systems and related information technologies enables the planning of smart services, intelligent infrastructure, and automation of tasks in a cost-effective manner. Details on the role of advanced technologies are presented in following sections of the paper.

2. Role of advanced technology

For the study of system requirements and the role of advanced technologies to improve public transportation, it is useful to briefly characterize these systems and define their operational requirements. The classification used is as follows: rapid transit (rail or bus), partially or fully shared right-of-way transit, demand responsive systems, future smart transit concepts, and paratransit services. Table 1 provides a definition of transit types and key features.

Table 1: Public Transit Systems

Public Transit Type	Key Features
Rapid transit (rail or bus)	Dedicated access controlled facilities (tracks/transitway), control system, stations, information displays
Partially or fully shared right-of-way (bus, street car)	Exclusive lanes/tracks or mixed operations, signal preemption, stops, information displays
Demand responsive	Non-fixed route service is requested by user and provided by the transit operator.
Smart transit (concept)	It is a demand responsive service but with a difference. The location of each vehicle and availability of space must be tracked on a real-time basis and communications have to be maintained with the dispatcher. In response to a call for service, the dispatcher can contact the vehicle operator in the vicinity to provide the service. If a vehicle/seat is not available at that moment, the next available vehicle is directed to the traveller.
Paratransit for physically challenged.	Dedicated non-fixed route service provided in response to requests from users.

The rail and bus rapid transit systems have dedicated access controlled facilities, including stations for loading/unloading operations. The movement of vehicles is controlled and monitored. Fleet management system is implemented and user information systems are available.

Bus and street car can operate in partially or fully shared right of way. In a number of cities, bus transit is provided with exclusive lanes, but frequently buses operate in mixed traffic. Street cars are normally given an exclusive right of way and other traffic is not permitted in their path. There are also mixed traffic cases for street cars. Bus and street car stops are well marked and sometimes shelters are provided. Information system displays such as routing information are provided. The buses/street cars are controlled by traffic signals and priority could be given to these vehicles.

Demand responsive bus service is available in some cities on non-fixed route basis. For the use of this service, the traveller has to plan trips a day or so in advance and make reservations for pick-up and delivery at specified locations.

Smart transit system is at the concept stage. In effect, it is a demand responsive service but its operations have to be assisted by advanced technology. The vehicles are equipped with real-time vehicle locator, vehicle occupancy tracker, and communication devices such as a CB radio or a cellular phone. In response to a call for service, the dispatcher can direct the operator of the vehicle close to the pick up point to provide the service. If a vehicle/seat is not available at that moment, the dispatcher can direct the next available vehicle to the traveller (Salon et al., 2000).

For the above noted services, fares are collected in a variety of ways. Passengers can use transit passes, pre-purchased tickets or pay cash for service.

Paratransit for physically challenged persons is a dedicated non-fixed route service provided in response to requests made in advance.

Public transit systems have very demanding mandates. In addition to serving their mission as a public service, these have to be cost-efficient and compete with private automobile in terms of service quality (Table 2).

Table 2: Potential Improvements

Improvement Requirements
• Enhance public transit ridership and revenue.
• Improve the operating efficiency of the system – by reducing costs and enhancing productivity.
• Improve the overall reliability of service; enhance on-time arrival performance at the stop/station or pick-up location for demand responsive transit service.
• Enhance the safety and security on-board and in public areas such as stops, stations, park-and-ride lots.
• Enhance user/public information and improve the visibility of public transportation in the community.
• Improve intermodal and multimodal information availability.
• Enhance customer convenience.
• Improve security of transit revenue.
• Reduce fare collection and processing cost.
• Design and implement flexible fare structures.
• Reduce cost of transit vehicle maintenance and repairs.

There is pressure to enhance ridership and revenue, reduce costs and enhance productivity. There is a need to improve service reliability in overall terms, on time arrival and availability of space on-board. Ways have to be found to overcome the effect of congestion in mixed traffic operations. Traffic safety and security has to be enhanced on-board and in public areas such as stops, stations, and park-and-ride lots.

Studies have shown the need to improve user/public information, including intermodal and multimodal information availability. Most cities lack real-time dynamic transit user information systems. The visibility of public transportation in the community needs to be improved trough user and public information.

There is a need to enhance customer convenience in terms of access to services and there is a lack of flexible on-demand cost-effective service. Studies have identified deficiencies in marketing in terms of lack of flexible fare system (e.g., distance-based fares). Also, security of revenue is an issue. There is a need to reduce the cost of transit maintenance and repairs as well.

3. ITS in public transit

The ITS and related information technology solutions can address public transit deficiencies identified earlier. Table 3 presents these in summary form.

3.1 Fleet management systems and closely related technologies

The fleet management systems cover a broad range of ITS and closely related information system technologies that are designed to enhance the planning and scheduling of transit services as well as the operations of transit vehicle fleets. The benefits of these systems are (1) increased transit safety and security, (2) improved operating efficiency, (3) improved transit service and schedule adherence, and (4) improved transit information (FTA 2000).

A number of technologies contribute to these multi-faceted activities. These include vehicle location and control, fleet-based communications, automatic passenger counting devices and transit management systems. Automatic vehicle location systems are designed to track the transit vehicle’s real time schedule adherence and to update the transit system’s schedules in real-time. Vehicle position can be determined by using a variety of approaches. For example, an on-board position finder linked with GPS can be used. A vehicle’s position may be determined directly by the communications infrastructure. A two-way wireless communication link with the transit management and control centre can also be used to relay vehicle’s position and control instructions. In the case of fixed route transit service, beacons along the route can be used to determine vehicle position and facilitate communications with each vehicle at fixed intervals. The management and control system processes the information, updates schedules and transmits the real-time schedule information to other parts of the public transit agency.

Smart infrastructure systems can be installed for giving transit vehicles priority over private vehicles, exempting transit vehicles from tolls within area-wide electronic road pricing or on toll roads, automatically tracking vehicles, and supporting better management of traffic flow.

3.2 Fixed route systems

The fixed route transit operation systems can handle scheduling tasks, through computer-aided dispatch in real time provided that these are linked with vehicle monitoring and location system. Automatic driver assignment and monitoring can be performed and vehicle routing and scheduling can be carried out. Sophisticated software is also available for service planning and operations. Through communications links with other modal and intermodal information centers, integrated dynamic schedules can be provided to travellers.

Table 3: ITS Applications

Requirements	ITS Applications
Fleet management, vehicle Monitoring, control, Communications.	• Fleet management systems • Vehicle monitoring and location • Fleet-based communications • Automatic passenger counting • Vehicle control technologies • Transit management system
Transit fixed route operations (rapid transit and shared right of way): operational software, computer aided dispatch, automatic driver assignment and monitoring, vehicle routing and scheduling for fixed route services.	• System for transit scheduling • Computer-aided dispatch (can be real time if linked with vehicle monitoring & location system, transit operational software, and computer aided dispatch). • Service planning Operations
Demand responsive transit operations.	• System for automatic driver assignment and monitoring, for vehicle routing, and scheduling for demand responsive service.
Para transit	• Real time vehicle locator, communication system
Smart transit service	• Real time vehicle locator, occupancy tracker, computer-aided dispatch, vehicle routing software, communication system.
Traveller information: transit stop annunciators, imminent arrival signs, real-time transit schedule display, custom transit trip itineraries and other tailored transit information services.	• Transit traveller information systems (pre-trip and real-time information): - In-vehicle annunciations & displays - Transit stops, terminal or wayside based information systems - Telephone information systems - Information via cable TV, interactive TV and internet - Communication links with traveller information systems of other modes and intermodal systems
Transit passenger and fare management: management of passenger loading and fare payments – to make fare payment more convenient for users and fare collection more efficient and more flexible for transit providers.	• Fare media (magnetic strips, smart cards) and associated fare collection and processing systems.
Transit safety and security	• On board security system for surveillance and to warn of potentially hazardous situations; security systems for public areas (e.g. stops, park and ride lots, stations); communication link to transit management centre; communication link with Emergency Management System; Communication link with incident management centre.
Transit maintenance	• Automatic maintenance scheduling and monitoring: - on-board condition sensors for monitoring critical system status and to transmit critical status information to the transit management centre. - Systems for processing data and scheduling of maintenance activities.

3.3 Demand responsive & smart transit systems

The demand responsive transit operation system can perform automatic driver assignment, monitoring, vehicle routing and scheduling. The automatic vehicle location and control (AVL&C) database is used to monitor current status of vehicles and fleet resources can be allocated to serve incoming requests.

The smart transit version of the demand responsive system can be designed to include a real-time vehicle locator, computer-aided dispatch, vehicle routing software, and communications systems. Availability of real-time traffic information can be taken into account in vehicle routing and for estimating arrival times at pick-up and delivery sites.

3.4 Paratransit service systems

Specialized transit services for the physically challenged can be assisted by the real time vehicle locator and communications systems.

3.5 Transit traveller information systems

Systems can be designed to provide pre-trip and real-time information. These systems can consist of in-vehicle annunicators and displays, transit stops, terminal or wayside-based information systems, telephone information systems, information via cable TV, interactive TV and the internet, and communication links with traveller information systems of other modes and intermodal systems for exchange of information. Dynamic transit vehicle arrival information (provided on board, at bus station/stop, at home or office) can be implemented. Wireless (e.g. cellular phone) and internet technologies can be used for giving individuals seamless information anywhere on transit schedule/vehicle arrival and other items. Technologies are available for providing system integration information.

3.6 Transit fare and revenue management

At present, many transit agencies are keen on finding ways to improve their fare collection and revenue processing. Advantages include elimination of cash and token handling so as to improve security of transit fares, reduce processing cost, introduce more flexible fares, etc.

ITS technologies can be used to manage fare payments on-board vehicles and off-vehicles. Fare media (i.e., magnetic strips, smart cards and associated fare collection and processing systems) can be deployed. These systems use readers located either in the infrastructure or on-board the transit vehicle to allow fare payment. The associated fare processing systems can be developed as well. These systems can be linked with passenger counters that rely on sensors mounted on the vehicle to permit the driver, and transit management & control centre to determine vehicle loads. These technologies can make fare payment more convenient for transit users and fare collection more efficient and flexible (e.g., distance-based fare payment systems) for transit agencies.

3.7 Transit safety & security

Systems can be placed on-board for surveillance from a security point of view. These can warn of potentially hazardous situations. Likewise, security systems for public areas (e.g., stops, stations, and park-and-ride lots) can be designed and installed. Communication links can be provided to transit management and control centre. These can also be linked with specialized emergency management and incident management systems (if other than the centralized transit management and control centre).

3.8 Transit maintenance systems

The ITS and related technologies can be used for automatic maintenance scheduling and monitoring tasks. On-board engine condition sensors can be used to monitor critical system status and to transmit this information to the transit management and control centre. At this centre, data can be processed and maintenance activities can be scheduled.

4. Selected ITS applications

Public transit agencies in most industrially advanced countries appear to be very eager on reaping the benefits of ITS applications. A priori, there is no reason why public transit agencies of any country cannot fully capture the benefits that ITS and related information technologies could provide. In Canada, some progress has already been made in integrating advanced technology in all facets of providing transit service. The next step is to investigate the benefits and costs of new applications, with special attention to the treatment of risk. The methodology illustrated in the next section of the paper can be used for this purpose.

Table 4 presents selected areas for action by the Canadian public transit agencies in terms of applications of ITS. Potential benefits of these applications are also enumerated in qualitative terms.

Table 4: Selected ITS Applications and Their Benefits

ITS Applications	Benefits
• Integration of vehicle monitoring and location system with transit operational software, computer-aided dispatching, ridership tracking, vehicle scheduling, and real-time user information systems.	• Improved operating efficiency, enhanced user information, improvement of ridership, revenue gains.
• Advanced traveller information systems, including the provision of real-time information and the use of internet for information dissemination.	• Improved customer convenience, increased ridership and revenue, improved service and visibility within the community.
• Electronic fare payment systems	• Improved customer convenience, enhanced security of transit revenues, reduced fare collection and processing costs, flexible fare structures.
• Smart transit system	• Improved customer convenience, expanded base of transit revenue.

Integration of vehicle monitoring and location system with transit operational software, computer-aided dispatching, ridership tracking, vehicle scheduling, and real-time user information systems is another area of action for transit agencies.

It is known that computer-communication systems are already widely used to manage inventory and for various other aspects of bus operation and maintenance, such as driver scheduling, vehicle location, and dispatching. However, the full potential of AVL& C and other systems for customer service, ridership tracking, and vehicle scheduling are not fully exploited by most members of the transit industry.

The public transit traveller information systems require attention. Advanced traveller information systems can be developed that can provide real-time information about vehicle arrival time and system status. Also, the internet technology can be used for information dissemination through mobile and fixed units. In a number of countries in Europe, users can obtain transit information via internet accessed by their cellular telephones.

The electronic fare payment system is receiving attention in many countries in the context of ITS programs. The City of Gatineau in Canada has recently implemented ‘smart card’ fare payment system in a limited scale. Given its potential benefits, this area is worthy of attention.

There is also the need to carry out research and demonstration studies on smart transit. For low density suburban areas, smart transit can be an alternative to conventional transit as well as to single-occupant automobile travel. The enabling technology of real-time vehicle locator, occupancy tracker, and the increasing availability of the up-to-the-minute service and traffic information are the ingredients for the provision of smart transit service.

5. Risk analysis

The result of an investment decision is almost always affected by uncontrollable influences. Simplifying assumptions are commonly made that the analyst can predict cash flow with certainty. However, for situations where it is prudent to study risk, simulations can be carried out so as to produce results for informed decision-making.

An example of the economic feasibility of ITS and related information technologies is provided in the form of an investment in a fleet management system. The methodology is based on analysis of benefits and cost. Following a deterministic analysis, the Monte Carlo Simulation Model is used for the treatment of risk (Riggs et al., 1997).

To illustrate the process, let us assume that an AVL&C technology based on Global Positioning System (GPS) type is under consideration by a bus transit organization. The current riders amount to 4.603 million per year. A 10 year horizon is to be used for feasibility analysis. The ridership is estimated to grow at 1.5% per year. For the 10 year period, a total of 50 million trips will benefit from this installation. The average ridership per year amounts to 5 million/year.

It is intended to carryout the feasibility analysis in constant dollars. The initial cost is estimated to be $5 million. The operating and maintenance costs are estimated to be $50,000/year or $0.01/trip. The benefits of this AVL&C system occur in the form of savings in transit fleet operations. These are based on a one-time reduction in fleet operating costs, following deployment of the AVL&C system, and the annual recurring savings in fleet operating costs as a result of the assumed fleet efficiency savings. There are also benefits enjoyed by travellers through the availability of real time schedules. The benefits are estimated to be $750,000/year. On a per trip basis, benefits amount to $750,000 per year for 5 million trips or $0.15/trip. Salvage value is estimated to be $250,000.

Using 6% (real) interest/discount rate for a 10 year period, the following results are obtained from a deterministic analysis:

Net Present Worth (NPW) = $291,660
Equivalent Annual Worth (EAW) = $39,627
IRR = 7.2%

Changing the interest rate to 7% (real) produces the following results.

Net Present Worth (NPW) = $43,595
Equivalent Annual Worth (EAW) = $6,207
IRR = 7.2%

According to these results, the project is feasible. However, these results do not reflect the stochastic aspect of various cash flow items.

In order to account for risk, the Monte Carlo Simulation Model was used. In this technique, random numbers are generated to select events from a probability distribution of occurrences (Riggs et al., 1997). The salient features of the Monte Carlo Simulation Model are noted below.

- It is used to systematically address risk/uncertainties involved in input data and output results.
- Input variables are described by using probability distributions.
  - Inputs: Initial cost, trips served/year, operating and maintenance cost/trip, benefits/trip, salvage value at the end of the analysis period.
  - Probability distributions: Normal distribution, standard deviation set at 5% of the mean value of the input.
- Samples are randomly drawn from input distributions to calculate results. Numerous samples are drawn to form a distribution of results.
- Results: Expected Net Present Worth, Standard Deviation, P(NPW<0)

All inputs to the analysis, except interest rate and number of years of the analysis period, are treated as probabilistic. A normal probability distribution is used with a standard deviation of 5% of mean value of each input. For 6%(real) interest/discount rate, the following results are obtained after 100 simulations:

NPW mean value = $246,119
Standard deviation = $381,273
P(NPW<0) = 0.26

These results obtained from the use of Monte Carlo simulation technique and 6% (real) interest/discount rate suggest a feasible investment and the probability of a negative NPW is low.

Next, the use of 7%(real) interest/discount rate produced the following results.

NPW mean value = $21, 501
Standard deviation = $353,426
P(NPW<0) = 0.48

Although these outputs still indicate a positive net present worth, as compared to the expected value of the NPW, the standard deviation is high and the probability of a negative NPW is also rather high at 0.48. These results imply that caution should be exercised and better estimates of inputs should be sought.

A comparison of the investment analyses is presented in Table 5 for the purpose of illustrating the differences between deterministic and probabilistic analysis. The results of deterministic analysis convey a false sense of certainty. On the other hand, the probabilistic analysis produces a realistic picture in terms of chance of loss.

6. Conclusions

Public transit planning, operation, maintenance and management can be enhanced through the applications of intelligent transportation systems and related information technology. All types of public transit systems and services can benefit from the use of advanced technology. In this paper, linkages between improvements required in public transit operations and the capabilities of intelligent transportation systems to meet these challenges (requirements) were identified.

Table 5: Comparison of Deterministic and Probabilistic Analyses

Method	Interest/discount rate	NPW	St. deviation	P(NPW<0)
Deterministic	6%(real)	$291,660	0	0
	7%(real)	43,594	0	0
Probabilistic	6%(real)	246,119	$381,273	0.26
	7%(real)	21,501	353,426	0.48

Transit systems can fully capture the benefits that ITS and related information technologies can provide. There are no inherent hurdles to the adoption of these innovations. Available information suggests that ITS applications in public transit are cost-effective and their benefits exceed costs (FTA, 2000).

For example, while computer-communication systems are widely used to manage inventory and for various other aspects of bus operation and maintenance, such as driver scheduling, vehicle location, and dispatching, there is no reason that the full potential of automatic vehicle location and control systems for customer service (e.g., dynamic traveller information systems), ridership tracking, and vehicle scheduling is not fully exploited by most of the transit industry. Likewise, the capabilities of electronic communication, such as those provided by the Internet, can be used by the transit industry. Suggestions made are guided by the objectives of enhancing service efficiency and cost-effectiveness.

In economic feasibility studies, it is recommended that risk analysis should be made a part of the investigation. As illustrated in previous section, the Monte Carlo Simulation Model is an appropriate technique for this purpose.

Acknowledgments
This paper is based on research sponsored by the Natural Sciences and Engineering Research Council of Canada (NSERC). The opinions are those of the authors. A preliminary version of this paper was read at the Canadian Institute of Transportation Engineers 2001 Conference held in Calgary, Alberta.

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