FINAL REPORT

A National Agenda for Technological Research and Development in Road and Intermodal Transportation

Transportation Association of Canada
Association des transports du Canada

September 1999

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September 1999

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Executive Summary

This report documents the conclusions of the TAC initiative to develop a National Agenda for Road and Intermodal Transportation in Canada. The agenda identifies trends, opportunities and needs, as well as specific high priority R&D projects, relevant for advancing Canadian highway transportation. The focus of the Agenda is on identifying R&D opportunities to optimize the management of the road system and intermodal transportation, and minimize the cost of road transport while maintaining or improving safety. The Agenda can be also used to identify opportunities for collaboration between research agencies on common issues and problems, and to reduce duplication of effort between agencies.

The Agenda was developed by a team of ten highway technology experts through a widely-based consultative process. Input for the agenda was systematically solicited from provincial, territorial, municipal, academic, and industry representatives. The consultative process was achieved through direct contacts by the project team members, a questionnaire presented to over 40 Canadian highway transportation professionals, and an Open Forum held during the 1999 TAC meeting in Toronto.

The results are presented in the following nine technology sections addressing all key areas of road and intermodal transportation.

- Strategic issues
- Asset Management
- Vehicle technology and environment
- Transportation of goods
- Pavement technology
- Structures
- Safety and human factors
- Traffic management and ITS
- Winter maintenance operations

Information presented for the nine technology sections is systematically organized and identifies technology-specific trends, opportunities and needs, as well as over 50 specific R&D projects recommended for implementation. The recommended R&D projects are described in terms of proposed solution, expected benefits, partnership opportunities, and resources required.

The availability of the agenda is only the first step in advancing, invigorating and co-ordinating R&D activities. We also need an action plan to implement the agenda and we need to keep in mind that the proposed agenda needs to be periodically reviewed.

ACKNOWLEDGEMENTS

This National Agenda for technological research and development in road and intermodal transportation was made possible with funding provided by the Research and Development Council of the Transportation Association of Canada.

The report was developed under the guidance of a project steering committee of volunteer members. TAC and the authors of this document would like to express their appreciation and gratitude to the committee members for their time and effort throughout the project.

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Table of Contents

Foreword

Study Origins and Objectives

The mission of the Transportation Association of Canada (TAC) is to promote the provision of safe, efficient, effective, and environmentally sustainable transportation services in support of Canada's economic and social goals. In fulfilling its mission, TAC strives to influence the resolution of transportation issues through technological and policy research, consensus building, standards development, and program review.

In 1994, TAC stated that "the cost effective use of new technology plays a fundamental role in stimulating progress within all modes, and is a source of competitive advantage. A continuing commitment to research and development (R&D) and technological innovation ensures that Canada sustains a competitive international position from the use of new technology for its infrastructure, equipment, operations, and management in domestic and export markets [1]."

To support this perspective on the importance of R&D, TAC, through its Research and Development Council, commissioned, in 1994, the study necessary to produce an overview report on Canadian transportation research in all transportation modes, and a comprehensive research agenda for the highway mode. The two documents were made available to the Canadian transportation community to provide guidance and focus to Canadian research. The intent, at that time, was to encourage and enhance R&D programs, which address unique Canadian problems, and to encourage R&D spending in joint ventures which leverage each partner's investments.

The 1994 National Research Agenda was intended to have a "shelf-life" of four years, and to be updated at the end of that period. Consequently, the Research and Development Council commissioned the present $35,000 study with the focus on highways and intermodal transportation. Again, the intent has been, as it was in 1994, to help focus the efforts of the Canadian transportation research community, and to encourage research activity that will yield the maximum benefit.

The principal objective of the study was to identify and prioritize road and intermodal transportation issues, opportunities, problems, and needs in Canada over a four year planning horizon.

This report is intended to meet the needs of different users. For managers and decision-makers who may not be familiar with specific technological issues, the report provides background information, particularly for specialized technology areas such Intelligent Transportation Systems (ITS) and vehicle technology. For researchers who are searching for research ideas, it provides specific recommendations for high-priority R&D projects.

Study Organization and Authorship

In order to develop specific and credible R&D agenda, it was necessary to assemble a project team whose members are nationally recognized experts and who have the expertise to propose and prioritize specific R&D projects. It was also necessary to ensure that the project team members as a whole encompass all major highway technology areas.   These requirements led to the creation of nine technology clusters organized using the following principles.

i) The clusters were organized to address specific technologies rather than specific concerns. For example, environmental concerns have been be addressed by all clusters in the context of the clusters' technologies.
ii) The clusters were centered on the technologies with particular relevance to Canada. For example, Cluster I, Winter Maintenance Operations, captures the unique Canadian combination of high traffic volumes, large snowfalls, and Canadian leadership in privatizing winter highway operations.
iii) The clusters must provide coverage of the entire highway technology area.

Each cluster was headed by a team member who is also a co-author of this report. The list team members and their affiliation, together with the name of technology clusters, is given below. The overall project management was provided by Dr. Jerry Hajek, Researched Response Inc.

	Technology Cluster	**Cluster Leader and Affiliation**
A	Strategic Issues	**Norm Mealing, B.A., CPAD** Mealing Consulting Services
B	Asset Management	**Jerry Hajek, Ph.D., P.Eng.** Research Response Inc.
C	Vehicle Technology and the Environment	**Ovi Colavincenzo, M.A.Sc., P.Eng**. Colavincenzo Consulting
D	Transportation of Goods (includes inter-modal issues, containerisation, & vehicle weights and dimensions)	**John Billing, B.A., M.A.**
E	Pavement technology	**Guy Dore, ing., Ph.D.** Universite Laval
F	Structures	**Paul Carter, B.Sc., P.Eng.** Reid Crowther and Partners, Ltd.
G	Safety and Human Factors, and Geometric Design	**Alison Smiley, B.Sc., M.A.Sc., Ph.D.** Human Factors North
H	Traffic Management and ITS	**Milt Harmelink, B.Sc., M.Sc.** M.D. Harmelink and Associates
I	Winter Maintenance Operations	**George Comfort, M.A.Sc., P.Eng.** Fleet Technology Ltd.

The Agenda was developed through a widely-based consultative process. Input for the agenda was systematically solicited by the following means:
i) Direct contact between the team members and over a hundred provincial, territorial, municipal, academic, and industry representatives.
ii) By a questionnaire, presented to over 40 Canadian highway transportation professionals including leading members of TAC Councils, and Committees.

iii) Organizing an Open Forum staged during the 1999 TAC meeting in Toronto. The forum was attended by about 45 people.

Report Organization

The report is divided into nine chapters. The Chapter A outlines strategic issues and factors shaping transportation R&D in Canada and its current state, the methodology used to prioritize R&D activities, and several strategic research projects. The remaining Chapters (Chapters B to I) identify trends opportunities and needs, as well as specific R&D projects, in eight specific highway and intermodal transportation areas: Asset management, vehicle technology, transportation of goods, pavement technology, structures, safety and human factors, traffic management and ITS, and winter maintenance operations.

Concluding Remarks

The availability of the R&D agenda is only the first step in advancing, invigorating and co-ordinating R&D activities. We hope that with this agenda, Canadian transportation professional can build on the past successes and advance confidently into the next century. We also need an action plan to implement the agenda and we need to keep in mind that the proposed agenda needs to be periodically reviewed and refined.

A/ STRATEGIC ISSUES

Cluster Leader

Norman E. Mealing, B.A., CPAD
Mealing Consulting

1. The Strategic Context

The initiation of this study is very important and timely. Canadian governments at all levels are restructuring and redefining their relationships, and are seeking new transportation service delivery approaches which involve private industry, contain costs, and improve efficiencies. In this period of flux, it is important to have a clearly defined and credible national R&D agenda, continue with R&D efforts, and to maximize R&D payoffs.

The 1994 National Agenda for Technological Research and Development in Canada [1,2] outlined the "mega-trends" shaping transportation in Canada at that time. Factors identified as influencing transportation were the globalization of the economy, the urbanization and the aging of society, fiscal and monetary pressures on government, environmental sustainability, technological advances, and institutional reform and restructuring.

In setting the strategic context for the 1999 version of the National Agenda, it is affirmed that the factors identified in 1994 remain, and are, if anything, more severe. The globalization of the Canadian economy continues, we continue to elect living in urban settings, our society continues to grow older, concern for the environment has increased, partly due to our international commitments, and the restructuring of our institutions, especially in terms of responsibility and accountability, has accelerated. In addition, the fiscal and monetary pressures, felt by government at all levels, continue to shape and influence all policy deliberations.

It can be argued that governments are fully aware of these economic, social, environmental, and technological factors, and that these factors have been fully integrated into the policy development and program planning processes of government. It can also be argued that government focus on fiscally responsible management, the judicious allocation of resources, and the restructuring of our institutions remain the most dominant influences on government policy making. Therefore, in setting the strategic context for the National Research Agenda, it is necessary to examine how these influences have shaped the country's transportation priorities.

1.1 Transportation Priorities

In developing a strategic context for the National Research Agenda, the nation's transportation priorities were identified through six main sources of information.

i) We reviewed the Business Plans of most of Canada's provincial transportation authorities.
ii) We examined the Strategic Plan for Intergovernmental Cooperation prepared for the Council of Deputy Ministers of Transportation and Highway Safety by the TAC Policy and Planning Support Committee [3], and the Initial Five-Year Plan for Increased Cooperation in the Field of North American Transportation Technologies [4].
iii) We sought input from the members of TAC Councils and Committees through a survey questionnaire circulated by the project team.
iv) We directly contacted a number of provincial and territorial transportation officials, and the representatives of other stakeholders.
v) We held an Open Forum on the National Research Agenda in April 1999 under the auspices of the 1999 TAC spring meeting.

vi) We reviewed R&D agendas prepared by other organizations such as OECD [5] and TRB [6].

In the following, the transportation priorities obtained by harnessing the above sources of information have been summarized from the perspective of

- Core businesses of transportation authorities,
- Strategic Plan For Intergovernmental Cooperation, and
- Input from provincial officials, and other stakeholders.

1.1.1 Core Businesses of Transportation Authorities

Almost uniformly, provincial highway agencies identify as their mandate contributing to social and economic growth. The role they play in achieving their mandate is changing, however, with a shift in emphasis from providing services to ensuring the provision of services. Their priority is on planning, developing, preserving, enhancing, and managing a transportation system which is safe, efficient, effective, affordable, reliable, integrated, sustainable, accessible, and of high quality.

Provincial highway agencies have developed a focus for their activities which they refer to as the Core Businesses. For the majority of provincial highway agencies, the Core Businesses are as follows:

a) Highway infrastructure; roads and bridges

The objective is to provide, and sustain, the highway system through design, construction, rehabilitation, and maintenance. The evolution from delivering to managing has led to a greater concern with quality and performance, and a priority on guidelines and standards for design, construction, maintenance, and traffic management and control.

b) Highway management and planning, including systems to enable investment decisions

There is a need for the development, implementation, and/or improvement of systems, which facilitate sound infrastructure investment decisions. Priority areas include management systems for highway infrastructure assets, winter maintenance, cost/benefit analysis, performance measures, and quality control and assurance. Highway infrastructure planning is focused on public-private sector partnerships, cost recovery, and commercial development opportunities.

c) Safety, from both the user and the infrastructure perspective

There is a need to develop and set safety standards and performance measures for highway infrastructure, and to improve data collection and analysis relating to accidents. The objective is to reduce accidents and fatalities through such initiatives as improved signage, better maintenance, and improved designs.

Transportation policy

The emphasis is on multi-modal policy development, and intergovernmental relations. With a focus on economic policy, the needs include better integration of all modes for both freight and passenger transportation, better data on freight and passenger traffic patterns, and cooperation between all levels of government. There is also a reference to the need to cooperate with municipalities as they assume more responsibility for transportation infrastructure and services. The potential of providing technical assistance to municipal authorities is also put forward.

e) Information and technology

Provincial transportation authorities have articulated a strategic interest in information and technology as it relates to transportation. Within the context of both R&D and technology transfer, the emphasis is on cooperative programs in R&D with the research aimed at improving the performance of highway infrastructure and safety. A major area of interest is maximizing the utilization of Intelligent Transportation Systems (ITS) to improve traffic flows, maximize capacity, and facilitate goods movement.

a) Environmental sustainability

All jurisdictions identified the environment as the area of high priority. Specific needs included the development of strategies to minimize the impact of transportation on the environment, specifically in terms of air pollution and greenhouse gas emissions. Also of interest was the need to develop better standards to deal with the impact of highway construction and maintenance, particularly in terms of roadside vegetation, storm water management, and winter snow and ice control.

1.1.2 Strategic Plan for Intergovernmental Cooperation

In 1998, the Policy and Planning Support Committee presented a report to the Council of Deputy Ministers responsible for Transportation and Highway Safety titled A Strategic Plan for Intergovernmental Cooperation [3]. The plan focuses on the following five areas of strategic interest which provide the parameters within which a national framework for Canadian transportation R&D can be developed.

a) Making strategic investments

The plan identifies the responsibility for competent fiscal management, and the need to invest available resources strategically. The development of tools to facilitate this investment analysis is a priority, and specific mechanisms are required to address the following:
- National strategic land transportation investments
- Funding tradeoffs between expansion and rehabilitation investments
- Alternative funding and delivery mechanism.

b) Supporting economic development, trade, and tourism

The plan identifies the critical nature of trade and tourism to the economic development and wellbeing of Canada. The enhancement of trade and tourism within Canada and internationally is a priority, and specific action is required to address the following areas of strategic interest:

- International and domestic trade
- Vehicle weights and dimensions
- Intelligent transportation systems, and
- Harmonization of regulations and reduction of regulatory burdens.

c) Developing sustainable and efficient systems

The plan identifies the need for smart investment in the management and preservation of transportation infrastructure to enable an informed allocation of resources. To sustain the system, the plan speaks of the need to understand the long-term impacts of various modes, and to make choices that consider the broader social, economic, and natural environments. Wise investment and sustainability are priorities, and attention must be paid to the following areas:

- Asset management and preservation
- Environment and assessment implications
- Greenhouse gas emissions
- Modal optimization
- Taxation and user fees
- Intermodal / multimodal issues, and
- Information, education, and training.

d) Enhancing safety

The plan outlines the overriding importance of safety, and its impact on all modes of transportation, and all transportation decisions and activities. Safety is a priority interest, and the following areas need to be addressed:

- A National Transportation Safety Policy
- Highway safety
- Risk management
- Public awareness and public perspectives.

e) Technology, and guidelines for maintaining and rebuilding transportation infrastructure

The plan identifies the size and scope of the investment in the country's transportation infrastructure and services, and the need for the tools necessary to protect and manage that investment. It acknowledges the considerable expertise required to address the following issues:

- Management and development of technical expertise
- Guidelines, standards, and practices, and
- R&D needs.

1.1.3 Input from Provincial Officials and Other Stakeholders

Input from provincial officials and other stakeholders was obtained through a survey questionnaire and an Open Forum organized during the 1999 TAC spring meeting. A number of provincial, territorial, and municipal transportation officials and other stakeholders were also directly contacted.

The survey questionnaire, sent to Chairs of TAC Councils and Standing Committees and to the members of the TAC Research and Development Committee, posed the following three fundamental questions:

i) What are the most important challenges and opportunities facing Road and Intermodal Transportation in Canada during the next four to five years?
ii) What are the most important R&D needs and projects in Road and Intermodal Transportation to be carried out over the next 4 to 5 years?
iii) What should be done to make Canadian R&D in Road and Intermodal Transportation more cost-effective?

The Open Forum (a meeting of interested parties) was organized as an integral step in the process of developing the National Agenda. The Forum was held in conjunction with the 1999 TAC spring meeting in Toronto, and was attended by about 45 people. The objectives of the forum were to (a) identify research opportunities and (b) to discuss how to ensure that the funding sources and any necessary coordination mechanisms are in place to meet Canadian R&D needs.

A large number of submissions, suggestions and comments has been received from the stakeholders during the course of this project. Because of space limitations, the results this consultative process presented herein are intended to represent the scope of the material received rather than to provide an exhaustive enumeration of the material. The results are summarized under the following headings:

a) Challenges and Opportunities
b) Needs and Projects
c) Actions.

a) Challenges and Opportunities

The following challenges and opportunities were identified in the responses:

- Reducing transportation costs and improving competitiveness
- Providing efficient and cost effective road construction and maintenance
- Mitigating the environmental impacts of transportation, and improving and streamlining environmental regulatory practices
- Upgrading aging, deteriorated, and congested infrastructure within economical and political limitations, including the higher priority being placed on the funding of road services by government.
- Utilizing Intelligent Transportation Systems (ITS) and managing the existing networks in order to maximize capacity
- Renewing and optimizing the National Highway System in order to maintain competitiveness

- Accommodating impacts of the Kyoto accord on transportation
- Coordinating regulatory policies and practices and dealing with North American integration
- Improving road safety
- Innovative private-public financing and development of partnerships
- Accommodating changing demographics
- Introducing new technology for road design, vehicles, and computerization of transportation and commerce
- Promoting intermodal efficiency
- The need to focus on urban road needs and to bring the municipal sector into the R&D process as a contributing partner
- Maintaining transportation funding in light of other budgetary pressures
- Identifying the cost of urban congestion
- Succession planning; developing skilled workforce; retaining and encouraging highly qualified people
- Improved technology transfer

b) Needs and Projects

The following needs and projects were identified:

- Road used costs and their relationship to highway conditions
- Development of new highway infrastructure restoration techniques
- Development of new diagnostic techniques for highway infrastructure such as acoustical tomography, gamma ray and X-ray
- Development of improved methodology for the integrated assessment and management of the impact of transportation on the environment
- Mechanistic methods for pavement design
- Implementation of SHRP and C-SHRP technologies
- ITS standardization for communications
- ITS systems for commercial vehicles, travelers, and road weather information
- Truck / rail and truck / water interfaces
- Safety, including human factors, road design, traffic operations, and enforcement technologies
- Environment and climate change
- Transportation demand management
- Examination of fare strategies and new fare collection systems to improve transit administration and efficiency
- Identification of the cost of doing nothing (in terms of upgrading the highway infrastructure)
- Development of models to simulate intervention strategies for intermodal passenger and freight transportation
- Promotion of the use of alternative fuels
- Improved public transit, and
- Structural research.

c) Actions

The actions and activities recommended by respondents for making R&D more cost-effective have been categorized into those to be done
i) by TAC
ii) by provincial highway agencies
iii) by universities, and
iv) by industry.

i) By TAC

- TAC must fight to remain the national voice on transportation issues. TAC needs to develop an issue paper that explains the importance of a single national voice and explains how a unified national approach to transportation issues has definite long-term benefits for the country and those large provinces that currently are of the opinion that they can "do it alone."
- Promote public awareness of the importance of transportation systems
- Focus on supporting fundamental R&D in transportation
- Leadership on prioritization concerns and the building of consensus for action. Promote partnerships and pool funding of R&D.
- Coordinate / integrate R&D activities with the AASHTO and the International Road Federation (IRF)
- Establish formal partnerships with others, e.g., with NSERC
- Partner with FHWA and National Highway Institute to develop training and educational programs for Canadian transportation professionals
- Focus on technology transfer and development of standards
- Facilitate jointly sponsored initiatives with other stakeholders such as provinces, universities and industry
- Ensure that duplication of R&D activities is minimized. Develop a mechanism to disseminate draft versions of annual research plans prepared by key stakeholders.
- Continue to provide liaison between the stakeholders
- Provide national R&D data base
- Continue to provide funding to leverage research from US and other countries.

ii) By the provinces

- Promote public awareness of the importance of transportation systems
- Continue funding research
- Harmonize regulations
- Develop contacts and agreements with universities and US DOT research groups
- Develop incentives to encourage research by others
- Seek partners for common interest projects
- Rationalize inter-jurisdictional transportation routes and corridors
- Help industry by making available test facilities, advice from staff, and documentation.

iii) By universities

- Develop Centres of Excellence in specific transportation functions and establish working relationships with transportation agencies and industry
- Expand transportation research programs
- Participate in road R&D forum
- Work in cooperation with provincial highway agencies
- Develop curriculum, which balances the practical, and the theoretical acquisition of knowledge.

iv) By industry

- Develop a culture of innovation with the intent to add value to the customer
- Promote the development of improved construction techniques and construction materials
- Explore opportunities for innovative financing options.

2. Statistical Trends

This section provides a brief review of trends in the fundamental indicators of highway transportation in terms of (a) highway investment, (b) aging of infrastructure, (c) road safety, and (d) other trends. Even though these trends (as well as many other trends and statistical data) are available in the specialized publications cited in the following, the selected trends are included here for better understanding of highway transportation milieu, and because they provide the basic underpinning for the development of the National Agenda.

a) Highway Investment

Highway investment includes the cost of new highways and rehabilitation and upgrading of existing highways. It does not include land acquisition costs and costs to maintain operating efficiency. Overall, provincial expenditures on transportation have been declining. In 91/92, provincial expenditures on transportation amounted to 5.4% of the total government expenditures. By 96/97, this percentage declined to 4.7%.

Figure 1 indicates that the highway investment rate (total highway investment divided by the Gross Domestic Product, GDP) declined rapidly from 2.5% in 1961 to about 1% in 1981, and has flattened out since then [7].

The trend of flat highway investment is illustrated in Figure 2 which shows historical provincial and territorial governments expenditures on highways and transit [8].

Even though highway investment has been flat since the early 80's, the growth in population and vehicle use has continued. For example, since 1970, the highway capital stock per registered vehicle has declined by almost 50% [7].

The following observations are based on data presented in Figures 1 and 2.

- During this decade, the volume of highway construction has been flat or declining.
- The value of highway capital stock per $GDP has declined.
- The trends may suggest growing congestion on the highway system or improvements in the efficiency of highway traffic operation.

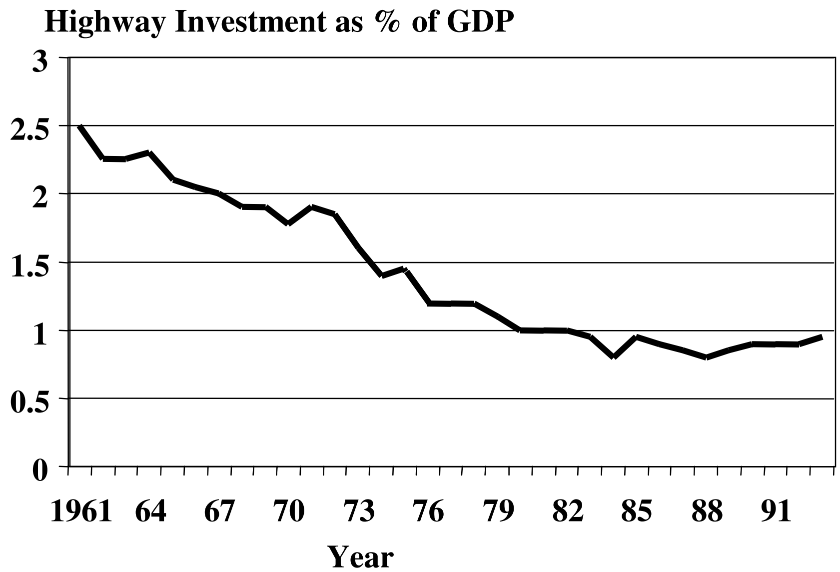


Figure 1/ Highway Investment Rate

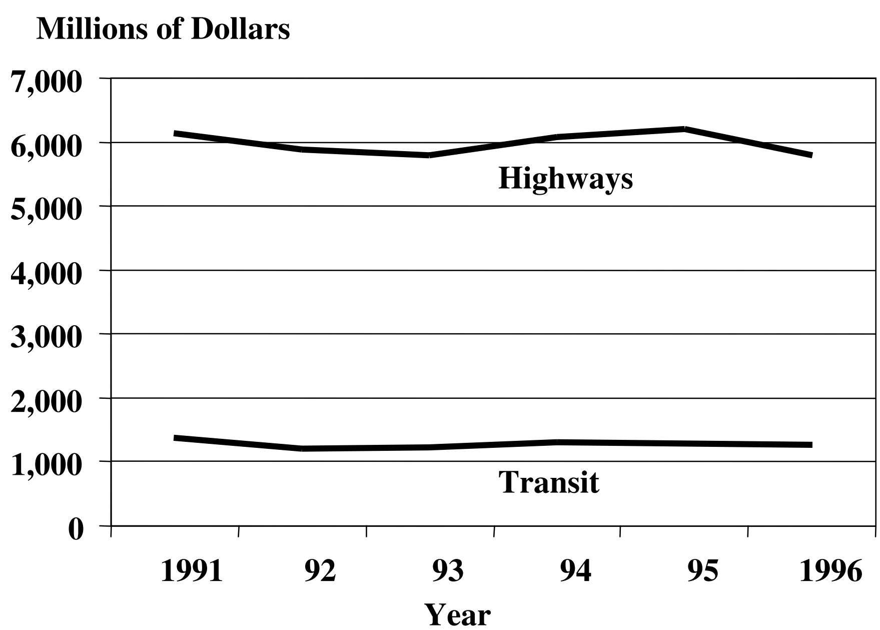


Figure 3/ Provincial Government Expenditure on Highways and Transit

b) Ageing of Highway Infrastructure

According to Statistics Canada, the average age of the highway and bridge capital stocks is increasing. From 1961 to 1993, the average age of all highways and roads in Canada (excluding bridges) increased from 9 to 14 years. (Note: Highway age does not equal pavement age.) During the same time period, the average age of the bridge infrastructure increased from 11 to 23 years (Figure 3 [7]). The provinces of Nova Scotia, Saskatchewan and Quebec have the oldest infrastructure, while Alberta has the youngest infrastructure. Except for a few exceptions in the 1960s, the ageing of the highway capital stock has been steady [7]. The ageing of the highway infrastructure is the result of the past infrastructure investment pattern. It also and underlines the importance of continuing strategic investments in the infrastructure.

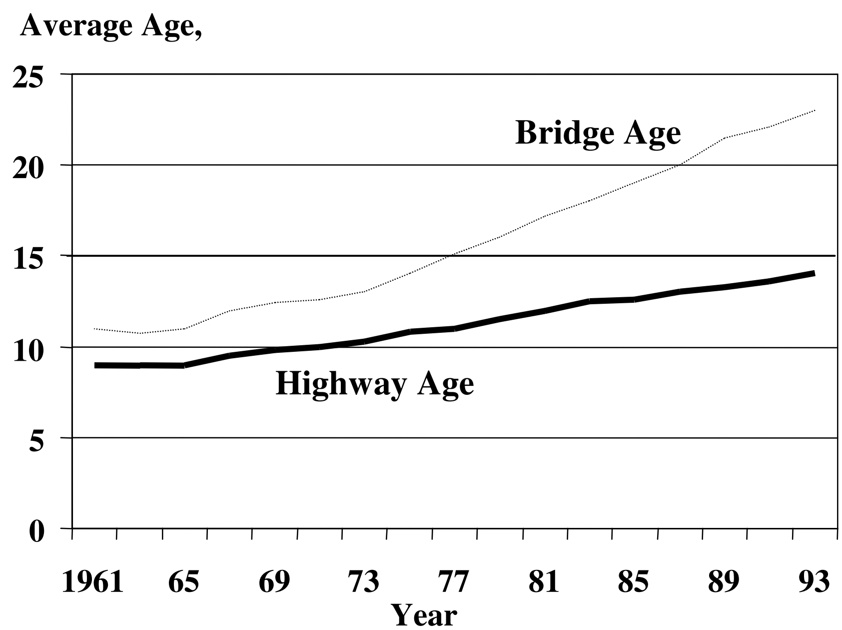


Figure 3/ Average Age of Bridge and Highway Infrastructure

b) Road Safety

Approximately 95 per cent of all transportation fatalities occur on the roads. The number of fatalities and collisions has been steadily declining (Figure 4 [8]). For example, the number of collisions in 1996 was five per cent below the 1995 numbers, and seven per cent below the 1991 –1995 average. The fatality rate (number fatalities per 10,000 motor vehicles registered) has been also declining steadily in Canada over the years but varies considerably among provinces. For example, during the 1993 – 1995 period, the fatality rate in Yukon was 3.5 while in Newfoundland it was only 1.2.

Assuming that driving exposure has remained steady or increased over the last 10 years, the steady decline in fatalities and injuries is likely due to many contributing factors such as:

- improved medical care by the roadside, in part due to faster reporting of accidents,
- improved roadside design, which lessens the risk of injury when an accident occurs,
- driver education in combination with enforcement, which has reduced the incidence of drinking and driving, and increased seat belt wearing,
- improved crash-survivability of vehicles including the introduction of airbags, and
- a greater prevalence of heavier personal vehicles (about 1/3 of all cars on the road are now sport utility, light trucks, or van models) which improves occupant protection in a crash.

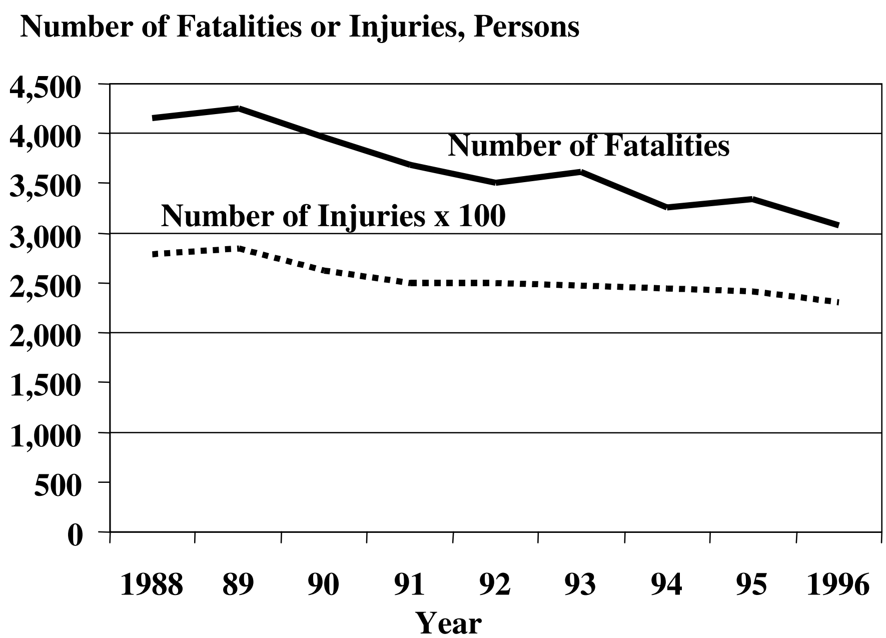


Figure 4/ Injuries and Fatalities on Canadian Highways

c) Other Trends

Reference 9 provides wealth of information on the size and characteristics if Canadian highway infrastructure. References 10 and 11 are good sources of information on trends in highway freight transportation. Trends in car and truck registrations are also provided in Chapters C and D respectively

3. Canadian Transportation R&D

3.1 Financing

In 1994, the Overview of Canadian Research Activity and Issues [3] identified surface transportation R&D expenditures in Canada as totaling approximately $52 M in 1991. Of that total, 19 M, or approximately 37%, was spent by the three federal agencies, National Science and Engineering Research Council (NSERC), Transport Canada, and National Research Council

(NRC). Of the provincial transportation authorities, only Ontario, Quebec, and Alberta were shown as having separate surface transportation R&D expenditures. At that time, Ontario's expenditure was $12 M, Quebec's was $4 M, and Alberta's was $2 M.

The period from 1991 to 1998 has seen a significant reduction in the R&D funding in Canada. Ontario's support has declined to $3.4 M in 1998, with further very significant decline in 1999. Alberta's support has declined to approximately $0.5 M per year. Only Quebec's expenditures increased from $4.0 to $5.7 M. Federal funding for surface transportation R&D has remained relatively stable.

3.2 Organization

While the federal government maintains its organizational focus on R&D through distinct entities, namely TAC, Transportation Development Center of Transport Canada, and NRC, at the provincial level only Quebec Ministère des Transports maintains a separate R&D organization and funding. Ontario has recently dispersed its R&D Office and has placed the responsibility for R&D with its specialty head office engineering units.

Recently, Alberta has initiated the Center for Transportation Engineering and Planning (C-TEP) devoted to transportation research. The founding partner members include the provincial transportation department, several engineering consulting firms, two major Alberta universities, and the two major cities (Edmonton and Calgary). So far, the focus has been on technology transfer. A similar initiative to establish transportation R&D center involving the provincial transportation department and municipalities is also under consideration in Ontario.

3.3 R&D Delivery

Increasingly, the preferred approach for transportation R&D emphasizes an integrated effort involving government and other public sector entities, the university sector, and the transportation industry. This approach recognizes the limited nature of government funding and calls on the industry to contribute. It integrates the objectives of the partners, provides for joint direction to the research, and establishes targets and success measures for each project. By involving all of the constituents, it enables pursuance of more focused and informed R&D objectives, and sets the conditions for improved implementation of the findings.

4. Opportunities and Needs and Strategic Initiatives

To be relevant, transportation R&D must support the priorities and objectives of the transportation sector. R&D is an adjunct to the policy and program development process, and can, if successful, improve that process significantly. The priorities and objectives of the transportation sector have been clearly stated in the Strategic Plan for Intergovernmental Cooperation and the Business Plans of the federal, provincial, and territorial highway agencies. By and large, the message is constant and the concerns are consistent across all jurisdictions.

The message concerning objectives and priorities becomes the framework within which the R&D agenda is developed. The National Agenda should support the effort to deal with the following priorities:

- International and domestic trade, including vehicle weights and dimensions, ITS. Truck corridors and border crossings, a harmonized regulatory regime, and reduced regulatory burdens
- National strategic transportation investments, including tradeoffs between modes and programs
- System management and preservation, including technologies for maintaining and rebuilding transportation infrastructure
- Alternative funding and delivery mechanisms
- Highway and roadway safety
- Greenhouse emission strategies
- Taxation policies and user-fee approaches
- The optimal use of transportation modes
- Urban transportation.

4.1 Methodology for Prioritizing R&D Initiatives and Projects

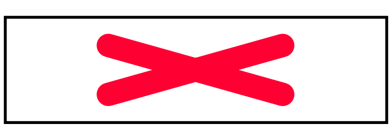
Prioritization of R&D initiatives and projects was based on the objectives and priorities developed through the consultative process described in Section 2. R&D initiatives recommended in this section (dealing with strategic issues), as well as R&D projects recommended in the subsequent sections (dealing with specific highway technologies), were rated using following criteria.

a) Social and political importance
    - Support of core businesses of Canadian highway agencies
    - Support for economy, competitiveness, and financial leverage
    - Support for important public and community concerns (e.g., environment)

b) Technical relevance
    - Technical relevance in the Canadian context
    - Contribution to innovative thrust
    - Estimated time to implementation

c) Economic viability
    - Benefit / cost implications
    - Probability of success
    - Likelihood of implementation if research is successful.

The following ranking model was used for ranking R&D initiatives and projects.



Where:

Ranking Score = Index related to relative importance of the R&D initiatives or projects towards fulfilling goals and objectives of Canadian highway agencies
w_i = weight assigned to a criterion
c_i = criterion score
n = number of criteria used to calculate Ranking Score

An example of a scoring sheet for evaluating R&D initiatives or projects is given in Table 1.

Table 1/ Example scoring sheet for evaluating projects

Main Criterion	Sub-criteria and considerations	Score 1 - 10	Weight	Wted. Score
Social and Political Importance	• Support of core businesses		**2**	
	• Support of economy, competitiveness, and financial leveraging		**1**	
	• Support of important public and community concerns such as safety and environment		**2**	
Technical Relevance	• Technical relevance in the Canadian context		**1**	
	• Contribution to innovative thrust		**1**	
	• Estimated time to implementation		**1**	
Economic Viability & Risk	• Estimated benefit-cost implications		**1**	
	• Likelihood of success		**0.5**	
	• Likelihood of implementation if research is successful		**0.5**	
Totals			**10**	Total*

*Maximum 100

4.2 Strategic Transportation R&D Initiatives

The review of background material and input from provincial officials and other stakeholders, as well as the review of the Open Forum proceedings, suggest that road and intermodal transportation R&D should focus on several strategic issues. In this context, the following strategic research projects, which address the identified priorities, are put forward.

(a) Asset Management Systems

Canada's road system is well-developed, and not likely to expand significantly over the next five to ten years. The expansion that will take place will likely be selective, and involve expanding existing capacity rather than constructing entirely new links. Government's focus, therefore, will be on rehabilitation and maintenance.

Individual provinces have initiated work on the development of asset management systems to meet their individual needs, but what is required, at the national level, is the ability to assess the system against a common set of criteria in order to identify, at the national level, priorities for national investment. Building on the work already done in support of a National Highway Policy should be a priority.

(b) Strategic Investment Tools

A recurring theme in discussions of transportation funding is the need for management information systems which will inform, facilitate, and guide investment decisions. Asset management systems will provide the basic underpinning to a management information system, but they will need to be supported by systems, which identify, quantify, and prioritize the economic, social, environmental, and safety impacts and benefits of infrastructure investments.

(c) Alternative Financing of Highway Infrastructure

Governments at all levels are faced with increasing demands for the expenditure of limited government funds. With the advent of balanced budgets, governments are focusing more and more on those areas of public service where there is a strong level of public support, most notably health and social services. Within this constrained financial environment, transportation authorities will be required to support their capital programs with alternative financing scenarios. Several provinces, such as Ontario and New Brunswick, have already moved towards toll highways as one method of financing system expansion. Specific research of alternative financing mechanisms, such as toll roads, shadow tolls, and dedicated taxes, should be done in order to better facilitate the financing debate, and to complement the development of investment and asset management systems.

(d) R&D Support for Municipalities

With the general restructuring of responsibilities between all three levels of government, urban road, intermodal, and transit systems are managed and largely funded by the municipalities. Fully two-thirds of Canada's road infrastructure fall within the municipal jurisdiction. In Ontario, this proportion reaches approximately 85%. Urban congestion in major metropolitan centres, such as Montreal and Vancouver, and at major international border crossings, such as Detroit/Windsor corridor, have an enormous, negative impact on the movement of goods and people. Yet, investment decisions, modal tradeoffs, and intermodal and multi-modal planning at the municipal level involve limited participation by the more senior levels of government. Municipal transportation requires focused R&D support. TAC needs to extend its interest more directly to include the municipal sector to bring that perspective to the discussion of national R&D issues.

(e) Assessment of R&D Delivery

Canadian transportation R&D has been undergoing, and continues to undergo, significant changes. These changes include the movement away from dedicated R&D funding and distinct organizational R&D entities within the provincial transportation agencies, and can be interpreted as a lack of understanding or scepticism, on the part of decision-makers, regarding the efficacy and relevance of transportation R&D. What is required is an examination of the benefits and the effectiveness of R&D spending, an assessment of the various organizational and funding models for R&D, and a restatement of the roles and responsibilities of governments (federal, provincial, and municipal), the universities, and the private sector for transportation R&D. TAC should lead this effort.

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B/ ASSET MANAGEMENT

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1. Introduction

Asset management has been defined as a systematic process of maintaining, upgrading, and operating physical assets cost-effectively, combining engineering principles with sound business practice and economic theory, and providing tools to facilitate a more organized, logical approach to decision making [1]. A good understanding of the role of asset management in transportation area can be gained through its evolution from engineering-based infrastructure management systems. Since the mid-1980's, the engineering concepts of pavement and bridge management, first formulated in the early 1960's, have been evolving into a much broader concept of asset management at two distinct levels.

On the first level, the evolution has been in terms of integration by encompassing the management of all major infrastructure components, such as the right-of way, pavements, bridges, and even other transportation modes. For example, Hudson and Hudson [2] described common aspects of all management systems and proposed an overall framework for infrastructure management systems, and Talvite [3] has proposed a transportation infrastructure management system encompassing all major transportation modes.

On the second level, infrastructure management has been evolving into a business-like or financial management of the infrastructure with the business-like objectives of maximizing the return on investments and minimizing liabilities. Thus, asset management involves (a) an integrated management of assets owned and administered by an agency, and (b) a business-like approach to the management of assets supported by appropriate marketing, financing, accounting and reporting mechanisms.

Considering the diversity and extent of the multi-modal transportation infrastructure, and the associated complex socio-economic aspects of its management, asset management of transportation infrastructure is still in its initial stages. It should be also noted that the technical and engineering aspects of the traditional transportation infrastructure management are similar to those of asset management. In both cases, the engineering objective is to preserve and operate the asset at its lowest life-cycle cost. Both TAC and FHWA have recently published primers on asset management of transportation infrastructure [1,4].

2. Overview of Trends

Overall trends affecting highway infrastructure and highway transportation research are discussed in Section 1. The following discussion concerns specific trends affecting asset management of highway infrastructure.

a) Increasing public demand for accountability

Issues such as fiscal restraint, focus on the return on investment, competition for funding, value for the money, and accountability are increasingly forcing public agencies to practice (and to be seen to practice) the efficient utilization of public resources. Asset management can play a vital role in enhancing public's perception of government agencies as cost-effective custodians and managers of public assets. Asset management not only promotes utilization of economic optimization tools, but also challenges engineering managers to become economic managers.

b) Continuing shift and re-balancing between funding of new facilities and the preservation of existing facilities

According to FHWA's 1994 Highway Statistics [5], about 52 percent of capital outlay spending on highways by all units of government went for new capacity. Comparative data for Canada are not available. However, transportation agencies in both countries must evaluate the merits of competing programs of expansion and preservation according to the shifting goals set by public. To do so, agencies need tools, such as asset management.

c) Increasing trend toward privatization of financing, operating and maintaining highway infrastructure

The involvement of private stakeholders results in (a) increasing demand to document the efficiency and cost-effectiveness of investment decisions, (b) the need to assess risks, liabilities and returns of the decisions, and (c) the need to employ recognized accounting procedures supported by professional bodies (Canadian Institute of Charted Accountants and the Public Sector Accounting and Auditing Board). This new financial perspective of highway infrastructure calls for asset management approaches which incorporate the generally accepted accounting and reporting mechanisms.

d) *Emergence of "absentee" owners*

Increasingly, asset owners concentrate on goal setting, planning and budgeting, while the actual maintenance and operation of highway infrastructure is done by agents acting on behalf of the owners. This modus operandi calls for well-documented management procedures, objective assessment of asset conditions, and verifiable standards for asset performance. These demands can be met within the scope of asset management business framework.

3. Opportunities, Needs, and Problems

The following description of opportunities, needs is based on the premise that the primary engineering-based asset management technology already exists (e.g., software packages for pavement and bridge management, including multi-year prioritization and optimization analysis, and project-specific life-cycle economic evaluation procedures), even though ongoing improvements are necessary. Consequently, opportunities and needs for enhanced engineering asset management tools are addressed directly in Sections E and F dealing with pavement technology and structures, respectively.

The provision of highway infrastructure has been identified as the core business area of all provincial highway agencies. Furthermore, the development of tools to facilitate strategic investment analysis has been identified by the Policy and Planning Support Committee as one of the five areas of strategic interest [6]. The following opportunities and needs have been ranked according to the procedure outlined in Chapter A, Section 4.1.

a) Objective measurement of asset condition and value

Objective, verifiable (repeatable and "auditable"), and time-stable assessment of asset condition and value is the cornerstone of all asset management systems. Yet, in Canada, there are no standardized or agreed-on asset condition measures available. Many Canadian agencies, which systematically monitor the performance of highway infrastructure, use a variety of subjective condition assessment methods.

The lack of standardized and objective asset condition measures has several consequences:

- Objective data on the performance of the Canadian National Highway System are unavailable.
- The lack of objectivity and the absence of adequate quality control and quality assurance measures can discredit subjective data.
- It is increasingly difficult to obtain funding without the objective assessment of funding needs (which requires objective assessment of asset condition) on the provincial as well as on the federal level.
- The lack of objective data hinders benchmarking. It is difficult or impossible to compare (a) the condition of highway assets across surrounding jurisdictions and (b) the performance results achieved by adjacent or similar highway agencies (e.g., condition of the pavement network in relation of the moneys spent).
- It is difficult for absentee owners to monitor the performance of the agents maintaining and operating highway infrastructure on their behalf, and to enforce agents' performance results.
- The lack of objective data causes serious hindrance to sharing engineering information, improving communications, and reducing costs of managing asset condition information.

Since the existing technology used for objective assessment of highway infrastructure is mostly in private hands, the development and implementation of the new technology calls for public/private partnership.

Recently, TAC awarded an R&D project on "Measuring and Reporting Highway Asset Value, Condition and Performance". This is a very positive step towards improving asset-monitoring technology.

b) Tradeoffs between different programs or classes of assets

One of the principal premises of asset management as an "umbrella" asset management tool is its ability to facilitate efficient allocation of resources to different programs (e.g., expansion of capacity, preservation, environment, and safety) and different assets (e.g., pavements, bridges, transit). Hand in hand is the ability to evaluate the consequences of different resource allocation strategies. The tradeoffs also imply the evaluation of risks and returns. For public sector, the return is often perceived as meeting public goals, and risk (and liability) is viewed as part of doing business to meet public goals. For private sectors, the return and risk are usually translated to profits and a threat to profits.

The technology required to (a) determine the value users place on different programs and classes of assets and (b) to translate these values into resource allocation decisions is in its infancy. Ideally, asset management should enable decision-makers to readily evaluate tradeoffs among funding policies and use a common yardstick for judging different programs.

c) Determination of desirable asset condition

As with the provision of any other service or asset, the higher the level of transportation service provided by an agency, the more it costs the agency to provide the service. In other words, the smoother the pavement and the lower the congestion on the road, the higher the costs to the agency. (Of course, the opposite is true for user costs.) Thus, to minimize the cost of providing the transportation facilities and services to the public (disregarding other considerations), the agency must minimize the level of service it provides. But which level of service should be provided to the public? What is the minimum level of service acceptable to the public? For which level of service is public willing to pay?

For services where a market exists, the equilibrium between the level of service on one side and the benefits or willingness to pay for the service on the other is established by market forces. However, there is no market to determine the willingness of the public (the travelling public and the taxpayers) to pay for the provision of different levels of transportation services. We need to develop methodology for evaluating public willingness to pay for transportation services. Only through the knowledge of user benefits, and the willingness to pay for these benefits, it is possible to allocate funds to transportation infrastructure and to its competing parts rationally.

Note
Although users pay for highway infrastructure through a variety of taxes, the user costs are not directly related to the costs and benefits of the highway system. Also, available U.S. data indicate that in spite of the long-term, consistent U.S. attempts to finance highways from dedicated accounts, the users pay only 80 percent of costs incurred by highway use [7]. In the regular market place the customers must pay the full cost for goods and services. In Canada, highway infrastructure is usually financed from general accounts.

d) Responding to industry demands for changes in vehicle weights and dimension regulations

To maximize the productivity of highway transport industry and to maximize the benefits derived from infrastructure investments, there is the need to develop methodology for assessing changes in heavy vehicle weights and dimension (VW&D) regulations on industry productivity and infrastructure impacts. In particular, there is the need to develop assessment methodology for evaluating new infrastructure “friendly” truck suspension systems. The results of the recent Ontario study suggest that the benefits incurred through increasing heavy vehicle weights surpass the increased infrastructure costs by the ratio of 10 to 1 [8]. Considering the potential gains in productivity, the beneficiaries of resolving this issue will be the industry, highway agencies, and the public.

e) Advances in electronic data processing

Highway asset management systems require large amounts of easily accessible data. The recent advances in the application of Global Positioning Systems to highway inventory, utilization of pattern recognition techniques, video-recording for monitoring asset condition, and advances in data processing and storage capabilities are favorable for the development of highly integrated, widely distributed and user-friendly databases. Opportunities exist for harnessing these new technological developments for asset management purposes. The new electronic data processing capabilities make highly integrated asset management system possible. They can also put knowledge and data-based management tools into the hands of a broad range of front-line staff and involve them in decision-making process. The lead in this area should be taken by private industry with public agencies supplying design specifications.

e) Social and economic importance of highway infrastructure

All stakeholders need to promote public understanding that highway infrastructure is not a fixed asset that must be maintained at the expanse of economic growth. Rather, it is an investment with high rate of return that supports economic activities and increases productivity. To do that, the benefits of highway investments, in terms of economic growth, productivity gains, and employment opportunities must be better understood and the results should be effectively communicated to the public. This activity should be undertaken jointly by the transport industry and the highway infrastructure owners.

4. Research and Development Projects and Activities

A number of projects were formulated in response to the trends, opportunities and needs identified in Section A and in this section. The following four projects were identified as high priority projects according to the criteria formulated in Section AA.

a) Development of condition measures and performance standards for the National Highway System
b) Desirable pavement service levels
c) Model procedures for initiating changes in vehicle weights and dimension regulations
d) Analytical tools for strategic investment decisions

a) Development Of Condition Measures And Performance Standards For The National Highway System

Problem Description: The National Highway System is a coast-to coast network of approximately 25,000 km of highways of national significance, consisting of 7,300 km of multi-lane highways and 17,000 km of two-lane highways. For the cost-effective maintenance and upgrading of this system, including securing adequate funding, it is important to have appropriate performance standards and to

	monitor the condition of the network objectively across the country.
Proposed Solution:	The development of condition measures and performance standards should encompass pavement performance indicators, such as ride quality and frictional resistance, as well as bridge performance indicators, such as the condition of bridge components and the load carrying capacity. Condition measures must be objective, verifiable, time stable, and must be related to the benefits provided to the users. Performance standards must consider user costs, available resources, the current condition of the network, and input from stakeholders.
Expected Benefits:	Objective assessment of funding needs for maintaining and upgrading the network, improved investment decisions, judicious comparison of the network condition across jurisdictional boundaries, and reduced costs of providing condition information.
Partnership Opportunities:	A study should be commissioned by TAC on behalf of Provincial and Territorial jurisdictions involved.
Resources Required:	Estimated cost: $65,000 to $80,000.

b) Desirable Pavement Service Levels

Problem Description:	Roadway authorities need to balance the cost of providing pavement service (in terms ride quality and frictional resistance) with the benefits the users obtain from this service. In the absence of market forces linking the cost of service and the willingness to pay for the service, roadway authorities determine the level of service rather arbitrarily.
Proposed Solution:	Development of cost functions linking the cost of providing pavement service of different quality to the benefits accrued by the users (as a function of traffic volumes). Analysis should also take into effect potential benefits derived from productivity and competitiveness advantages associated with highway investments.
Expected Benefits:	Rational setting of pavement condition levels leads to cost-efficient allocation of transportation investments and increased user benefits and satisfaction.
Partnership Opportunities:	There is an opportunity for partnership between the service providers (road agencies) and service users (industry and consumer associations).

Resources Required: Estimated cost: $70,000 to $80,000.

c) Model Procedures For Initiating Changes In Vehicle Weights And Dimensions Regulations

Problem Description: Canadian highway authorities are frequently faced with transport industry demands for changes in the allowable truck weights and dimensions. There is a need to develop a general assessment methodology to evaluate the impact of proposed changes in truck weights, dimensions, and suspension systems on highway infrastructure.

Proposed Solution: Development of a model (generic) procedure for evaluating the impact of industry proposals on highway infrastructure. The procedure must address on all aspects of potential infrastructure impacts including safety, geometrics, pavements and bridges.

Expected Benefits: The development of rational methodology for evaluating impacts of industry proposals on highway infrastructure will facilitate shifting the onus of assessing the infrastructure impacts from highway agencies to the proponents of the changes. Ultimately, it will contribute to increased productivity of transport industry and better utilization the public investments in the highway infrastructure.

Partnership Opportunities: A combined effort of highway agencies and transport industry is essential.

Resources Required: Estimated cost: $70,000.

d) Analytical Tools For Strategic Investment Decisions

Problem Description: Competent fiscal management requires that available resources are invested strategically. There is a need to develop tools which will facilitate making strategic investments.

Proposed Solution: Specific investment tools are required to address (a) national strategic highway investments, (b) funding tradeoffs between expansion and rehabilitation investments, (c) funding tradeoffs between different transportation modes, and (d) alternative funding and delivery mechanism.

Expected Benefits:	Better strategic management of highway infrastructure. Cost-efficiency improvements due to better strategic investment decisions.
Partnership Opportunities:	Limited partnership opportunities.

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C/ VEHICLE TECHNOLOGY AND THE ENVIRONMENT

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1. Introduction

As outlined in the Strategic Issues section, all provincial jurisdictions identified the environment as the area of high priority. Specific needs included the development of strategies to minimize the impact of transportation on the environment in terms of air pollution and greenhouse gases. Since vehicles are one of the major sources of air pollution and greenhouse gases, this section outlines a research agenda concerning vehicle trends and technology developments that will reduce the impact of transportation on the environment.

Canada, along with other nations, continues to face a number of transportation related environmental issues. Two of the current and urgent issues that are closely associated with the transportation sector are climate change and urban air quality. While the transportation, power generation, and industrial and commercial sectors all produce pollutants which contribute to these two issues, transportation is considered to be one of the more significant. Concern with these two issues has resulted in a number of initiatives being undertaken to reduce the impact of transportation on the environment. One of these is the investment of research and development funds by the Canadian and U.S. governments and the private sector in the development of new vehicle technologies to reduce pollution.

Climate change is associated with the increasing amount of carbon dioxide in the earth's atmosphere, and has been addressed on a world scale by the Kyoto agreement. This agreement requires that Canada undertake to reduce its annual greenhouse gas emissions by 6 percent from 1990 levels between 2008 and 2012. This is a significant reduction after accounting for the projected economic growth by the year 2012, and could have a significant economic impact. In 1995, the transportation sector accounted for 27% of greenhouse gases. Of this total, approximately 82% (22% from the overall total), came from ground transportation. The Federal government has initiated a number of studies to assess a wide range of measures to determine how the Kyoto targets can be met.

Urban air quality is related to the levels of oxides of nitrogen, volatile organic compounds, ozone and particulate matter (soot) in the air we breathe. It continues to be an issue in Canada's largest metropolitan areas. Since urban air quality is affected by the pollution transported into a region and that produced in the region, urban air quality can be improved by reducing emissions from all sectors of the economy. While many conservation measures have been proposed and initiated to reduce pollution from transportation, increasingly it is being realized that new vehicle technologies will be required to address the issue. Some of the technological efforts for reducing pollutants from the transportation sector focus on stricter vehicle emission standards, cleaner fuels, alternative fuels, inspection and maintenance programs, and new propulsion technologies.

Although technological advances have reduced vehicle emissions and the impact of transportation emissions on urban air quality, these reductions are being offset by increases in the average number of vehicle kilometres driven, the vehicle fleet size, and shifts in the vehicle mix. Further technological advances will be required to offset future expansion of the fleet in order to minimize the impact of transportation on the environment.

The role that vehicle technology could play in providing Canada with sustainable transportation solutions is significant and requires further exploration. Technological advances that can reduce the environmental impact of transportation and are economical would be particularly appealing to governments because they can be implemented with minimal adverse public reaction and can result in long term structural changes.

2. Overview of Trends and Issues

Along with a number of other measures, advances in vehicle propulsion technology are key to addressing climate change and urban air quality. This section reviews energy demand trends and alternative fuels, makes projections on the current and future state of vehicle propulsion technology, and assesses its potential for reducing the impact of transportation on the environment.

2.1 Trends in Vehicle Energy Demand

The factors and trends influencing vehicle energy demand and emissions are discussed in Reference (1) and summarized herein.

2.1.1 Trends in the Size of the Road Vehicle Fleet

It is projected that the total vehicle fleet will increase at an average annual rate of 1.4% between the years 1995 and 2020 as shown in Table 1. However, there will be a significant variation in the rate of growth between the various vehicle categories. While the automobile fleet is expected to grow at 0.9% per annum from 1995 to 2020, light duty gasoline trucks and vans are expected to grow at 2.4% per annum. The light duty truck fleet is increasing faster because of the shift in consumer buying trends.

Table 1/ Size of road vehicle fleet (thousands)

Vehicle Type	Year				Annual Change, %
	1995	2000	2010	2020	
Automobiles	11350	11440	12250	14000	0.9
Gasoline trucks and vans	4230	4760	6160	7700	2.4
Diesel trucks	520	580	710	820	1.8
Total	16100	16780	319120	22520	1.4
Cars/ Household	1.08	1.02	0.97	0.96	
Light Vehicles/ Household	1.48	1.44	1.45	1.49	

From Table 2, it can be seen that the annual automobile sales were essentially flat from 1993 to 1998, while light truck sales increased at an average annual rate of 8.5% per year over the same period. Over the period 1993 to 1998, light truck sales increased by 50%, with a startling increase of 33% occurring in 1996. In 1997, the sales increase of trucks slowed and declined slightly in 1998. Sales growth is expected to drop to less than 2% per year over the next two years as the preferences of the baby boomers and the larger buying public changes. In 1998, automobile sales accounted for 53.5% of new vehicle sales and light trucks for 46.5%.

Table 2/ Annual automobile and light truck vehicle sales

Year	Automobiles	Light Trucks
1993	735000	429677
1994	745965	478984
1995	669641	460570
1996	660667	612423
1997	739926	654310
1998	745543	648029
Average Growth, %	0.3	8.5
Growth 93 to 98, %	1.5	51

It is interesting to note that if automobile sales continue at the 1997 and 1998 rates until 2000, a total of approximately 3.7 million automobiles will be sold in the years 1996 to 2000. However, in Table 1 it is projected that the automobile fleet will increase by a total of only 90,000 vehicles from 1995 and 2000. This indicates that approximately 700,000 vehicles per year will be scrapped during this period.

It is projected that the heavy duty diesel truck fleet will increase at an average rate of 1.8% per annum over the years 1995 to 2020. This is the result of the increased demand for freight movements by trucks in response to the need for just in time deliveries and the increase in north-south freight movements.

2.1.2 Trends in New Vehicle Fuel Consumption

The average fuel consumption of new automobiles decreased by 35% between 1978 and 1985, from 13.1 l/100 km to 8.6 l/100 km respectively. This occurred as a result of a combination of competitive pressures and voluntary corporate average fuel consumption standards in Canada. However, the rate at which new automobile fuel consumption has decreased since 1985 has slowed as the limits of vehicle weight reductions and improvements in the efficiency of conventional drive trains are being reached. Consequently, it is projected that during the period of 2000 to 2020, the fuel consumption of new automobiles, shown in Table 3, will decrease at an average rate of 0.7 percent per annum. This projection does not allow for the introduction of new vehicle technologies, such as hybrid propulsion systems or fuel cells, with significantly lower fuel consumption.

The fuel consumption of light gasoline trucks will continue to improve as vehicle manufacturers introduce improvements to meet stricter fuel consumption standards. The standard for new light duty truck has been reduced from 11.8 l/100 km in 1990 to 11.4 l/100 km in 1999. During the period 2000 to 2020, the fuel consumption of new gasoline trucks is expected to improve by an average of 0.5% per annum. For heavy diesel trucks, the improvements are expected to average at 0.4% per annum.

Table 3/ Projected new vehicle fuel consumption (l/100 km)

Vehicle Type	Year			
	1995	2000	2010	2020
Automobiles	9.7	9.6	9.0	8.3
Gasoline trucks and vans	13.4	13.3	12.7	12.0
Heavy Diesel trucks	41.2	40.0	38.8	37.0

2.1.3 Trends in Vehicle Travelling Distance

It is projected that the growth in the average distance travelled by vehicles, shown in Table 4, will begin to moderate in the early years of the next century relative to the growth rate in the 1990s. The growth rate for automobile travel will decline from 0.5% per annum in the 1990s to 0.2% in the period 2000 to 2020. Over the same period 1990 to 2020, it is projected that there will be a very slight decline in distance travelled by gasoline trucks.

Table 4/ Average annual vehicle kilometres

Vehicle Type	Year				
	1990	1995	2000	2010	2020
Automobiles	20630	21580	21720	21980	22510
Gasoline trucks and vans	21480	21230	21060	21100	21370
Diesel trucks	78340	95180	102100	100300	100100

For heavy duty diesel trucks, the highest growth rate occurred from 1990 to 1995. From 2000 to 2020, the average distance is expected to decline slightly due to better use of intermodal freight transfers.

2.1.4 Trends in Road Energy Consumption

All of the above trends combine to determine the fuel consumed by the vehicle fleet. The transportation sector consumed 25% of total energy demand in 1995. Of the 25%, 82% was used in the road sector. The remaining 18% was used by the air (9%), marine (5%) and rail (4%) modes. In total, 2026 petajoules (PJ), approximately 56 billion litres, of oil demand was consumed in the transportation sector in 1995. The road transportation component accounted for 1659 PJ, i.e., 82%. It is expected that road energy demand will increase by approximately 1% per annum from 1659 PJ in 1995 to 2154 PJ in 2020. The results of the trends discussed above are that fuel demand will continue to grow up to the year 2020 unless the projected trends can be changed. From 1990 to 2010, energy demand is expected to grow by 26%.

As can be seen in Table 5, there has been a shift in the percent utilization of gasoline and diesel fuel in the 1990s. This is a reflection of the increased use of trucking to move freight in the 1990s. However, in the post 2000 period the percentage demand for gasoline and diesel is expected to remain the same.

Table 5/ Road transportation energy demand

Year	Gasoline (%)	Diesel (%)	Alt Fuels (%)	Total Demand (PJ)
1990	78	20	2	1513
1995	73	24	3	1659
2000	72	25	3	1723
2010	72	25	3	1908
2020	72	25	3	2154

It should also be noted that the penetration of alternative fuels into the transportation sector is projected to remain constant at approximately 3% from 1995 into the next century. Actual consumption of alternative fuels will increase from 45 PJ in 1995 to 59 PJ in 2020.

2.2 Technology Development Options for Automobiles, Trucks and Transit Buses

Some of the innovations in vehicle propulsion technologies and alternative fuels are focussed on producing near zero emission vehicles. If near zero emission vehicles can be produced at an affordable cost, it should be possible to make major reductions in gaseous pollution from the transportation sector in the next century without affecting people's lifestyles.

2.2.1 Automobiles

Governments have regulated vehicle emissions since the early 1970s and fuel economy since 1978. Over that time, vehicle emissions have decreased to the point that new automobiles in 1999 emit approximately 95% less pollution per kilometre than those of the early 70s. On a fleet basis, it is expected that total vehicle emissions will decline into the new century. However, the increased vehicle fleet size, along with the move to light trucks and the increase in travel distance, will cause emissions to begin to increase during the period 2005 to 2010.

The fuel consumption of new automobiles has also been reduced by 35% since 1978 and by approximately 50% since the mid 70s. However, little progress has been made in reducing fuel consumption of new vehicles since 1985. To make a major change in the trend for lower fuel consumption and emissions, a new type of technology will be necessary to power vehicles.

It is with this intention in mind that the Partnership for New Generation Vehicles (PNGV) was announced in the U.S. PNGV is a ten year joint research effort between the U.S. Government and industry and it was established in 1993 to develop new automotive technology [2]. The goal is to design a new automotive technology that will reduce air pollution by tripling the fuel economy of typical family sedans without sacrificing safety, performance or affordability.

PNGV is committed to having concept vehicles by the year 2000 [3] and production prototypes by 2004 of mid-sized automobile capable of reducing fuel consumption by 66% from today's standard, i.e. 8.7 l/100 km to 2.9 l/100 km. Such a vehicle will produce 112 grams/mile (g/mile) of carbon dioxide rather than the average 1999 automobile that produces approximately 325 g/mile on the standard emission certification cycle.

As well as improving fuel economy, the new vehicles must meet stricter Tier 2 vehicle emission standards. The current Tier 1 emission standards for new vehicles, along with Tier 2, low emission vehicle (LEV) and ultra low emission vehicle (ULEV) standards for non-methane hydrocarbons, carbon monoxide and NOx are given in Table 6.

Table 6/ Light duty vehicle emission standards (g/mile)

Standard	NMHC	CO	NOx
1993	0.41*	3.4	1.0
Tier 1	0.25	3.4	0.4
Tier 2	0.125	1.7	0.2
Low Emission Vehicle (LEV)	0.075	3.4	0.2
Ultra LEV (ULEV)	0.04	1.7	0.2

* Total hydrocarbons

A number of concept vehicles demonstrating new technologies began to appear in 1998 and in 1999. These vehicles showcased different propulsion concepts and components. All of the vehicles are hybrid powered, i.e. the vehicles have an electric drive and a primary power source to produce the electricity. At the present time, statements made by the PNGV consortium members indicate that limited production hybrid vehicles will be available by the year 2004 or possibly earlier. Given the current schedule and progress, a number of affordable high efficiency vehicles could be available by the year 2010. However, it should be noted that these vehicles may fall short of some of the targets in order to reduce costs.

The type and size of primary power that will be used in these hybrids is still being evaluated. The primary power sources under development at this time to power these hybrid vehicles are advanced spark ignition (SI) and compression-ignition direct injection (CIDI) engines, fuel cells, and the turbogenerator. The latter is an integrated high speed single-shaft turbine combined with a very small electric generator. The SI and CIDI engines provide the power to drive an onboard electric generator. The fuel cell produces electricity directly from hydrogen and air through an electro-chemical process.

The two leading vehicle concepts closest to meeting the fuel economy target of 2.9 l/100 km are a hybrid electric vehicle using a CIDI engine for primary power and the fuel cell electric vehicle. The challenge for the CIDI engine is to meet the NOx emission standard and to produce very low levels of particulate matter (PM). PM has become a serious issue since California has designated that PM in diesel exhaust is a toxic air contaminant. Some of the challenges for the fuel cell are to reduce cost and to make it carbon monoxide tolerant. While initial estimates indicate that a spark ignited engine hybrid vehicle, i.e. gasoline powered, would be approximately 15% to 25%

short of the fuel consumption target, the standing committee which has reviewed the PNGV program has recommended that research work on the spark ignited engine be continued.

In addition to power sources, electric power converters and controllers, advanced batteries, and ultra capacitors and flywheels are being developed and evaluated as part of the hybrid vehicle development program. The latter three are used to provide temporary storage for the energy produced by the generators and the electric motors during braking. Examples of batteries under consideration for the year 2000 concept vehicle include nickel-metal hydride and lithium-ion. Regarding ultra capacitors, research is aimed at improving performance and reducing cost because they are not ready for the year 2000 concept vehicle.

Other areas of research to reduce fuel consumption include aerodynamics, material substitution to achieve weight reduction, low rolling resistance tires, and engine frictional losses. All of these improvements will be required to meet PNGVs goal.

In March 1999, Daimler-Chrysler introduced the first compact car powered by a fuel cell made by Ballard Power Systems in Vancouver. This car was a breakthrough because the fuel cell technology was small enough to fit in a compact car and still provide room for 5 passengers. The fuel cells were mounted underneath the car's floor and the liquid hydrogen tank took up space in the small trunk. The car can travel at speeds up to 150 km/h and has a range of 450 km [4]. It currently weighs 500 kg more than a conventional gasoline powered car. The fuel cell hardware alone costs approximately $45,000 compared to $4,500 for today's engines.

The rate at which manufacturers are developing and showcasing new concept hybrid cars provides an indication of the level of effort being put forth. Also, we are seeing the first announcements for production hybrid vehicles. In Japan, Toyota is currently marketing and evaluating a limited production run hybrid vehicle capable of reducing fuel consumption to one half of today's standard. Toyota plans to introduce this first generation hybrid vehicle in North America in the year 2000. Honda has also announced plans to introduce in North America during 1999 its first generation hybrid vehicle capable of achieving a fuel consumption target of approximately 3.5 l/100 km. A further 17% improvement is requirement to meet the PNGV target of 2.9 l/100 km.

It now appears that the introduction of very low fuel consumption vehicles might occur naturally for economic and competitive reasons, without having to resort to CAFE/CAFC standards. Since cost is one of the major challenges facing PNGV, an affordable vehicle might result in a vehicle with a fuel efficiency less than the current target. Through public education and the availability of affordable vehicles, high efficiency hybrid vehicles could achieve significant penetration levels beginning late in the next decade.

2.2.2 Light Duty Trucks

The advanced technology propulsion systems being developed for automobiles can also be applied to pickup trucks, SUVs and vans. In fact, it should be easier to find the space to package the new hybrid propulsion systems in these vehicles.

2.2.3 Transit Buses

Transit buses are an important component of the transportation system in Canada's urban centres. It is recognized that buses reduce congestion, pollution and energy consumption and are viewed as one component of the solution to global warming. However, most of the transit buses in operation are powered by diesel engines. Environmental concerns with diesel particulate matter in the late 1980s resulted in a search for a cleaner buses, leading to the development and demonstration of buses equipped with diesel particulate traps and buses powered with alternative fuels such as methanol, ethanol, natural gas and propane. While demonstrations were initiated with propane, natural gas, methanol, and ethanol in the 1980s, all of these, except for natural gas, have been discontinued.

In Canada, there are currently 363 natural gas powered transit buses out of a total fleet of approximately 11000 transit buses. The Canadian cities using natural gas buses are listed in Table 7. In 1997, approximately 5.6% of the buses in the U.S. were powered with alternative fuels, the most common being natural gas at 4%. Canadian natural gas powered transit buses account for 3.3% of all transit buses.

Table 7/ Canadian Natural Gas Bus Fleet

City	Number of Buses
Burlington	15
Cornwall	10
Hamilton	91
Kitchener	23
London	48
Toronto	125
Vancouver	51
Total	363

It is estimated that a transit bus powered by a ULEV natural gas engine emits approximately 60% less NOx and 75% less PM than a diesel bus. Reductions of this magnitude make natural gas buses particularly well suited for use in downtown urban centres. Carbon dioxide emissions of natural gas transit buses are projected to be about 5% less than their diesel counterparts.

As we have moved into the latter part of the 1990s, the desire to develop cleaner buses has continued and has resulted in a number of hybrid buses being developed. All three of Canada's transit bus manufacturers are either producing hybrid buses or have them under development. Vancouver is currently evaluating three fuel cell buses manufactured by New Flyer Industries. These buses are equipped with three Ballard fuel cells and are powered by hydrogen stored in roof-top cylinders. Also, conventional hybrid buses using a diesel engine for the primary power source are being developed, demonstrated and evaluated.

Transit buses, along with heavy duty trucks, are made from a number of standard components, such as engines, transmissions, axles, etc. Standardized emission data are typically not supplied for each of these configurations for cost reasons. As the number of fuel and propulsion system options increase, the difficulty of assessing the environmental merits of these options increases.

2.2.4 Heavy Duty Diesel Truck and Bus Engines

At present, the primary focus on diesel truck and bus engines is to reduce oxides of nitrogen (NOx) and PM, because NOx is precursor to smog and PM is considered to be carcinogenic. In California, the PM from diesel engines has been identified as toxic air contaminants (TACs). TACs are those air pollutants that may contribute to an increase in death or serious illness, or may pose a hazard to human health.

The emission standard for diesel engines has been made stricter in 1998 and is scheduled to be made even stricter in 2002. As the standard becomes stricter, it is anticipated that fuel consumption will increase. To compensate for this increased fuel consumption, the vehicle manufacturers are researching improvements in the areas of aerodynamic streamlining, weight reduction and, low rolling resistance tires.

As with diesel buses, the concerns with diesel exhaust and fuel economy is resulting in research being initiated into the use of hybrid technology for heavy trucks. The initial research is being conducted on a short haul truck with a GVW of between 12,000 and 40,000 kg operating in an urban area.

2.2.5 Impact of Introducing New Technology Hybrid Vehicles

As indicated in section 2.1.2, the energy demand projections to the year 2020 in Section 2.1.4 did not contemplate the introduction, during that time period, of new vehicle technologies, such as hybrid propulsion systems or fuel cells. However, since those projections were made, a number of developments and announcements have been made indicating that gasoline hybrid vehicles, capable of reducing the fuel consumption of today's vehicle by approximately half, will be introduced in limited numbers beginning in 1999 by Honda and in 2000 by Toyota.

In Figure 1, a projection has been made on the annual CO2 produced by the light duty vehicle fleet using current standard propulsion technology and assuming small yearly fuel consumption improvements. The impact of introducing hybrid gasoline vehicles that consume 1/2 and 1/3 of the fuel consumed by today's standard technology vehicles is shown in Figure 1. If 0.5x technology vehicles begin to be introduced in 2010 and their percentage of new vehicle sales increases at the rate of 5% per year for 20 years, the CO2 produced in 2030 is less than that produced in 1995.

2.3 Alternative Fuels

The primary fuels used in the transportation sector today are gasoline and diesel. Alternative transportation fuels (ATFs) such as natural gas, propane, ethanol and methanol are in limited use. As shown in Table 5, in the year 2000, it is expected that 3% of energy demand will be from alternative fuels. The demand for each of the alternative fuels is given in Table 8.

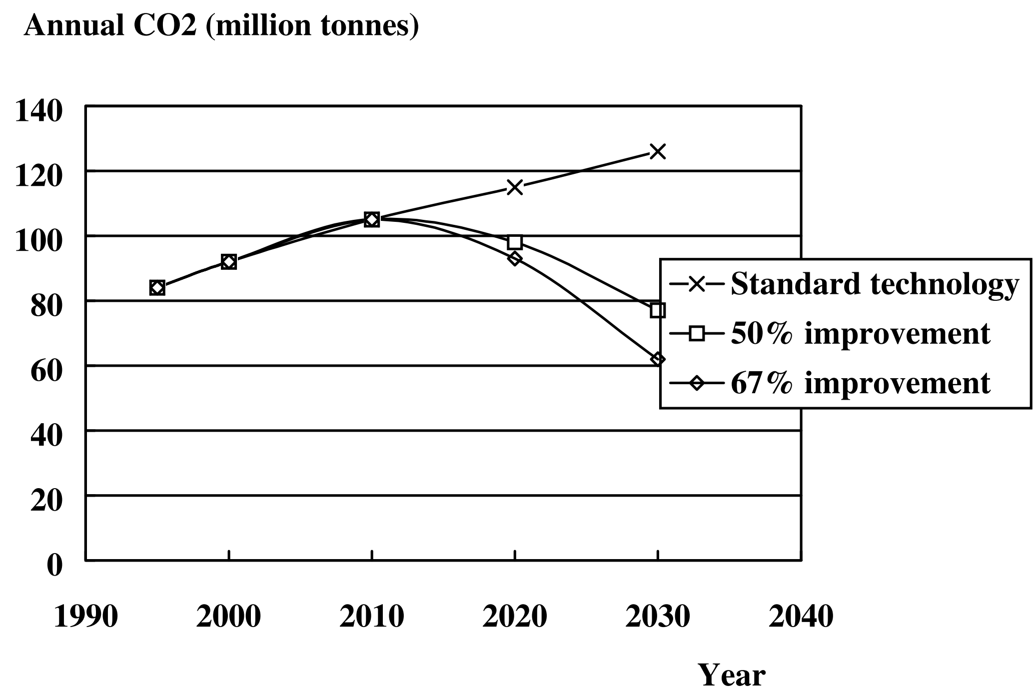

Figure 1/ Impact of New Vehicle Technology on Annual CO2 Production

Table 8/ Projected alternative transportation fuel demand (PJ)

Alternative Transportation Fuel	Year		
	1995	2000	2020
Propane	33	35	44
Natural Gas	8	8	10
Ethanol	1	2	2
Electricity	3	3	3
Total	45	48	59

In previous years, the car manufacturers offered a limited number of dedicated natural gas and propane vehicles and flexible-fuelled alcohol vehicles. Today, the car manufacturers only offer a few production automobiles and light trucks powered by dedicated natural gas. The dedicated natural gas cars and light trucks are classified as ULEVs and Super ULEVs respectively, and are the cleanest in their class. Bi-fuel natural gas and propane vehicles, along with flexible-fuel vehicles that use ethanol can also be purchased. These last three vehicles are classified as bi-fuel because they can also use gasoline.

There are several reasons for using alternative fuels, such as environmental, economic, public relations (good corporate citizenship), government policy, and industrial opportunities. While all of these reasons can influence the choice, it is interesting to note the influence of government policy.

In the 80s and early 1990s, the Ontario and Federal governments were interested in promoting industrial opportunities and the use of ATFs in Canada. One of the ways this was done was through the use of incentives. This resulted in a significant number of transit systems purchasing natural gas powered buses. In the mid-nineties, the Ontario government eliminated its transit capital funding policy (75% subsidy for capital costs) and decided not to cover the incremental costs associated with natural gas powered buses. In a subsequent move, it ceased all transit funding and transferred the funding responsibility entirely to the municipalities.

Discussions with bus manufacturers indicate that no natural gas bus sales are on the books for Canadian agencies for 1999, 2000 and 2001. This is in sharp contrast to the U.S. where the market share of natural gas buses has climbed to 20%, and sales of approximately 600 natural gas buses are on the books for the years 1999 and 2000. In the U.S., the federal government covers 80% of the capital cost of buses.

2.3.1 Natural Gas

Natural gas has been in use as an alternative transportation fuel for many years. One of the early users of natural gas in transportation was Italy. In 1980, Italy had approximately 270,000 vehicles operating on natural gas. In Argentina, there are currently approximately 330,000 natural gas powered vehicles [5].

In North America, interest in the use of natural gas in automobiles began to grow in the early 1970s when methods to reduce vehicle emissions were being researched. It was shown that significant reductions could be achieved by substituting natural gas for gasoline. Interest waned when it was found that a catalyst could be used to reduce emissions from gasoline vehicles.

In the 80s, interest in natural gas and other alternatives reappeared as they were viewed as a means of reducing Canada’s dependence on petroleum. In the 1990s, natural gas has re-emerged as a clean alternative to the use of diesel in transit.

Currently, there are approximately 25,000 vehicles operating on natural gas in Canada. The majority of these are gasoline vehicles converted to bi-fuel natural gas. However, the rate at which vehicles are being converted has slowed because of the complex nature of the electronic fuel and emission control equipment installed on new vehicles. As of 1998, new gasoline vehicles are equipped with on board diagnostics II (OBD II). This system is designed to inform the driver that the emission control equipment has malfunctioned and is also equipped to detect tampering. Consequently, it is difficult to convert a 1998 vehicle to natural gas.

Research in the natural gas vehicle area is focussed on reducing cost and improving reliability of components in the vehicle fuel system and the fuelling infrastructure. Also work is being done to increase the efficiency of natural gas in diesel engines.

2.3.2 Propane

Propane is a by product of refineries and the production of natural gas. It is used as an energy source in the major sectors of the economy, with one quarter of total production being used in transportation. According to Table 8, propane is the most widely used alternative fuel in transportation. In the year 2000, it is projected that propane will provide 73% of the ATF demand. As with natural gas, propane has been an automotive transportation fuel for many years around the world. It came to prominence in the 1970s because of its low emissions characteristics.

There were approximately 120,000 propane powered vehicles in Canada in 1998, down from a high of 150,000 in the early 1990s. An indication of what is happening in the propane market can be garnered from the conversion rate of propane vehicles in Alberta. In 1997, only 550 vehicles were converted to propane. This is down from a high of 20,000 in 1990. As with natural gas, the introduction of OBD II has made it increasingly difficult to convert vehicles to propane.

In order to alleviate the difficulties associated with conversions, Ford has initiated a Qualified Vehicle Modifier (QVM) program. Under this program, Ford has certified outlets that can convert special factory produced light duty vehicles to a bi-fuel ATF vehicle. The vehicles are prepared at the factory so that they can readily be converted to a bi-fuel propane vehicle by an approved outlet. A similar type of conversion is available for a limited number of bi-fuel natural gas light trucks.

2.3.3 Ethanol

Ethanol is a renewable energy resource that can be manufactured from biomass such as corn, grapes, wheat, etc. It can also be produced directly using chemical processes that begin with ethane. The principal use of ethanol in transportation is as an octane enhancer in low level gasoline-ethanol blends. These blends contain from 6% to 10% ethanol.

There are currently four plants producing ethanol in Canada, two in western Canada and two in Ontario. In November 1997, Commercial Alcohols, opened a plant in Chatham, capable of producing 50 million litres of fuel grade ethanol each year. This fuel is sold primarily to the Suncor plant in Sarnia to make low level gasoline-ethanol blends which contains 8% ethanol.

Ethanol can also be used directly as a alternative transportation fuel in specially converted vehicles. Although pure ethanol can be used, it is difficult to start vehicles using pure ethanol in cold weather. As a result, a blended fuel containing 85% ethanol and 15% gasoline is used to increase startability. This type of fuel is known as a high level blend and is designated as E85

Flexible fuel vehicles which use ethanol fuels from low level blends to E85 can be purchased from some original vehicle manufacturers. These vehicles have the ability to operate on almost any mixture of gasoline and ethanol. The vehicle can be fuelled at any time with gasoline and the fuel mixture sensor will provide information to the fuel injection system to immediately compensate for whatever blend of ethanol and gasoline is in the fuel tank.

2.3.4 Methanol

Methanol is an alcohol that is typically manufactured from methane. It came into prominence in the late 1970s as a transportation fuel because of its potential to reduce emissions in the automotive sector. The use of methanol in transportation appeared to be a good choice for Canada since Canada produced significant volumes for export to the U.S. A significant research effort was launched both in Canada and to U.S. to develop light and heavy duty vehicles to operate on methanol.

In the light duty vehicle market, flexible fuel vehicles (FFV) were developed which could operate on gasoline or any methanol-gasoline mixture containing up to 85% methanol and 15% gasoline. FFVs were required because of the lack of availability of methanol stations.

For a number of reasons, including the cost and price swings of methanol, the early enthusiasm for the use of methanol in transportation waned. It is still widely used in auto racing for its high performance. At the present time, no production vehicles are made which use methanol. In spite of this, the use of methanol in transportation appears to have a bright future as the future fuel for fuel cell powered vehicles.

2.3.5 Use of Methanol in Fuel Cells

The majority of fuel cell powered concept vehicles being demonstrated today, such as the Ballard fuel cell bus and the recently announced Daimler Chrysler Necar 4, use pure hydrogen as a fuel. In the case of the bus, the hydrogen is stored in high pressure cylinders as a compressed gas at 3600 psi on top of the bus and occupies a significant volume. In Necar 4, the hydrogen is stored as a liquid at - 260 degrees C in a “thermos bottle” type tank using a double wall vacuum evacuated construction. Both these storage types are inconvenient for light duty vehicles.

Methanol is considered to be the future fuel for hydrogen fuel cells because it is a convenient source for hydrogen. Methanol can be stored as a liquid at room temperature and pressure, and through reformation used as the source of hydrogen for the fuel cell. Since each molecule of methanol carries four hydrogen atoms, the methanol can be split in a reformer into two gases, carbon dioxide and hydrogen. The hydrogen can then be supplied to the fuel cell to produce the electricity. It is believed that Necar 5 will be powered with hydrogen produced by a methanol steam reformer.

A more advanced, but more difficult challenge being researched is the direct methanol fuel cell. In this type of fuel cell, methanol is supplied directly to the fuel cell. The methanol reacts directly to produce electricity and carbon dioxide. While the potential for this type of fuel cell is great, its development lags significantly behind that of the methanol steam reformer hydrogen fuel cell.

3. Description of Research Opportunities

3.1 Inspection and Maintenance (I/M) Programs

Emission standards for new vehicles are set by the Federal government and are given in Table 6. Until recently, in-service vehicles did not have to be tested for emission compliance to assess whether the emission control system was working. However, three I/M testing programs were initiated in the 1990s to test the emissions of in-service vehicles.

In August 1997, Ontario's Minister of Environment announced Ontario's Drive Clean program to reduce pollution from vehicles used in transportation. British Columbia initiated its Air Care program for the lower mainland in 1992. Calgary introduced, Smog Free, the world's first voluntary emissions testing program. The objective of these programs is to reduce the pollutants from the transportation sector which contribute to smog formation, along with toxic pollutants and global warming gases.

It is interesting to note that each of these programs uses a different method to test vehicles and has different rules for repairs. The merits of developing a standardized Canadian vehicle emission testing program should be investigated.

3.2 Fuel Cell Technology

As discussed in Section 2, new hybrid propulsion systems are being researched and developed to power vehicles in the next century. These new propulsion systems use spark ignited engines, compression ignition engines, and fuel cells as their primary source of power in combination with batteries and electrical motors. In addition, auxiliary and control systems are required. Since Canada is a leader in the development of fuel cell technology, research into fuel cells, and their associated systems should be continued.

Considerable work is still required before this technology can be fully developed and commercialized. Research on cost reduction, reliability, durability, power density, operation in cold climates, carbon monoxide tolerance, and mass production processes will continue to be required. In addition, research is required in making methanol reformers smaller and more efficient since methanol is viewed as the best candidate fuel for fuel cells.

3.3 Emission and Fuel Economy Testing of Transit Buses

Transit buses, along with heavy duty trucks, are typically tailor made for each customer from a number of standard components, such as engines, axles transmissions, etc. Standardized emission data is typically not supplied for each of these configurations for cost reasons.

Although the transit buses and trucks are manufactured with certified engines, there is no requirement to provide emission and fuel economy data for the complete vehicle as it is required in the automotive sector. Since the environmental benefits which each of these types of transit buses can provide are useful to planners, a research program should be established to provide data and a methodology for assessing the life cycle emissions of the various propulsion systems.

3.4 Alternative Fuels

Alternative fuels can provide clean transportation systems. However, each fuel appears to have some characteristics which limit its market penetration. For instance, gaseous fuels have to be stored in high pressure cylinders or as a liquid in a cryogenic tank. Storage under high pressure requires heavy cylinders and high capital infrastructure. Storage as a liquid is also costly and inconvenient.

Studies on alternative fuels, in the broadest sense, should continue to be undertaken to minimize those characteristics that make them inconvenient and to increase their market penetration.

4. Description of Research Projects

a) Demonstrate Hybrid Electric Vehicles in Canada

Problem Description:	An evaluation of hybrid electric vehicles should be undertaken in Canada to assess their performance under harsher Canadian climatic conditions. In particular, fuel cell electric vehicles along with gasoline powered electric vehicles, should be assessed to evaluate the impact of snow, ice, salt and cold climate on these systems.
Proposed Solution:	A two or three year demonstration of these new vehicle technologies should be undertaken to assess whether Canadian climatic conditions will require revisions to their design.
Expected benefits:	Advanced technology vehicles that can operate reliably under Canadian climatic conditions.
Partnership Opportunities:	This type of project is usually conducted under a public/private financing initiative.
Resources required:	Estimated $250,000-$350,000 for two to three vehicles.

b) Emission and Fuel Economy Testing of Transit Buses

Problem Description:	The range of environmental benefits provided by transit buses powered with alternative fuels, fuel cells and diesel electric propulsion systems under a range of typical urban driving conditions is not known. Since the environmental benefits that each of these types of transit buses can provide would be useful to municipal, provincial and federal planners, a research program should be established to provide data and a methodology for assessing the life cycle emissions benefits of the various propulsion options being developed.

Proposed Solution:	A program to test a number of transit buses with different propulsion systems to quantify their emission benefits using a standardized test procedure at the Environment Canada facilities.
Expected benefits:	A set of data and a methodology for evaluating the environmental benefits of transit buses using advanced propulsion systems.
Partnership Opportunities:	This type of project is usually conducted under public/private financing initiative.
Resources required:	Estimated cost to test 7 buses is 150,000.

c) Alternative Fuels

Problem Description:	The market penetration of alternative fuels remains low.
Proposed Solution:	Studies on alternative fuels, in the broadest sense, should continue to be undertaken to assess all of the factors, i.e. cost, technical, convenience, etc., which account for their low penetration rate.
Expected benefits:	Policies designed to increase the market penetration of alternative fuels.
Partnership Opportunities:	This type of project is usually conducted under public/private financing initiative.
Resources required:	Estimated $50,000 - $75,000

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D/ TRANSPORTATION OF GOODS

Cluster Leader

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1. Introduction

1997. Transportation of goods on highways means trucking and highway movement of intermodal containers. Trucking pays a predominant role in shaping highway facilities. Truck characteristics govern many aspects of the design of highway facilities, and truck traffic volumes, composition and speed play a dominant role in determining highway maintenance and rehabilitation needs, and in the operation of the highway system. Truck safety is a very public issue.

For the purpose of developing the R&D agenda, the transportation of goods issues were divided into three groups:

- Vehicle weights and dimensions;
- Harmonisation of regulations; and
- Inter-modal freight.

2. Trends and Issues

2.1 Introduction

Truck traffic affects most aspects of the highway system. An estimate of the future trend in truck traffic is therefore central to planning future system growth, developing rehabilitation, rebuilding and replacement strategies, improving standards and procedures, and developing road safety strategies.

It is difficult to establish a single representative growth rate for transportation of goods. There are a number of measures commonly used to estimate the growth rate, such as number of shipments, tonne-km, vehicle-kilometres of travel (VKT), shipment value, fuel usage, vehicle production, and vehicles registered. Each of these measures is affected by secondary factors like changes in vehicles, technology or freight characteristics that are significant over periods of ten years or more, and prevent the use of any of these measures as an overall long-term measure.

The historical compound annual growth rate of truck traffic tonnage in Canada was 3.6% from 1990 through 1997, with a projected growth of 2.6% from 1997 through 2005. The historical compound annual growth rate of truck tonne-km in Canada was 5.6% from 1987 through 1997 [1]. The projected growth rate for truck VKT in the U.S. is 2.6% to the year 2000 [3]. A recent U.S. study projected a 34% increase in truck traffic over eight years, or 3.7% per annum. More recent U.S. data suggests an actual increase of 22% for the last five years, or 4.0% per annum.

At a macro level, Canada's average long-term GDP growth rate is about 3.8% per annum. There are a number of reasons for goods transportation to be increasing at a greater rate than the economy as a whole. Manufacturing industries have re-structured so that the assembly plant no longer takes in raw materials and makes the finished product. Many small plants now take in raw materials, and make components, which may then be shipped to other plants for assembly into larger components before ultimately becoming a part of the finished product. The prime example of this is the auto industry. However, many other industries are doing the same thing, focussing on their core business and core competencies, and buying specialised parts and services from others more expert and cost-efficient in those fields. The consequence is that there is more transportation, both in processing natural resources and in manufacturing. This trend will continue as long as the cost of transportation does not overcome the cost efficiency of small, specialised plants. Further, the North American Free Trade Agreement has substantially changed goods distribution in Canada, from east-west from Canadian branch plants, to north-south from warehouses along the border. Finally, the steady decline of the Canadian dollar has made Canadian resources and goods very competitive in the U.S. and world markets. These considerations suggest that over the last six to ten years, goods transportation in Canada has been increasing at a greater rate than the GDP.

According to Table 1, illustrating the effect of different compound rates, a 3.0-4.0% growth rate for 5 years would result in a total truck traffic increase of 15-20%. This is probably a reasonable prediction when combined with fine-tuning for some heavily trafficked localities.

Table 1/ Overall Growth for Various Periods and Growth Rates

Growth (%)	Time period (years)				
	5	10	15	20	25
0.5	2.5%	5.1%	7.8%	10.5%	13.3%
1.0	5.1%	10.5%	16.1%	22.0%	28.2%
1.5	7.7%	16.0%	25.0%	34.7%	45.1%
2.0	10.4%	21.9%	34.6%	48.6%	64.1%
2.5	13.1%	28.0%	44.8%	63.9%	85.4%
3.0	15.9%	34.4%	55.8%	80.6%	109.4%
3.5	18.8%	41.1%	67.5%	99.0%	136.3%
4.0	21.7%	48.0%	80.1%	119.1%	166.6%
4.5	24.6%	55.3%	93.5%	141.2%	200.5%
5.0	27.6%	62.9%	107.9%	165.3%	238.6%

A steady 3.0-4.0% growth rate over 20-25 years would result in an increase of 80-166% in truck traffic. Combining the potential rehabilitation and rebuilding needs with traffic growth of this magnitude suggests significant needs for capital investment. It may therefore be prudent to start laying a foundation for longer-term needs, by considering the characteristics and growth of truck traffic over at least the next twenty years.

Any projection of the future entails risk of error. Over a short period, it is likely that there will be errors from an unexpected downturn or growth spurt in the economy. Longer-term projections may be less dependent on such factors, but instead are at risk from structural changes in the economy, and from changes in technology and culture. The power demand projections of Ontario Hydro are an example. The projections produced redundant nuclear generating capacity while society was responding to the need to conserve resources. The trend towards a stable population in Canada, and factors such as offshore resources, may temper the long-term overall growth towards the end of a 20-25 year time horizon.

2.2 Vehicle Weights and Dimensions

The program to establish greater uniformity in vehicle weights and dimensions began shortly after Ontario began regulating axle group and gross weights by a bridge formula in 1970, and permitted a maximum gross vehicle weight of up to 63,500 kg. The first round dealt principally with bridge issues. After some bridge and highway strengthening, principally in western Canada, gross weights were in the range 53,500-56,500 kg for most provinces. The provinces were not prepared to consider any further increase without dealing with vehicle issues, because most provinces did not want many of the vehicles that were used for heavy haul in Ontario. The CCMTA/RTAC Vehicle Weights and Dimensions Study defined objective vehicle performance standards, which served as the basis for the vehicle configuration and weight and dimension limits defined in the national Memorandum of Understanding on Vehicle Weights and Dimensions ("the M.o.U.") [3]. The M.o.U. was initially signed in 1988, and defined the most common configurations used in inter-provincial commerce. It was subsequently amended in 1991 to add trucks and truck-trailer combinations, and has since been amended twice to refine details.

The issues and relationships that arise from different regulations between provinces, states and the U.S. federal government, and different permit and enforcement policies, are very complex. The consequence is that trucks are configured for one of four missions:

- Intra-provincial;
- Inter-provincial;
- Local international; and
- Go-anywhere international.

The intra-provincial fleet provides local service, such as urban pick-up and delivery, local distribution, and most heavy haul for commodities such as construction materials, beer, fuels, farm produce and logs. The heavy haul sectors make full use of the allowances the provinces provide by regulation, permit, or policy. Consequently, some very specialised local vehicle configurations have evolved, like the western log trucks, long combination vehicles in the prairies and Quebec, twin-steer straight trucks in Quebec, and various configurations with liftable axles in Ontario.

The inter-provincial fleet provides primarily long-distance service across provincial boundaries, as there are several locations where two significant cities are separated by a provincial border. The inter-provincial fleet in the four western provinces is close to the M.o.U. The trend in the eastern provinces is towards that standard. Tri-axle semitrailers (a tandem and a single liftable axle) are now diminishing rapidly due to a reduced weight allowance for the tri-axle in Quebec and New Brunswick. Quad-axle semitrailers (a tridem and a single liftable axle) will likely remain a permanent feature between Quebec and Ontario.

The local international fleet provides service between one or two provinces and one or two adjacent states. These vehicles are often configured as a compromise between conflicting sets of regulations. They often accommodate the differences by re-configuration, such as by lowering a liftable axle, sliding axles, or changing drawbar length or other dimensions. They may operate on state roads in the U.S. or under federal grandfather rights to achieve gross weights much higher than the nominal 36,287 kg (80,000 lb) U.S. federal weight limit.

The go-anywhere international fleet must conform to U.S. federal rules, which means a 5-axle tractor-semitrailer or a 5-axle A-train double with trailers 8.53 m (28 ft) long and a maximum gross weight of 36,287 kg (80,000 lb). Nothing will happen to this fleet unless and until the U.S. federal government makes a change to the U.S. federal regulations to allow configurations with greater weight capacity.

The consequence is that particular carriers either have to specialise in a particular market, or have different fleets to be competitive in each of several markets. This is not to say that vehicles are not used for more than one mission. They can be, and are, when suitable freight is available, or a suitable vehicle is available, even if it operates off its design mission.

The M.o.U. is still very much a work in progress. A study of the outcomes of the M.o.U. conducted in 1994 found net savings in transportation costs of $142 million by 1992, and estimated savings of $222 million by 2002, for traffic on the National Highway System [4]. Traffic into Ontario accounted for 40% of the savings by 1992, although Ontario had not at that time done anything to recognise the M.o.U. The subsequent introduction of 16.2 m (53 ft) semitrailers into Ontario and eastern Canada should approximately double the numbers. Expansion to the entire highway system could double them again.

A number of items remain on the table for resolution, and form part of the current workplan of the Task Force on Vehicle Weights and Dimensions Policy. The other major outstanding issue is response to changes that may occur in the U.S. It is likely that these will be driven almost entirely by U.S. domestic politics, but Canada and Mexico do have a role through the NAFTA process, which includes a mandate for harmonisation of vehicle weights and dimensions [5].

A fairly consistent process has now been established whereby the jurisdictions and industry make proposals for changes to the M.o.U. There is enough now known about the characteristics of vehicles and their relationships to roads, bridges and transportation costs that the evaluation of a proposal is a straightforward process. However, considerable judgement and insight is still required, and the achievement of uniform regulations remains an elusive goal.

2.3 Harmonization of Regulations and Standards

There are four areas for harmonisation of regulations and standards:

- Vehicle weights and dimensions;
- Operating standards;
- New vehicle design standards; and
- Vehicle systems.

First, regulations are already harmonised for local trucking that operates in only one provincial jurisdiction. Differences in regulations are an issue only for operation between jurisdictions, which applies to about 40% of truck travel.

The provinces and territories in Canada, and states and the Federal Highway Administration in the US set operating standards. Harmonisation of these standards in Canada is a significant part of the mandate of the Canadian Council of Motor Transport Administrators (CCMTA). Harmonisation of new vehicle standards is primarily a bilateral matter between Transport Canada and the National Highway Traffic Safety Administration in the U.S., with some impact where operating standards effectively set vehicle manufacturing requirements. Vehicle systems include miscellaneous items such as driver and vehicle licensing, taxes, and ITS applications.

The licensing agencies have often different regulatory powers provided by their legislation, different structures and formats for their regulations, rely on different definitions, and use different procedures to implement changes. Existing and prior regulations have simply been different, and even incompatible. There have been various initiatives to harmonise regulations. Typically, the jurisdictions agree in rather general terms on what they will do. The agreement must be general, as cabinet and legislative authority must prevail. Consequently, each jurisdiction then implements the agreement within the structure and format of their existing regulations, often to ensure that certain features of the local status quo are preserved. It is hardly surprising, then, that the new regulations differ even before interpretations are issued. The jurisdictions also have difficulty implementing the same change on the same date. It often becomes difficult for manufacturers, shippers and carriers to know what to do for the best in the interim period between the announcement of change and the time when it actually occurs, particularly if there is a protracted delay.

Equitable treatment of carriers between jurisdictions means that rules must:

- Apply equally;
- Be exactly the same in all jurisdictions;
- Come into force at the same time in all jurisdictions; and
- Be interpreted and enforced in the same way, both within and between jurisdictions.

Most attempts to harmonise regulations have fallen far short of providing equitable treatment. There are some exceptions, though. For transportation of dangerous goods, the leadership of the federal government created a model regulation. Because the content was so technical, there was no evident benefit to doing anything different than the model regulation. Most jurisdictions did not have the technical expertise to do anything different, so simply adopted it by reference. On-highway enforcement of vehicle standards is another, largely because all jurisdictions subscribe to the Commercial Vehicle Safety Alliance standards and procedures.

In Canada, the federal government, as well as provinces and territories can make regulations in their areas of authority. However, there is no clear mechanism for the provinces and territories to make truly harmonised regulations or impose common standards where they have a common interest. Indeed, some jurisdictions may have real or imagined barriers to doing this, and these may change from time to time. There is a need to learn from the prior attempts, and define a process that can actually fulfil promises made to industry that regulations will be harmonised.

There is a number of pre-requisites to adoption of harmonised regulations:

- The jurisdictions and industry must agree on the broad scope of the proposal;

- The benefits of uniformity must allow small disagreements to be overcome, and must outweigh the cost of change;
- The regulation must be suitably housed so that it can be adopted by reference in each jurisdiction;
- The regulation must be based on its own definitions of terms, pre-empting other interpretations that jurisdictions may already have for those terms; and
- Above all, the will to succeed must be driven downwards from the highest levels.

A harmonised regulation can be made to happen by leadership as outlined in the last bullet point. It may happen occasionally by good fortune. More likely, though, without the leadership, the outcome of most attempts will be as unsatisfactory as that of past attempts.

2.4 Inter-Modal Issues

Inter-modal transportation of goods in this context refers to a container or a trailer making a trip partly by road and partly by rail. The historical compound annual growth rate of rail intermodal traffic tonnage in Canada was 4.2% from 1985 through 1996, with a projected growth of 7.3% from 1996 through 2001. Actual annual growth of total rail tonnage from 1985 through 1996 was 0.9%, with a projected growth of 1.4% from 1996 through 2001. Intermodal shipments were 4.8% of total rail tonnage in 1985 and are now projected to be 9.1% in 2001 [1]. The projected growth rate for rail car miles in the U.S. is 2.2% to the year 2000, and for intermodal car miles it is 5.5% [2].

Canadian vehicle weight and dimension limits allow any container up to 16.2 m (53 ft) long, 2.6 m (8 ft 6 in) wide and 2.9 m (9 ft 6 in) high, with a weight rating up to 30.48 t (67,200 lb) to be carried on the highway. Canada is the only country in the world where this is possible [6]. These parameters cover the full size and weight capacity of all international (ISO) and most domestic containers. Some 14.65 m (48 ft) domestic containers with a weight rating higher than 30.48 t (67,200 lb) can also be accommodated on the highway in central Canada. The U.S. federal weight limits restrict road transportation of 6.1 m (20 ft) ISO containers rated over 20 t (44,000 lb), and 12.2 m (40 ft) ISO containers, when the container is loaded to its weight rating. Most other countries have length limits, and many cannot even accommodate containers longer than 6.1 m (20 ft) on their roads. Canada thus provides unrivalled opportunity for growth in containerised inter-modal transportation.

3. Description of Research Needs

3.1 Vehicle Weights and Dimensions

The issues in this section are the mandate of the Task Force on Vehicle Weights and Dimensions Policy. In most cases, they do not involve a large element of technical research, but still involve work which needs to be addressed. In general, these are long-term issues, and their resolution will stretch well beyond the current mandate of the Task Force. It should be noted that the Task Force does not completely control its own schedule. It depends on the provinces giving timely responses to Task Force proposals. Recently, Ontario has been unable to take a position on a number of issues. This may have slowed progress at the national level, but it has allowed work to proceed in the eastern and western regions that could well later receive quick acceptance at the national level. The present process is working well.

a) Impacts of Changes to U.S. Federal Size and Weight Regulations

The largest and most far-reaching impact on Canada tracking happens if, and when, the U.S. makes changes to its truck size and weight regulations. Canada is currently providing leadership in development of a policy framework through participation of the Task Force on Vehicle Weights and Dimensions Policy in the NAFTA process [5]. Ideally, the ultimate outcome would be the same regulations coming into effect on the same day in all three countries. However, decisions will be made through the U.S. political process, which makes the outcome difficult to predict. Canada needs to understand the implications of potential U.S. policy changes on Canadian industry, so that it has the insight and data to argue for decisions that may be more favourable to Canada.

b) Understand Industry Needs

Industry is quite specialised, and very nimble. Governments tend to have little understanding of industry needs, and industry often has difficulty finding or articulating a consistent position because the needs of different companies or sectors may not only be misaligned, but also contradictory. If governments, through focussed studies, would understand better the needs and forces driving various sectors of industry, better policy decisions could be made. This applies both to the highway carriers that operate in a similar manner in all provinces, and to specialised service sectors that are now beginning to get attention by the Task Force to harmonise their situations on a regional basis.

c) A Sound Technical Basis for Spring Thaw Period Weight Reductions

All provinces have spring thaw period rules. However, Quebec has a unique set of rules for the spring thaw period, which create some hardship for the Atlantic Provinces, as their route to Ontario is through Quebec. Quebec is currently reviewing these rules (which impose axle weight restrictions even on freeways), at the request of industry. If Quebec would consider to bring its rules more in line with those of other provinces, a study could set a common and sound technical basis for thaw period rules, based on truck loads, pavement structure, and weather conditions. The study might also identify enforcement strategies.

The pressure to increase axle weights during the spring thaw period can have a serious impact on pavement maintenance costs. On the other hand, spring load restrictions have a serious impact on the ability of a number of sectors to conduct their business during the spring. Consequently, the regulations should be set on a sound technical basis that can be applied uniformly across the country. The existence of uniform rational regulations will also help the municipal sector in provinces where significant amounts of roadway have recently been devolved to municipalities.

3.2 Harmonization of Regulations and Standards

There have been many initiatives to harmonise regulations, principally the numerous operating regulations. Most such initiatives have probably ended up with regulations that are actually more complex than before, because they have to recognise the new requirements, some local exceptions to those, and perhaps continue to allow some old or grandfathered requirements. However, to the extent that the new regulation does increase common content between provinces, the outcome may actually simplify compliance for many carriers even though the regulation itself has become more complex.

The various phases of the M.o.U. have not been implemented uniformly. Work is underway in the Task Force on Vehicle Weights and Dimensions Policy to achieve a higher level of uniformity in regulations, in standard special permits, and in enforcement policies. The objective should be WYSIWYG, "what you see (in the regulations) is what you get". This is a very challenging task, and will stretch far beyond the present mandate of the Task Force. Some of the issues are being explored and tested, such as by the ongoing work of the Task Force on Vehicle Weights and Dimensions Policy, and the goal of a North America-wide uniform standard for cargo securement being jointly pursued by CCMTA and FHWA.

Uniform regulations adopted by reference from a central source will simplify design, operation, compliance and enforcement. These uniform regulations would apply where there is the desire for uniformity. All provinces will need to keep other regulations, policies and procedures for other vehicles.

A Mechanism for Harmonisation of Regulations

An effective process for provinces and territories to develop, adopt, enforce and maintain harmonised regulations or standards needs to be developed. It is clear that the existing process consumes a lot of effort and does not achieve the desired result of achieving uniformity in regulations.

Harmonised regulations accrue benefits to jurisdictions. Jurisdictions would only need to repeal the existing regulation and write a one-line statement to adopt harmonised regulations. There would be no need for each jurisdiction to transform the agreement into its own legal language, structure, and format for implementation. The benefits accrue to industry by ensuring that compliance in one jurisdiction ensures compliance in others. Also, the more uniform regulations become, the less likelihood there is of incidental non-compliance.

3.3 Inter-Modal Issues

The service efficiency and reliability of the rail part of inter-modal goods transportation is a concern to users and potential users of these modes. Service is governed by a combination of factors arising from traffic volume, train scheduling, and trailer or container handling and processing at terminals. It is clear that the time taken to assemble the cargo, load the train, unload the train, and disperse the cargo is a severe problem. Other issues include computerised cargo tracking, standardised manifest, co-ordination of schedules, and electronic data exchange.

Consequently, inter-modal service generally requires significant freight volume over a relatively long distance, maybe 1,000 kilometres or more. However, there are other more modest market niches, some short line railroads are beginning to develop inter-modal traffic, and new specialised technologies like EcoRail (C.N.) and IronHighway (C.P) look promising.

In Canada's de-regulated transportation environment, any particular trailer or container moves by the mode that provides the required level of service or price. However, all jurisdictions support the concept that trailers and containers should preferably travel by rail where the principal part of the trip could be conducted by that mode. The concern of highway departments is that diminished level of inter-modal service will gradually result in transfer of short moves, up to 1000 km, onto the highway. However, while the highway jurisdictions have a clear interest in the outcome, the particular problems are entirely within the purview of the service operators. Governments could assist with projects that meet specific public interest criteria, such as facilitating development of small intermodal terminals or trans-shipment yards, to relieve some of the pressure on roads and the environment. There are some enlightening examples of this from the U.S., at both federal and state levels. It is not clear if there is, or should be, an additional role for governments that is not already met by the operators' own need to be competitive in a de-regulated environment.

Intermodal transportation planning is an evolving discipline, and its implementation is facing many jurisdictional barriers because of the diversity of stakeholders. Specific research opportunities in this area are limited. As a starting point, we should be developing intermodal mobility and safety indices, and other intermodal performance measures to facilitate intermodal transportation planning.

The one area where there is a public interface is the road access to intermodal facilities. Many are municipal roads that may not have been designed for the kind of traffic they are now carrying, or need to carry. Improvement of access roads is generally a municipal planning issue. However, it is clearly secondary to the issues in the terminals.

Viable Competitive Short-haul Inter-modal Service

Inter-modal service has been increasing faster than either rail or trucking. However, freight flows through the terminals seem to make it difficult to be competitive for shorter hauls, maybe less than 1,000 km. If short-haul inter-modal operations diminish or cease, the freight ends up on the highway. Continued growth of a viable competitive short-haul inter-modal service tempers the growth of truck traffic, and keeps costs down for shippers.

4. Descriptions of Research Projects

a) Impacts of Changes to U.S. Federal Size and Weight Regulations

Problem Description: Any changes in weights and dimensions by the U.S. will affect Canada-U.S. trade. There may be positive effects, as an increase in weights will allow greater economic radius into the U.S. for

	Canadian products that compete with offshore products. There may be negative effects where Canadian products compete with U.S. domestic products. These issues need to be understood.
Proposed Solution:	Commission a study or studies by consultants, with the participation of interested stakeholders, to examine the impacts of possible U.S. weight and dimension scenarios on Canada.
Expected Benefits:	This work seems necessary to provide background for Canada to develop positions regarding possible changes that the U.S. would make to its weight and dimension regulations.
Partnership Opportunities:	While the outcomes may critically affect much of Canadian industry, it is primarily a responsibility of the federal government to be developing this kind of information to support its own negotiating position.
Resources Required:	Estimated $150,000 - $250,000.

b) Understand Industry Needs

Problem Description:	There are various sectors that are subject to different regulations in different provinces. If regulations are to be harmonised for a sector, the best solution may not be a simple compromise between the current rules. If a solution is to be found that allows the sector to grow and prosper, it may require some understanding of the particular needs and operating conditions of that sector and its clients.
Proposed Solution:	Commission studies by consultants, with the participation of interested stakeholders, to examine the impacts of possible weight and dimension scenarios on the subject sector.
Expected Benefits:	This work should allow policy development that fosters opportunities for the sector and results in productivity advantages.
Partnership Opportunities:	There is clear potential for the sector being considered to play a significant role in the study.
Resources Required:	Estimated $20,000 - $30,000 per study.

c) *A Sound Technical Basis for Spring Thaw Period Weight Reductions*

Problem Description:	Quebec's spring thaw period weight restrictions are a barrier for traffic between the Atlantic provinces and Ontario. If Quebec would consider changes, a consistent rational methodology for setting thaw period weight restrictions should be developed.
Proposed Solution:	Commission a study by consultants.
Expected Benefits:	Increased industry productivity and reduction of pavement damage during the spring thaw period.
Partnership Opportunities:	This is primarily an interest of the provinces, though it should also be of interest to the industry and to municipalities.
Resources Required:	Estimated $150,000 - $250,000.

d) *A Mechanism for Harmonisation of Regulations*

Problem Description:	There is no rational methodology available to provinces to make and adopt common regulations and standards.
Proposed Solution:	Commission a study by consultants, with the participation of the provinces and territories. The objective would be to develop a process that jurisdictions could follow to develop or adopt new regulations or standards. The study should also define the requirements and format for the regulations or standards to ensure their Canada-wide acceptance.
Expected Benefits:	This work should identify the means and process that will allow provinces to achieve identical regulations and standards.
Partnership Opportunities:	The project relates to internal government processes, and would not likely be amenable to outside partnership.
Resources Required:	Estimated $150,000 - $250,000.

e) *Viable Competitive Short-haul Inter-modal Service*

Problem Description:	Current inter-modal traffic is primarily medium and long distance, which provides limited markets as most freight moves involve a relatively short distance. As the economic range of inter-modal transportation is reduced, the potential market size increases.

Proposed Solution: Commission a study by consultants, with the participation of interested stakeholders, to examine the factors that inhibit expansion of inter-modal service, and identify the barriers that need to be addressed.

Expected Benefits: This work could identify some of the barriers and issues to continued expansion of inter-modal freight transportation.

Partnership Opportunities: Railway, trucking and possibly some shipper associations could potentially be partners in such a study.

Resources Required: Estimated $150,000 - $250,000.

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E/ PAVEMENT TECHNOLOGY

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1. Introduction

The Canadian territory is covered by nearly 840,000 km of roads. Only about 37% of these roads are paved, and a very small proportion of these roads is subjected to intense traffic loading conditions. Most of them are, however, subjected to very harsh climatic conditions. Canadian roads are the product of many decades of development, and are managed by private, municipal, and provincial administrations.

Canadian roads provide essential transportation links connecting people, resources and markets. At the national scale, they represent an asset with a current value of about $75 billion and they require annual maintenance and rehabilitation expenditures of about $12 billion. Problems affecting major arterial highways, representing a very small proportion of the Canadian road network (but serving a significant proportion of the users), have traditionally attracted most of the research attention to the detriment of lower volume roads [1]. Consequently, despite the availability of advanced pavement management technology (including design, construction, rehabilitation and maintenance), the current pavement management practice for low volume roads is still essentially based on local experience.

The majority of the existing Canadian roads were built between 1950 and 1980. The following decades have been dominated by a need to rationalise administration of public assets. During that period, investments into new roads have significantly decreased. The primary concern has been to maintain the existing infrastructure. Many existing pavements have reached or surpassed their expected design life-spans. The cost of maintenance and rehabilitation is therefore likely to increase, and the need for more durable solutions to pavement deterioration is becoming urgent.

The challenge of the next decade is to effectively maintain the level of quality of the existing highway infrastructure through better decision making processes, more durable materials, optimised pavement structures, and through constant focus on material recycling, sustainable development, and innovation.

2. Trends and Issues

2.1 Trends

In the 80s, North-American highway administrators realised that they were facing a major problem of the ageing highway infrastructure. A major research initiative, called Strategic Highway Research Program (SHRP), and its Canadian parallel, Canadian SHRP (C-SHRP), were launched in 1986. The objective was to develop more durable and longer lasting pavements through improved pavement materials and pavement design technologies. These programs have resulted in several pavement technological products that need to be implemented in the Canadian context.

The need to improve the effectiveness of highway investments is resulting in the emergence of another major trend with an important impact on pavement technology: the transfer of the responsibilities associated with pavement construction and maintenance to the private sector.

The transfer is accomplished through performance-based specifications, warranties, design-build and design-build-operate contracts, and through direct privatization of highway infrastructure. The onus is on the private industry to develop and implement cost-effective pavement technologies, and gain a better understanding of the factors affecting pavement performance. Privatization also leads to the development and the standardisation of pavement performance evaluation technology and criteria accepted by all partners.

Environmental considerations combined with the need for low cost pavement materials are still driving the need for recycling of pavement materials, and industrial and household by-products, for pavement construction. Recycled asphaltic and Portland cement concrete and granular materials, scrap tires, roof shingles, glass, steel slag, and other materials, have extensively been used in pavement construction in the last decade. Lessons have been learned during these years and recycling technologies have been documented and improved. The use of other types of recycled materials should be considered in the future.

Pavement management systems have been evolving rapidly over the last decade [2]. Improvements in pavement condition evaluation technologies, traffic load estimates, computer technology and analysis software have among others, contributed to the ongoing development of pavement management technologies. Pavement management systems have a high potential to improve the effectiveness of highway investments by making the decision-making processes more rational.

Most of these developments have addressed the needs of large road jurisdictions. Developments are still required to improve the effectiveness of these technologies and to adapt them to the needs of local road administrations.

2.1 Issues

Pavement technology issues, identified through an extensive consultative process, were categorized as follows:

- pavement preservation decisions,
- durable pavement materials, and
- optimisation of pavement structures for new and rehabilitated pavements.

2.1.1 Pavement Preservation Decisions

Until recently, decisions on how and when to rehabilitate pavements were essentially based on expert judgement. The rapid emergence of pavement management technologies and systems has contributed to making the decision-making processes more efficient, objective, and rational. These systems and technologies have evolved rapidly but unevenly over the past few years. A few key technologies have still not reached industry expectations and are restricting the potential of modern pavement management tools. The following key issues and opportunities, grouped in three sub-categories, have been identified.

a) Pavement data

<u>(Issue A-1) Automation of data acquisition</u>
Important improvements have been made in recent years to data collection technologies supporting Pavement Management Systems (PMS). High-speed profilometers are replacing unstable response-type roughness measuring devices. Affordable technologies to measure objectively surface distress, pavement structure characteristics, and traffic loads are emerging. The measurement of pavement surface distresses and the characterisation of traffic loads are two critical pavement management data for which the measurement technologies have not yet reached a satisfying level of accuracy and reliability. Moreover, the cost of these technologies makes them unattainable for smaller road administrations. These technologies are the weak link of modern pavement management systems. Their development (to make them accurate, reliable and affordable) through co-operative research projects is highly desirable. These projects also offer interesting opportunities for partnerships between highway administrations, research centres, and the industry.

<u>(Issue A-2) Standardisation of data collection methods and performance indices</u>
One of major benefits of the SHRP and C-SHRP was the establishment of common definitions, procedures, and methodologies for collection and analysis of pavement condition data. This standardisation proved to be useful for participating agencies in providing them with a reference for the assessment of the condition and the performance of their pavement networks. Some provinces have adapted SHRP and C-SHRP pavement monitoring procedures. Adoption of a national standard for pavement performance monitoring, and the development of widely accepted pavement performance indices would greatly facilitate communications and exchange of information between different jurisdictions.

b) Pavement Management

<u>(Issue A-3) Pavement performance models for Canadian conditions</u>
Pavement deterioration models are required to support the selection of optimal strategies for pavement management. They are also required to support life cycle cost analysis of different alternatives when designing new or rehabilitated pavements. The development of distress specific models for pavements is one of the main objectives of SHRP and C-SHRP studies. The application of the models expected from SHRP-LTPP will require proper adaptation and calibration to Canadian conditions; i.e., lower traffic volumes and more aggressive climatic conditions. C-SHRP models should be well suited for our environmental conditions, but are applicable to one pavement type only (asphaltic concrete overlay of an existing asphaltic concrete pavement). Further development, validation, and calibration of these models will be critical to their successful implementation.

<u>(Issue A-4) National feedback system for new pavement technologies</u>
Most agencies are developing new standards and introducing new technologies based on the experience gained through demonstration projects. Since very few of these experiments end up being published, considerable effort and resources are spent by different agencies duplicating R&D work. The Quebec Ministry of Transportation has recently developed its own pavement monitoring program based on SHRP and C-SHRP monitoring procedures and standards. The

goal of the program is to systematically document and analyse the results of pavement demonstration projects, and to assess their performance cost-effectively. The benefits of a central monitoring and information system (e.g., on Internet) on Canadian demonstration projects would be considerable, and the system would facilitate the assessment of performance and cost effectiveness of innovative pavement maintenance and rehabilitation treatments.

(Issue A-5) Pavement management for low volume roads
Available pavement management tools are usually unsuitable for low-volume roads. Low volume roads often require specific condition rating procedures, deterioration modes, and pavement preservation treatments which differ from those used for arterial highways. Financial and technical resources available to collect, store, and analyse performance data for these roads are generally limited. Decisions are therefore often based on the judgement of local authorities. The development of low-cost technologies, procedures, and standards for the management of low-volume roads is required to increase the effectiveness of investment and design strategies for low-volume roads.

c) Construction/maintenance

(Issue A-6) Decision-making tools for rehabilitation and maintenance treatments
Maintenance and rehabilitation is becoming the dominant pavement activity of most highway agencies in Canada. These activities are often decentralised and managed by pavement engineers with various backgrounds and levels of experience. Decision making tools such as decision trees or expert systems would considerably improve the consistency of decisions made by local managers. It would also help to train new engineers and facilitate communication between central and regional offices.

(Issue A-7) Performance warranties and design-build contracts
Performance warranties, design-build contracts, and other new types of contractual arrangements are rapidly spreading across North America. With these new arrangements, the burden of the risk associated with the design and construction of pavements is partially or entirely shifted from the owner to the contractor. New contractual approaches require a thorough understanding of pavement deterioration mechanisms, a good control over the design and construction factors, clear definitions and criteria of pavement performance, and accurate and reliable technologies to measure pavement condition. Experiences in different countries have shown that these approaches could lead to substantial savings in road construction. However, in the absence of adequate tools to manage the risk, they also could result in increased life-cycle costs. The tools required for the successful implementation of these contracts include performance models and criteria with linkage to material characteristics, the understanding of the influence of design factors, and performance standards. There is also concern over the lack of financial services providing bonding to contractors making the attainment of long-term warranties often unrealistic.

(Issue A-8) Integration of pavement design and construction activities
The growing trend for design-build contracts in highway construction is bringing to the fore the importance of integrated pavement engineering activities in the construction of high quality pavements. These new contractual arrangements require the development of management tools integrating all aspects of pavement construction.

2.1.2 Durable Pavement Materials

Increased traffic loads and the rapid deterioration and ageing of materials used in pavement construction in the 60s and the 70s have brought to the fore the need to develop more resistant and durable pavement materials. Recent developments in engineered asphalts, SUPERPAVE binder and mix specifications, and high performance concrete have helped to resolve several pavement performance problems. Improvements are still needed in many aspects of material performance in the Canadian context. The growing preoccupation with environmental considerations and sustainable development during the last decade has forced the rapid development of technologies and procedures for recycling pavement and other materials in road construction. Research is still needed to refine the existing recycling processes and to develop new ones. The key issues and opportunities in this area are discussed in the following.

(Issue B-1) Development of surfacing materials resistant to reflective cracking
Asphaltic concrete (AC) has been substantially improved over the last two decades. The increasing use of polymers, fibers and engineered asphalts, combined with recent developments in mix design procedures and technologies, have contributed to reducing several performance problems affecting AC. The results are noticeable and, among other problems, rutting of AC has been significantly reduced. Other problems, such as reflective cracking, remain. An AC overlay of an existing AC pavement is now the most widespread pavement rehabilitation treatment in Canada, and reflective cracking has become the most prominent problem on AC-surfaced roads. The development of new tools is required to help control the factors affecting the propensity of AC overlays to develop reflective cracking.

(Issue B-2) Performance-based specifications for pavement materials
Effective quality control of pavement performance for warranty-based contracts, or simply for the production of long lasting pavements, requires knowledge and quality control of pavement design and material characteristics affecting long term pavement performance. In response to this need, an important research program was recently undertaken under SHRP auspices to reinvent mix design technologies for AC based on performance specifications. Similar efforts need to be made for other pavement materials and more specifically for base course materials. The objective is to link pavement material specifications with well-defined performance criteria.

(Issue B-3) Use of recycled by-products in highway construction
Social and political pressures to recycle pavement and other materials in road construction continue to be strong. A decade of experience in recycling scrap tires, asphaltic and concrete pavements, roof shingles, glass, and other household and industrial by-product materials has demonstrated that proper use of by-products in pavement construction can result in durable and economical pavements. The potential of other types of recycled materials, such as polystyrenes, plastics, and wood residues, should be investigated.

2.1.3 Optimization of Pavement Structures for New and Rehabilitated Pavements

(Issue C-1) Design procedures for new and rehabilitated pavements
Major developments led by TRB-NCHRP (AASHTO 2002), SHRP and C-SHRP are currently underway. These developments will eventually produce improved technologies for the design of new and rehabilitated pavements based on mechanistic principles and distress-specific empirical transfer functions calibrated to local conditions. It is expected that significant improvements will result from the developments made by the major ongoing research endeavours mentioned above. Important efforts will, however, be required in order to adapt and calibrate research results to Canadian conditions.

(Issue C-2) Variability of pavement design factors
The AASHTO and the OPAC 2000 design methods have incorporated the concept of reliability in pavement design. This concept, based on the quantification of the variability of significant design factors, is likely to be incorporated in other design methods in the future. Unfortunately, the information on the variability of design factors, as measured or estimated in Canadian pavement design practice, is almost non-existent.

(Issue C-3) Design procedures for pavements in frost conditions
In Canada, frost action is considered to be a major cause of pavement deterioration and yet, very little efforts are made to improve our prediction and design tools, which are still essentially based on empirical models. A few initiatives have recently been made to develop mechanistic-empirical models to predict frost effects on pavement performance [3,4]. Further development of these models, and their introduction into mechanistic-empirical design procedures, is required.

(Issue C-4) Policies and procedures for spring load restrictions
Bearing capacity loss during spring thaw period has long been recognised as a major pavement deterioration factor in pavement deterioration. Most Canadian highway agencies use springtime load restriction to mitigate the detrimental effect of heavy vehicles during spring. However, procedures and criteria to establish the beginning, the duration, and the magnitude of the restrictions vary considerably from one agency to the other. The development and promotion of a standard approach to spring load restrictions would greatly benefit both the highway agencies and the transportation industry.

3. Projects and Activities

Table 1 lists the projects formulated in response to the trends, opportunities, and needs identified above. The table also provides the name of the issue addressed by the project, and project priorities (Low, Medium or High). The project priorities were established using the procedure outlined in Chapter A, Section 4.1 and by considering the following specific criteria.

- They address universal needs of Canadian highway agencies;
- They address specific Canadian needs;
- They contribute to the exchange of information and co-operation among jurisdictions;
- They help meet the primary transportation objectives of mobility, efficiency and safety.

Table 1: Summary of proposed research projects in the pavement technology area

Project Number	Project category/title	Issue addressed	Priority
	Pavement preservation decisions		
P-1.1	Development of data collection procedures and pavement management tools for low volume roads.	A-3 and A-5	M
P-1.2	Standardisation of data collection methods and development of functional and structural performance indices for pavement management.	A-2	M
P-1.3	Calibration of SHRP performance models for pavements in Canadian conditions.	A-3 and A-7	H
P-1.4	Development of a national feedback system for experiments of new and existing pavement technologies.	A-4	M
P-1.5	Development of decision making tools for the selection of rehabilitation and maintenance treatments.	A-6	H
P-1.6	Development of tools to manage the risk in warranty-based contracts.	A-7, A-8	H
	Pavement materials		
P-2.1	Development of surfacing materials resistant to reflective cracking.	B-1	H
P-2.3	Development of performance based specifications for pavement materials (other than asphalt concrete).	B-1, B-2 and B-3	M
	Optimisation of pavement structure for new and rehabilitated pavements		
P-3.1	Development of mechanistically based design procedures for pavements in frost conditions.	C-1 and C-3	H
P-3.2	Assessment of the variability of pavement design factors.	C-1 and C-2	M
P-3.3	Development of policies and procedures for uniform spring load restrictions	C-4	H

4. Description of R&D projects

The six high priority R&D projects listed in Table 1are described in the following.

P-1.3: Calibration Of SHRP Performance Models for Pavements in Canadian Conditions.

Problem Description: SHRP and C-SHRP pavement studies will produce several performance models for different types of pavements in various exploitation conditions. It will be possible to incorporate these models into Canadian practice only if they are properly validated and adapted to our specific conditions.

Proposed Solution: Use a subset of SHRP-LTPP database (test sections exposed to northern conditions) to calibrate SHRP performance models and to use an independent data set (C-LTPP or other Canadian database) to validate the calibrated models for Canadian conditions.

Expected Benefits: This work is essential to provide a foundation for the development of mechanistic-empirical design procedures and to support modern pavement management tools.

Partnership Opportunities: This work will greatly benefit from co-operation between highway agencies, consultants, laboratories and universities.

Resources required: Estimated cost: $100,000-$150,000

P-1.5: Development of Decision Making Tools for the Selection of Rehabilitation and Maintenance Treatments

Problem Description: Maintenance and rehabilitation activities are often decentralised and managed by pavement engineers with various backgrounds and levels of experience. Decision making tools are required to improve the quality and consistency of decisions made by local managers.

Proposed Solution: It is expected that C-LTPP will produce performance models that will help to assess the cost effectiveness of different overlay strategies. It is proposed to expand these models to include other rehabilitation and maintenance strategies such as in-place hot and cold recycling, and pulverizing. The study should develop a user-friendly decision support tools, a strategy selection model, and a cost effectiveness analysis model.

Expected Benefits: This project is essential to improve the cost-effectiveness of pavement preservation decision on provincial and local levels.

Partnership Opportunities: This work will greatly benefit from co-operation between the highway agencies, consultants, laboratories and universities.

Resources Required: Estimated at $200,000-$300,000

P-1.6: Development of Tools to Manage Risks in Warranty-Based Contracts.

Problem Description: Emerging new contracting approaches require reliable information on the financial and the technical risks shared by the road administrations, contractors, and bonding companies, including

	thorough understanding of pavement deterioration mechanisms, clear definitions and criteria of pavement performance, and accurate and reliable technologies to measure pavement condition.
Proposed Solution:	Development of models linking site specific conditions, design and construction factors to pavement performance. SHRP-LTPP, C-LTPP and MnRoad data can be used as primary source of information to develop performance models that would then be packaged into a risk analysis model.
Expected Benefits:	Experience has shown that new contracting approaches could lead to substantial savings in road construction and maintenance, provided that the risks are properly managed.
Partnership Opportunities:	This project offers an excellent opportunity for co-operation between highway agencies, consultants, laboratories and contractors.
Resources Required:	Estimated at $200,000-$250,000

P-2.1: Development of Surfacing Materials Resistant to Reflective Cracking.

Problem Description:	Reflective cracking has become one of the most widespread performance problems of AC-surfaced roads in Canada. These cracks are the result of mechanical and thermal stresses induced in asphalt overlays in the vicinity of existing cracks in the old pavement surface.
Proposed Solution:	It is proposed to review existing knowledge and to assemble a set of practical guidelines to help pavement engineers select cost-effective solutions to reflective cracking problems. SHRP and C-SHRP long-term pavement performance programs can be used as a primary source of information for the assessment of the effectiveness of different mitigation strategies.
Expected Benefits:	This work is likely to produce a practical tool for pavement engineers, which would yield significant improvements in overlay performance.
Partnership opportunities:	The research project will greatly benefit from co-operation between highway agencies, consultants, laboratories and universities.
Resources required:	Estimated at $100,000-$150,000

P-3.1: Development of Mechanistically Based Design Procedures for Pavements in Frost Conditions

Problem Description: Refinements of existing Canadian pavement design procedures are required to maximise pavement performance in a Canadian context. Significant effort will be required in order to adapt and calibrate SHRP and C-SHRP models to severe climatic and low volume road conditions.

Proposed Solution: It is proposed to monitor closely the developments of the AASHTO 2002 initiative and to develop a Canadian version of a similar mechanistic-empirical procedure using performance models adapted to Canadian conditions.

Expected Benefits: A sound mechanistic-empirical design procedure based on reliable performance models is likely to yield important improvements in pavement life-cycle costs.

Partnership Opportunities: This work would benefit from co-operation between highway agencies, consultants and universities.

Resources Required: Estimated at $150,000 - $200,000

P-3.3: Development of Policies and Procedures for Uniform Spring Load Restrictions

Problem Description: Procedures and criteria to establish the beginning, the duration, and the magnitude of the restrictions vary considerably from one agency to the other. The development and promotion of a standard approach to spring load restrictions would greatly benefit the Canadian transportation industry.

Proposed Solution: It is proposed to use the existing state of knowledge on the effects of spring thaw on pavement deterioration and the state of practice in spring load restrictions in order to develop a proposed uniform procedure for the establishment of load restrictions. The procedure would then be submitted to a national council for potential inclusion in a national policy.

Expected Benefits: The transportation industry would benefit from uniform regulations. Highway agencies would benefit from the adoption of common procedures and policies on spring load restrictions.

Partnership Opportunities: The study would also benefit from the co-operation between highway agencies, consultants, and universities.

Resources Required: Estimated at $100,000-$150,000

5. References

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2. Transportation Association of Canada, 1997, Pavement design and management guide
3. OCDE, 1988, Heavy trucks, climate and pavement damage, Road transport research, Paris
4. Doré G., Développement d'une nouvelle approche de conception des chaussées en conditions de gel, Proceedings of the session on frost effects on road pavements, World summit on Nordicity, Quebec, Québec, Canada

F/ STRUCTURES

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1. Introduction

Bridge structures are a critical part of the Canadian highway transportation system. While bridges may represent only about ten per cent of the highway system replacement value, their importance to operational safety and transportation efficiency is greater. Bridge closures cause severe bottlenecks and delays to traffic, and sometimes loss of life.

The exact number of Canadian bridges and their value is unknown but is estimated to consist of roughly 80,000 crossings with a replacement value of $35 billion. The lack of precise inventory data is an example of the present bridge management problems, which include inconsistent bridge definitions, and incomplete reporting by some jurisdictions. The much larger US system has many similar problems as our bridge system, thereby creating opportunities for partnering and sharing of research. Being the populous country with less R & D resources, Canada has often benefited from this situation.

Most of the existing Canadian bridges were designed for a service life of 50 years, whereas new bridges are now generally being designed for a 75-year service life. This lengthy design life-span requires a special mind-set of long-term thinking for bridge planners and management personnel.

As described in Chapter A, the existing Canadian bridge inventory is old. About 50% of existing Canadian bridges were constructed between the great expansion period of the middle 1950's to the late 1960's. These structures are now between 30 to 45 years old, near the ends of their service lives. A large number of Canadian bridges will require replacement between years 2005 and 2020. This will create the need for an increase in the annual bridge replacement budget of about 50% during this 15-year time period.

Another important budget factor is that the large amount of the inventory constructed during the 1950's and 60's were not designed to withstand the deterioration caused by de-icing salts. Bare pavement policies did not become standard practice until the 1960's and, overall, bridge durability design standards did not catch up for about 15 years. Canada's cold northern climate increases the durability problems in comparison to milder climates. As a result, bridge deterioration and rehabilitation continue to be major problems. The older bridges on heavily travelled roads generally need major rehabilitation about every 20 to 25 years.

The primary construction material of Canadian bridges is concrete. Since the late 1940's, most decks have been constructed of concrete regardless of whether the girders were concrete or steel. Steel is the second most used bridge structural material. Steel is used for girders and superstructures on the long span bridges that have the highest replacement values in the inventory. On the local road system where deterioration rates are less due to lower traffic and less de-icing salt applications, there are numerous short span bridges made of timber or precast concrete, as well as of corrugated steel.

2. Overview of Trends

a) Traffic Growth

Many current bridge problems are related to population and urban growth. Continued population growth will increase the average annual daily traffic on the primary road arteries. This will increase the number of load cycles on bridge structures, thereby increasing their rates of aging and deterioration. Increased amounts of chlorides and other de-icing chemicals are being used to increase speed limits and improve safety. This is also resulting in higher rates of bridge deterioration and shorter service lives. Increased road congestion reduces public acceptance and patience with construction and repair delays. Repairs will have to be done faster and more often. Repair costs will increase.

b) Economic Trends

Increasing public debt, the ageing population and globalization are the driving forces as bridge management functions are increasingly privatized and as competition for funding. Expected results include greater diversity in bridge design. The need to compete in a global market will see the pressure to increase the size and legal loads of trucks and increase maximum allowable speeds, both of which will increase the rate of bridge deterioration. Despite greater complexity and increased construction and repair costs, publicly funded construction and maintenance budgets are likely to decrease.

c) Environmental Trends

Environmental constraints will likely continue to increase the scope, complexity and costs of bridge construction and rehabilitation. Examples include increased containment requirements for removal of lead-based paint from steel structures, spoil material disposal, and construction of bridges without interference to fish or stream habitats. New bridges must meet stricter environmental standards than in the past, resulting in delays, as well as increased engineering, construction and repair costs.

d) Technological Trends

The complexity of bridge design is increasing as new materials and methods are introduced to the market. Epoxy coated rebar, carbon fibre, silica fume, corrosion inhibitors, stainless steel rebar, chloride extraction and re-alkalization, high strength and high performance concrete, bridge management software, performance based specifications, and design-build contracts, are all examples of new products, materials, or tools coming into routine usage. This complexity will create the need for more specialists, as well as better education and technology transfer. Only by successful application of the new technology will costs be reduced.

2. Opportunities, Issues and Needs

a) Lack of bridge management know-how

The lack of quantitative bridge condition data inhibits decision-making and planning. Condition information is necessary for development of service life prediction models and prediction of deterioration rates of different materials in different geographical, climatic, and exposure locations.

a) Durable Construction Materials and New Products

Increased rates of deterioration and longer design service lives create the need for more durable construction materials, such as high performance concrete. There is a lack of knowledge about the performance and service life of many new bridge construction materials in various environments, including epoxy coated reinforcing steel. Differences in climate and culture across Canada result in different types of construction, different rates of deterioration, and different types of deterioration problems. An example is AAR, which is more prevalent in the east.

Many new products have recently appeared on the market. New technologies, such as chloride removal, need to be field tested to determine their service lives and the circumstances where they will be most cost effective.

b) Increasing Allowable Vehicle Weights and Dimensions

Increased load limits will create the need to strengthen existing bridges, many of which will be deficient in shear capacity. Higher speed limits and reduced public patience with repairs creates the need for faster, durable, less expensive repair methods and materials.

c) Ageing Bridge Infrastructure

Canada’s ageing bridge population is in need of more cost-effective management tools. Replacement costs for bridges are always much higher than for initial construction. Both replacement and rehabilitation needs will increase during the next twenty years. Significant financial commitments will be required.

A major challenge today is addressing the large number of bridges that will soon need replacement or rehabilitation to extend their useful service life. This comes at a time when government debt is forcing cuts to highway funding. New methods of service delivery are needed

e) Limited funding

Funds will be limited. Funds for research and maintenance have recently decreased and are now severely limited. Funds for maintenance, repair, and replacement of existing bridge inventory are limited.

The communication of financial requirements for bridge construction and maintenance to the authorities responsible for budgets needs to be improved. The ability to demonstrate consequences of budget decisions need to be addressed. Better methods are needed to establish priorities to allocate resources to the best possible advantage, as well as the means to improve serviceability and life-spans of the existing bridge system.

f) New Service Delivery Mechanisms

The frequency of design-build projects will likely increase. Field test methods are needed to measure durability-related concrete properties, such as air entraining and scaling resistance, for use in performance based specifications. More accurate accelerated laboratory test methods are needed to simulate aggressive exposure conditions. Service life prediction methods for various structure types, rehabilitation techniques and methods, etc. need to be improved.

f) Technology Transfer

Research findings from the Strategic Highway Research Program and the Canadian Strategic Highway Programs have not yet reached the working level where these findings can be fully utilized. More technology transfer would speed up the process.

The United States has many similar bridge management problems to Canada. Opportunities to work with the US should be further explored. Organizations such as Concrete Canada, Canmet, American Concrete Institute, and ISIS have been active in developing and disseminating knowledge and technology, particularly information related to durability, repair, and bridge management. Opportunities to joint technology transfer ventures with these organizations should be explored.

On-going privatization of bridge operations is providing new avenues for private-public cooperation. TAC, with membership in both sectors, is in an excellent position to nurture and promote joint efforts for research and development, standards, etc.

4. Recommended Projects

A number of R&D projects were identified in response to the trends, opportunities and needs discussed above, and through a consultative process involving many stakeholders. The projects are listed in the following together with their priority ratings (H = High, M = Medium and L = Low) assigned according to the methodology described in Chapter A, Section 4.1.

1. Repair and Mitigation of Corrosion Damaged Bridges H
2. Strategies for Managing Ageing Bridges H
3. Lead Based Paint Removal H
4. Field Performance Evaluation of Epoxy Coated Reinforcing Steel H
5. Utilization of High Performance Concrete H

6. Development of performance based concrete construction/repair specifications M
7. Development of durability tests for in place concrete – air entraining, salt scaling durability M
8. Development of realistic salt scaling durability tests M
9. Refinement of corrosion test methods for vertical surfaces, pre-cast girder legs, pre-stressed cables, etc. M
10. Evaluation of corrosion inhibitors and guide to usage M
11. Guideline document for replacement of bridge bearings M
12. Guideline document for replacement of bridge deck joints L
13. Development of software to assist bridge designers with new design code L
14. Crack mitigation in high performance and ordinary performance concrete L
15. Methods to quantify the measurement of deterioration of Bridges L
16. High load damage repair methods to pre-stressed and steel girders L
17. Rapid setting repair methods for decks M
18. Mitigation of alkali aggregate and alkali silica reaction in concrete bridge elements L
19. Alternative de-icing materials for roads and bridges M
20. Remote monitoring systems for large bridge movements and conditions L
21. Guide to carbon fibre sheet shear and flexural strengthening of bridge girders L
22. Estimating the service lives of corrugated structural steel plate culverts L
23. Guide to chloride ion removal L
24. Guide to practical effective design-build bridge project management L

The five high-priority projects are described below.

a) Repair and Mitigation of Corrosion Damaged Bridges

Problem Description: Corrosion of embedded steel in structural elements such as reinforced decks and pre-stressed concrete girders, is causing premature failure, high rehabilitation costs, and danger to traffic safety. Safety policies and climatic conditions require the use of deicing chemicals on the nation's roads and bridges, but bridges get additional attention due to their tendency to become more slippery than the adjacent roads.

Proposed Solution: Survey the lessons learned from repair contractors and from maintenance and repair personnel of Canadian bridge owners. The costs and the field performance of various repair methods currently used in Canada and the northern United States should be investigated. Information is needed on both the cost effective and non-effective methods and materials. Topics should include new processes such as chloride removal and old ones such as cathodic protection. Other topics should include geographic and climatic conditions affecting performance of corrosion repair and mitigation, prevention of the 'halo effect' in small patches, effects of patch geometry on service life, and required test data needed to design repairs and estimate their service lives.

Expected Benefits: The project would be intended to assist contractors, owners and others involved in the maintenance of existing bridges. The development of cost effective measures for mitigating or repairing corrosion damage will result in cost-savings by extending service life and improving level of service.

Partnership Opportunities: Potential partners to highway agencies include the National Research Council, National Association of Corrosion Engineers, and International Concrete Repair Institute.

Resources Required: Estimated at $150,000 to 200,000

b) Strategies for Managing Ageing Bridges

Problem Description: A large percentage of the Canadian bridge inventory will soon be due for replacement. Bridge replacement costs will be high due to higher durability standards and increased structural capacity to provide for anticipated future needs.

Proposed Solution: Information is needed by public and private sector managers and engineers in both large and small jurisdictions on cost effective strategies for managing ageing bridges. In particular, the need is on bridges in the latter half of their service lives. Proactive policies are needed to address the questions of what to do and when is the most cost effective time to slow the rate of deterioration and extend service life. Test methods and inspection policies are needed to prioritize and identify repair sites and the proper timing to maximize the results.

Expected Benefits: Development of new strategies for managing an aging bridge system could delay replacement and extend the useful life of many bridge structures.

Partnership Opportunities: This problem is common to all highway jurisdictions, and they would all benefit from new developments.

Resources Required: Estimated at $100,000 to $150,000.

c) *Strategies for Lead Based Paint Removal*

Problem Description:	Many older large steel structures are protected from corrosion by lead based paint. Environmental and worker safety requirements for removing lead paint have recently increased the cost of such work to a level where traditional funding levels are inadequate.
Proposed Solution:	Information is needed on the effectiveness of different processes of managing existing lead painted steel. Among others, field investigations are needed on the effectiveness and service life of top-coating, partial re-painting, compatibility between lead-based and currently available low VOC paints, costs of various alternate paint removal methods, rates of steel section loss, and climatic effects on rate of corrosion. Life cycle cost analysis could be used to assess the economics of different options in different situations.
Expected Benefits:	Lower cost alternatives for removing and disposing of lead paint will reduce maintenance costs and/or extend the life of steel bridges.
Partnership Opportunities:	Bridge owners, paint manufactures and contracting industry.
Resources Required:	Estimated at $80,000 to $100,000.

d) *Field Performance Evaluation of Epoxy Coated Reinforcing Steel*

Problem Description:	Epoxy coated reinforcing (ECR) steel is designed to extend the service life of chloride-exposed structural elements. Field reports are increasing to the effect that ECR is performing poorly in wet or marine environments. Very little is known about ECR's performance in drier Canadian environments or if other variables than moisture are involved. Current field data are limited, since the performance assessment method is destructive and expensive. Because ECR is currently the material of choice for bridges, and because the effectiveness of ECR is in question, knowledge of its typical field performance is needed to prevent premature and expensive future failures.
Proposed Solution:	Field performance test data is needed to establish service life prediction models for ECR under various climatic, geographic and exposure conditions. The field tests should involve extracting cores from concrete of different ages and parts of Canada. Variables to be considered include debonding of the epoxy coating to the reinforcement, degree of visible corrosion, cover depth, concrete permeability, chloride content, exposure conditions, site

	climatic conditions, and comparison of ECR service life with that of black steel in similar conditions.
Expected Benefits:	Cost-effective selection of reinforcing materials depending on anticipated in-service conditions.
Partnership Opportunities:	Bridge owners, steel industry, and contractors.
Resources required:	Estimated at $180,000 to $240,000.

e) Practical Utilization of High Performance Concrete

Problem Description:	Lack of concrete durability limits the life of bridge elements. Recent innovations in concrete technology are resulting in significantly higher strengths and more durable concrete, called ‘high performance concrete’ HPC. The challenge in the use of HPC is that the complexity of the material has increased, and users need guidelines on how to avoid problems due to the increased number of variables in the concrete mix.
Proposed Solution:	Practical ‘hands on’ guidance for HPC for users of concrete, such as small contractors and ready mix producers. Documentation of procedures for prevention of potential problems, such as incompatibility of various admixtures. Additional training and technology transfer is needed to increase use of HPC, eliminate fear of the unknown, and also avoid expensive field problems.
Expected Benefits:	HPC improves the physical properties, which lead to less permeability, improved resistance to cracking and ultimately better durability.
Partnership Opportunities:	Bridge owners, industry and universities.
Resources Required:	Estimated at $120,000 to $200,000

G/ SAFETY AND HUMAN FACTORS

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1. Introduction

This report addresses the safety, human factors, and geometric design issues which need to be considered in the development of the National Agenda. These three areas, safety, human factors, and geometric design are defined below.

Safety

The area of safety involves the study of the relationship between accidents and conflicts (surrogates for accidents) on the one hand, and traffic control devices and highway design on the other. Safety studies deal with issues such as the following:

- the impact of highway geometrics on accident rates,
- the impact of traffic control devices on accident frequency and characteristics,
- the impact of roadside features on accident rates,
- the impact of vehicle design features on injury characteristics and rates, and
- the impact of regulatory systems on accident rates.

Highway standards are assumed to have "built-in safety". However, a close look at most standards reveals that they are predicated on little empirical safety knowledge. Safety studies help to determine which standards do have "built-in safety" and which do not and should be modified. Further, safety studies reveal the relationship between important highway design features, such as distance between interchanges, which have major effects on safety, but for which there are no clear standards.

Human Factors

Human factors deals with human physical, perceptual and cognitive limitations which affect interaction with tools, machines and workplaces. The goal of human factors is to address these limitations through engineering design which optimizes human performance, in order to improve safety and efficiency. In the highway environment, human factors deals with issues such as the following:

- the design of traffic control devices so that they are conspicuous, legible at the distance at which the driver needs to read them, and understood by the majority of drivers,
- the design of highway geometrics so that drivers expectations are not violated, and
- the design of regulations that optimize driver performance.

Roadways can be made safer by taking into account drivers' limitations.

Geometric Design

Geometric design of highways is closely related to human factors and safety. Additional considerations include:

- economic considerations to minimize construction costs,

- functional considerations to minimize operating and maintenance costs (e.g., due to snowdrifting, maintenance of the right-of-way) and user costs,
- environmental considerations related to the impact of highway construction and operation, and
- aesthetics.

2. Overview of Trends, Opportunities and Issues

This section outlines some of the major factors shaping transportation R&D in safety and human factors in Canada.

a) Self Reporting of Accidents

A number of provinces (Ontario, B.C.) have resorted to self-reporting of property damage accidents as a cost-saving measure. This is resulting in a deterioration of the quality of accident reports which will in turn decrease the reliability of safety-related analyses using these reports. For example, drivers may report the location of the accident as the nearest intersection, whether it was there or not. Determinations of how accidents relate to intersection layout will be less reliable. If accidents cannot reliably be related with geometric design, it becomes more difficult to predict the safety-effectiveness of various design features (e.g. curve radii, intersection type: offset, obtuse, acute, lane width, shoulder width etc.).

b) Linking of Databases

In 1997, Transport Canada surveyed road safety related databases in Canada at the federal, provincial and municipal (Montreal, Toronto, Vancouver only) levels [1]. A total of 91 databases were identified with the following collection units: accidents (26), roadway sections (24), driver (16), vehicle (20). Of the 91 databases, 35% were linked with other databases.

Since accidents are rare events which occur randomly, large datasets are needed to provide the link between highway features and accidents. Alberta and Saskatchewan have links between accident and highway inventory databases and Ontario is in the process of creating this link. Large linked datasets are also needed to associate vehicle design features with injury types.

c) FHWA'S Interactive Highway Safety Design Model

For the past 5 years, the U.S. FHWA has been engaged in the multi-million dollar IHSDM project to assist roadway designers through a computer model that will predict crash rates expected given various highway designs. The aim is to help designers, particularly during preliminary design, to optimize roads for safety. The model is being built on the basis of safety studies on the impact of various highway geometric features on crash rates. This model could be modified for use by Canadian designers.

d) Automated Enforcement

To save costs, several provinces have implemented automated enforcement, mainly photo radar (B.C., Ontario) and intersection red light cameras. Concerns are that once drivers can identify the location of these enforcement devices (through published reports, or identification of the enforcement equipment), then the targeted behaviour is only affected at those locations and there is little general deterrence.

e) Graduated Licensing

Accident rates for teenage drivers are very high in the first two years of driving. Several provinces have undertaken graduated licensing programs in order to limit the conditions under which young drivers learn to those that pose lower risks. Generally, young drivers are restricted in time of driving (reduced at night), location (off freeway), and condition (BAC of 0%, accompanied by older licensed person). The restrictions which reduce kilometres driven (e.g., no night driving) have a major impact on accident rates. However, the goal is to select restrictions that go beyond simply reducing exposure, that is, they also reduce accident rates per kilometre.

f) Downloading of Road Systems

Provincial governments have reduced their highway networks, transferred responsibility to the municipal level of government, and increased the role of the private sector in the design, construction, operation and financing of provincial highways. A concern is that municipal governments and the private sector have varying degrees of knowledge and experience of current practice and standards. In Ontario, MTO has responded to this concern by starting the development of a 28 volume Ontario Traffic Manual (3 volumes are completed to date) which deals with all aspects of traffic management from traffic control devices, to operating issues related to various road designs.

g) Safety-Conscious Design

There is increasing recognition, spurred by the Highway 407 safety review in Canada, and by the U.S. IHSDM project on predicting safety on the basis of highway design choices, that designing highways to standards is not sufficient to build in safety. Standards do not deal well with interactions between various highway elements (median width, grade etc.) which impact safety. In response to concerns about road safety, the practice of road safety auditing has developed, most notably in Australia, to assess safety issues at the planning and development stage, at the preliminary design stage, at the detailed design stage, and in construction and reconstruction stages. The University of New Brunswick Transportation Group is currently engaged in a research project which is aimed at producing a road safety audit manual.

However, road safety auditing comes "after the fact". What is required is safety-conscious design, that is, designers who are informed about the safety implications of their design choices. Ontario's MTO has undertaken an extensive development and training program in this area. Safety performance functions (SPF's) were developed, using Ontario databases, which indicate the number of accidents expected for various classes of roadways according to traffic volume. These

SPF's can then be used to determine whether "high accident" locations are so because of the class of roadway and the traffic volume. For locations that are less safe than might be expected, a diagnosis process, similar to a road safety audit, was developed. Through diagnosis of the types of errors made by drivers, appropriate countermeasures could be selected. Accident modification factors (AMF's) were developed for various countermeasures (e.g. widening lane width). These can be used to calculate the likely effect on safety of making particular design changes. Based on this work, a one week training program, "The Science of Road Safety" was developed which dealt with:

- how road safety is measured
- how to identify, through network screening, sites which are less safe than might be expected given the accident record at similar sites
- how the application of human factors contributes to highway safety through an understanding of basic driver limitations in vision and information processing, and how these impact design of highways and traffic control devices
- how standards relate to safety, and the lack of a solid empirical basis for some standards
- the relationship between key highway design choices (e.g. lane width, shoulder width, curvature, median treatments, intersection layouts and accident rates)
- the relationship between roadway design and driver speed choice
- changes in standards (e.g. for highway signs and for stopping, and intersection sight distances) in light of new knowledge about driver performance
- how to diagnose the factors which are contributing to accidents at a selected site and select countermeasures
- how to calculate the expected reduction in accidents with the application of specific countermeasures.

This course has been given to MTO employees across Ontario and is being readied for presentation to consultants.

f) Shift from Geometric Design Standards to Design Guidelines

Reflecting safety-conscious design principles, there is a growing realization that geometric design parameters should not be defined as a minimum acceptable set of standards, but as a desirable domain of geometric design features. This design philosophy will be reflected in the “Geometric Design Guidelines for Canadian Highways”, sponsored by TAC, and due in the fall of 1999.

3. Description Of Research Opportunities

This section describes research opportunities in the area of human factors and safety, related to the trends, opportunities and issues described in Section 2, which are worthy of pursuit by Canada's transportation research community.

a) Improved Quality of Self-Report Accident Data

Self-reporting is leading to a deterioration of the quality of accident reports which will in turn decrease the reliability of safety-related analyses using these reports. It is most unfortunate that this is happening just as the potential for using accident reports is being realized both because of the emergence of databases linking accidents, vehicles, and highway geometric design, and because of increased interest in safety studies and road safety audits.

R&D is required to ensure that self-report data is made as reliable as possible. A key issue for safety studies is the accuracy of locating the accident within the roadway. More reliable accident data will lead to better estimates of the safety impact of highway design features. The principal beneficiaries of this research are agencies which are responsible for road safety related to highway design, and the general public who benefits from more accurate identification of sites of concern and from better prediction of the safety-effectiveness of various countermeasures and design features.

b) Development of Safety Knowledge

A Canadian program should be considered which draws on the safety expertise and funding from each province to develop safety performance functions and accident modification factors. (See TAC Research Report "Safety Analysis of Roadway Geometry and Ancillary Features"). This is akin to the current international genome project, where laboratories across the world co-operate in a research venture which benefits them all. Developing SPF's and AMF's for all possible road types, traffic volumes and countermeasures is an enormous project and is best done co-operatively. Real progress in road safety can only be made on the basis of such fundamental knowledge.

c) Driver-based Standards for Traffic Control Devices

Most traffic signs in the Manual of Uniform Traffic Control Devices were developed without explicit consideration of driver needs. The rule of thumb for many years was 6 m/cm (50 feet per inch). There were two problems with this rule of thumb. First of all it was based on performance of college students during daylight. Legibility is poorer for older people and for everyone at night. Based on studies of guide sign reading [2], a better rule of thumb would be 4.8 m/cm.

A second problem is that any such rule of thumb begs the question of what distance is required by the driver [3]. Current standards ignore these needs. Legibility distance is determined by letter height which is in turn determined by sign size. Standard sizes are used depending on the road class.

The legibility distance needed by drivers was not explicitly considered in these standards. For example, many urban street signs use 4 inch letters. This is adequate for pedestrians but is considerably less than what a driver requires if he or she is to be able to detect the sign (which can be located at any corner of the intersection or on the median), read the name, search for a gap and change lanes prior to reaching the intersection. Similarly, it is not possible to read left turn restriction signs until one is actually in the intersection. With the ageing of the driver population there is increasing recognition that legibility of many standard signs is inadequate.

Signing on freeways is also determined by such standards. In complex situations, where exits are closer than the required 300 m separation between signs, there is no formal guidance for how much time a driver needs to detect a sign, read the message (which will take more time and distance if it is lengthy), and carry out any manoeuvre required before reaching the sign (e.g., slow to exit, or change lanes).

Eye movement recording devices are now available that allow recording of driver eye movements on the road to determine when signs are first detected, when they are last looked at, and how long it takes to search for a gap prior to a lane change. These data would allow a model to be developed (such as the model for stopping sight distance) to predict driver sign sight distance requirements. Such a model would be invaluable to designers who wish to ensure their designs can be effectively signed, before the roadway is built. It would also be invaluable to traffic engineers who need to determine appropriate sign sizes.

d) Support for Safety Training

Highway research funds in Canada are extremely limited, especially in comparison to the U.S. The best use of Canadian funds is to reap the benefits of international research and in particular U.S. research on a highway network which is similar in many ways to our own. Literature review and meta-analysis should be pursued, along with continually updated training for road safety professionals based on the latest safety knowledge. Most designers are unaware of the safety implications of their designs, and rely on designing to standards. Highway planners, designers, traffic engineers and analysts need explicit training on safety. Such training would benefit the general public, in that safety would be better provided for in new road designs. Explicit knowledge of the impact on crashes of various road safety countermeasures would ensure the optimum use of funds for safety during construction and reconstruction.

e) Non-Enforcement Speed Control Measures

Speeding is a problem of wide concern. There is some evidence that higher speeds are associated with greater numbers of accidents; there is strong evidence that higher speeds are associated with increased likelihood of injury and fatality once a crash has occurred. Enforcement is costly, whether done in the traditional manner or by means of photo-radar. Drivers use many road features in selecting speed. These include lane width, shoulder width, pavement quality, innovative pavement markings and adjacent land–use. The better designers understand these perceptual cues, the more effectively they can use them to induce drivers to slow down, particularly when entering built up areas where the potential for traffic conflicts increases.

f) Effective Traffic Calming Techniques

Traffic calming has been used for decades in Europe, but is only now catching on in North America. Its increasing application may be related to the "NIMBY" (not in my back yard) syndrome wherein neighbourhoods try to restrict access in order to maintain social order. High speed traffic is undesirable, and the aim of traffic calming is to discourage non-residents from using neighbourhood streets. Many different approaches have been tried, for example, speed humps, staggered intersections, partially blocked access points, left turn restrictions and so on. There has been insufficient study of the effectiveness of traffic calming in reducing accidents, not only in the traffic calmed neighbourhood but on the surrounding arterials to which traffic is re-routed. In other words, exposure must be considered, before the claim can be made that traffic calming reduces accidents. Furthermore, there has been no study regarding which traffic-calming devices are effective without being irritating to drivers. The introduction of traffic calming often divides neighbourhoods. The more effective and the less irritating traffic calming measures are seen to be, the better.

g) Standardization of Traffic Control Devices

Movement of people from city to city, province to province and country to country has been increasing for many years. More and more drivers drive in environments different from those in which they learned to drive. This is a problem because, while moving along at rates of 12 to 30 metres a second, drivers do not always have sufficient time to comprehend new situations. They rely on previous experience in order to be able to respond rapidly in traffic. The more standardized traffic control devices are, the less likely it is that drivers will misinterpret or not understand devices they encounter. With the downloading of the provincial roadways to municipalities, there is likely to be less, not more standardization. The more agencies involved, the more variety there is likely to be. This can have dangerous consequences. For example, the meaning of a flashing green light in Toronto is a protected left turn. (This is understood by few American tourists.) In Vancouver, a flashing green light means something else entirely. A driver who incorrectly assumes that his or her turn is protected is at risk of an accident.

Even within a single city, devices can be applied inconsistently. In Toronto, widespread use of 4-way stops leads to driver expectation that all stops in the area are 4-way. At a 2-way stop, drivers making this assumption may, after stopping, pull out in front of a vehicle that is not required to stop. In Toronto, some pedestrian signals are timed to start flashing when it is estimated a pedestrian would not be able to cross within the remaining green period. Other pedestrian signals start flashing when the traffic light turns caution.

Research into this area would reveal where there are potentially dangerous inconsistencies in the use of traffic control devices.

g) Location and Configuration of Passing Lanes

Decisions involving the location and geometric design of passing lanes face three challenges specific to Canadian conditions.

h) Canadian trucks have considerably higher allowable gross vehicle weights (GVW) and are often longer then their counterparts in U.S. For example, typical allowable GVW in Canada is over 60,000 kg compared to 38,000 kg in US.

ii) Inclement driving conditions during winter (and longer winters) resulting in long periods with reduced visibility and lower pavement friction.

iii) Low population density necessitating the existence of 2-lane roads carrying long-distance heavy-haul truck traffic.

4. Description Of R&D Projects

Potential projects in the area of safety, human factors, and geometric design are listed below. The projects were prioritized according to the methodology outlined in Chapter A, Section 4.1. In addition, potential projects in the area of safety and human factors were also ranked by considering the following specific reasons:

- They form a foundation for improving road safety
- They contribute to safety in all jurisdictions
- They address needs that are found across Canada.
- They contribute to the Canadian government-identified core business of safety both from the user and the infrastructure perspective.

The projects were classified as high priority (H), medium priority (M) and low (L) priority projects.

i) Safety and human factors projects

1.	Development of procedures and technology to improve accident reporting	H
2.	Development of safety performance functions	H
3.	Development of accident modification factors	H
4.	Development of driver-based standards for traffic control devices	H
5.	Use of highway design features for speed control	M
6.	Deployment of automated enforcement tools to maintain effectiveness	M
7.	Identification of non-standard traffic control devices leading to potential safety impacts	M
8.	Safety impact of traffic calming	M
9.	Effective traffic calming techniques	L

ii) Highway and geometric design projects

1.	Location and configuration of passing lanes	H
2.	Value engineering evaluation of lane and shoulder widths	H
3.	Geometric design standards for work zones	M
4.	Low-maintenance roadside vegetation for northern climates	M
5.	Storm water management through facility design	M
1.	Rumble strips	L
2.	Geometric, safety, and operational characteristics of roundabouts	L

All high priority R&D projects identified in safety, human factors, and highway and geometric design areas are described in the following with the exception of the geometric design project on "value engineering evaluation of lane and shoulder widths" which has been launched by MTO in early 1999.

a) Development of Procedures and Technology to Improve Accident Reporting

Problem Description: Self-reporting is leading to a deterioration of the quality of accident reports, which in turn will decrease the reliability of safety-related analyses using these reports.

Proposed Solution: Procedures need to be developed to improve data quality, and ease of recording data by police, staff of self-report centres, and individual drivers. Technological solutions involving GIS and lap-top computers are being tried in various North American jurisdictions. Experience with these should be reviewed. A group of interested stakeholders, including researchers, police and staff of self-report centres should be formed to outline the issues requiring resolution. Procedures and technology to deal with these problems should be developed. Several jurisdictions, both urban, suburban, and rural should be selected in which new procedures and technology can be evaluated.

Expected Benefits: Cost-beneficial safety counter-measures cannot be developed without reliable accident report data. The integrity of the accident reporting system is paramount.

Partnership Opportunities: All provinces and large municipalities who collect crash data, researchers in driver, vehicle, highway issues, police and self-report staff all need to co-operate to improve the reporting system.

Resources Required: Estimated at $200,000.

b) Development of Safety Performance Functions

Problem Description: In order for highway designers to know the safety impact of their design decisions (e.g. radius of curvature, lane width, shoulder slope etc.) they need empirical data relating design features to expected crash rates.

Proposed Solutions: These are detailed in the 1997 TAC Research Report "Safety Analysis of Roadway Geometry and Ancillary Features" as well as in the 1997 report of the CCMTA Project Group of Safety, Data and Research Needs. The first stage is to develop safety performance functions. These indicate the expected crash rates, for a given AADT, for a given road category (e.g. 2 lane rural highways). These will vary from one province to another, given different reporting levels and criteria for property damage, injury and fatality accidents.

Expected Benefits: By knowing expected rates of accidents for a given road class and AADT, it is possible to judge whether a given roadway is operating above or below its expected safety level. Roads that are operating below this level are more amenable to safety improvements than those that are already operating well. Design and reconstruction frequently require tradeoffs. Safety can only be optimized with explicit safety knowledge. Explicit safety knowledge also allows safety related projects to be justified using cost-benefit analysis.

Partnership opportunities: Co-operation between several jurisdictions is desirable.

Resources Required: Estimated at $150,000.

c) Development of Accident Modification Factors

Problem Description: In order for traffic professionals to justify implementation of accident countermeasures (e.g. lighting, widening lanes, paving shoulders), better knowledge is needed about expected effectiveness. This will allow a cost-benefit assessment to be made of various possible countermeasures, so that the greatest safety benefit is obtained for the lowest implementation cost. A number of accident modification factors for a range of AADT's have already been developed. These include AMF's for lane width, paved vs soft shoulders, arterial lighting. However, these need revisiting as in some cases they are based on insufficient data. Many other AMF's remain to be developed, e.g. safety effects of paved vs unpaved vs partially paved shoulders.

Proposed Solutions: These are detailed in the 1997 TAC Research Report "Safety Analysis of Roadway Geometry and Ancillary Features" as well as in the 1997 report of the CCMTA Project Group of Safety, Data and Research Needs. AMF"s require meta-analysis of information from all the before and after studies available, which link highway geometric, road volume and accident record data.

Expected Benefits: All jurisdictions in Canada will be able to make use of AMF's to make safety decisions based on a cost-benefit analysis.

Partnership Opportunities: Highway jurisdictions should receive support from the insurance industry.

Resources Required: Estimated $50,000 per one accident countermeasure.

d) Development of Driver-Based Standards for Traffic Control Devices

Problem Description: Standards for traffic control devices have been developed, for the most part, without explicit measurement of driver behaviour. Standards may be insufficient, in that they do not meet driver needs, or result in unnecessary expense. When standards cannot be met, knowledge of driver behaviour is essential in order to make the optimum tradeoffs.

Proposed Solutions: Traffic engineers and human factors experts need to review traffic control device standards and warrants to prioritize those most in need of an improved foundation. These might include such items as: required spacing between signs to allow drivers to complete the reading of each one prior to encountering the next, length of caution for different speed limits that minimizes red-light running and rear-end conflicts, warrants for use of overhead flashing signals at intersections to ensure that such devices improve early driver detection of the intersection as compared to less costly alternatives such as enlarged stop signs or addition of stop ahead signs.

Expected Benefits: Traffic control devices based on driver needs and measured driver behaviour are more likely to be effective in eliciting desired road user behaviour.

Partnership Opportunities: Highway jurisdictions should receive support from the insurance industry.

Resources Required: Long-term endeavour with many activities.

d) Location and configuration of passing lanes

Problem Description: Location and geometric design of passing lanes is facing specific Canadian challenges caused by large heavy trucks, inclement winter weather conditions, and prevalence of 2-lane highways carrying heavy-haul, long distance truck traffic.

Proposed Solutions: Before formulating design guidelines, it is necessary to obtain fundamental data on operating characteristics of the traffic flow served by passing lanes under various weather conditions.

Expected Benefits: Safer and more efficient highway network in rural areas.

Partnership Opportunities: Highway jurisdictions should combine resources.

Resources Required: Estimated at $75,000.

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H/ TRAFFIC MANAGEMENT AND ITS

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1. Introduction

1.1 Background: What is ITS?

Various definitions of Intelligent Transportation Systems (ITS) have been put forward. For purposes of this report, the following definition of ITS will be used:

> **ITS:** The application of advanced and emerging technologies (computers, sensors, control, communications and electronic devices) in transportation, to save lives, time, money, energy and the environment.

Even with this definition, the term ITS is an elastic one, capable of broad or narrow interpretation. It covers all modes, although the emphasis in this study will be on road and intermodal transportation (where one of the modes is road), including private autos, commercial vehicles, and public transit. Because these are dynamic, not static systems, the term ITS is understood to include consideration of the vehicle, the infrastructure, and the driver or user interacting together dynamically. Also, the definition does not *per se* address one important national objective for ITS, namely industrial strategy and development of export potential for products and services.

Traffic management, and the application of ITS (Intelligent Transportation Systems) and technologies, are extremely important at a time of demand for increased transportation capacity and a time of funding constraints and changing roles (and the resulting difficulty in constructing new transportation capacity), because they (ITS) represent new opportunities and means of getting the most benefit out of existing infrastructure through improved efficiency. ITS provides an important key to achieving many of today's transportation objectives: mobility, safety, efficient transportation, financial base for new highway infrastructure (through tolling), public-private partnerships, and transportation demand management (through road pricing, transit, and HOVs), which in turn can benefit air quality and the reduction of greenhouse gases.

In North America, ITS was originally subdivided into six major categories:

1. Advanced Traffic Management Systems (ATMS)
2. Advanced Traveller Information Systems (ATIS)
3. Commercial Vehicle Operations Systems (CVO)
4. Advanced Public Transportation Systems (APTS)
5. Advanced Rural Transportation Systems (ARTS)
6. Advanced Vehicle Control Systems (AVCS)

More recently, it has become common in the U.S. to refer to seven major categories of ITS, covering 29 types of user services (listed alphabetically within each category), as follows:

1. Travel and Transportation Management (TTM)
   - Emissions Testing and Mitigation
   - En-Route Driver Information
   - Incident Management

- Route Guidance
- Traffic Control
- Traveller Services Information

2. Commercial Vehicle Operations (CVO)
   - Automated Roadside Safety Inspection
   - Commercial Vehicle Administrative Processes
   - Commercial Vehicle Electronic Clearance
   - Freight Mobility
   - Hazardous Materials Incident Response
   - On-Board Safety Monitoring

3. Electronic Payment (EP)
   - Electronic Payment Services

4. Emergency Management (EM)
   - Emergency Notification and Personal Security
   - Emergency Vehicle Management

5. Public Transportation Operations (PTO)
   - En-Route Transit Information
   - Personalized Public Transit
   - Public Transportation Management
   - Public Travel Security

6. Travel Demand Management (TDM)
   - Demand Management and Operations
   - Pre-Trip Travel Information
   - Ride Matching and Reservation

7. Advanced Vehicle Control and Safety Systems (AVCSS)
   - Automated Highway System
   - Intersection Collision Avoidance
   - Lateral Collision Avoidance
   - Longitudinal Collision Avoidance
   - Pre-Crash Restraint Deployment
   - Safety Readiness
   - Vision Enhancement for Crash Avoidance.
   -

Transportation is not an end in itself, but is a means to an end or ends. That is, transportation is not a primary need, but rather a derived or secondary need, to enable and facilitate the satisfaction of primary needs, such as work, personal business, goods distribution, shopping, health, education, social and recreational needs, and the like. In meeting these primary needs, transportation objectives are sometimes defined as safe, efficient, accessible mobility, while minimizing adverse effects such as high land use consumption, energy consumption, and environmental impacts. At a high level, these objectives apply to all transportation technologies, and so ITS's relation to other transportation technologies is that they all share, and contribute to, the same high level objectives.

There are also differences between ITS and other transportation technologies, however, particularly as related to road transportation infrastructure such as pavements and bridges. By way of extreme simplification:

- vehicle technologies are mechanical engineering technologies, individually mobile and dynamic in nature;

- ITS technologies are electronic, electrical, and information/communications technologies, operationally dynamic as an integrated system, often in real-time, and operating over a wide range of distances or areas.

ITSs are important transportation elements. They have been so for a long time, in the form of traffic control systems, but have been designated as ITS (or an earlier version, Intelligent Vehicle/Highway Systems or IVHS) only for about the last decade. ITS is important for what it can do. It cannot create capacity, but it can improve the utilization and efficiency of existing capacity and operations, and it can enhance safety.

The importance of ITS in improving transportation has long been recognized by many governments, as reflected in funding levels, particularly in the United States, the European Community, and Japan. This has led to growing appreciation outside these three major sectors of what ITS can do, and growing interest and more applications, in places like Canada, South America (especially Argentina, Brazil, and Chile), non-EC European countries, South Africa, Israel, and many additional Asia-Pacific countries, including Australia, China, India, Korea, Malaysia, New Zealand, Singapore, and Taiwan. Although Canada has not had ITS funding levels or applications to match those in the U.S., even on a proportional basis, Canada has actually been in the forefront of many ITS developments, from the first computer controlled traffic signal system in the world, in Toronto, starting with Eglinton Avenue in 1959, to an early freeway traffic management system on the QEW in Mississauga in the early 1970s, to early real-time transit schedule information systems, in the mid-1970s.

The funding levels for ITS in the U.S., Europe, and Japan have been substantial. Japan and Europe took the lead in developing advanced systems in the early 1980s. Japan's development emphasis, followed quickly by massive deployment, was on urban traffic management and driver information (navigation and route guidance) systems. Europe has had two broadly based programs, which continue in subsequent phases. Both DRIVE I and II (Dedicated Road Infrastructure and Vehicle safety in Europe) and Prometheus (PROgraM for European Traffic and Highest Efficiency and Unprecedented Safety) focussed on traffic efficiency and safety. DRIVE was funded and led by European Commission transportation agencies and research establishments; Prometheus was largely funded and led by the automotive industry, through there was participation by the public sector as well.

With the passage of the U.S. Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, major funding was provided for the U.S. ITS program, about $600 million over 6 years.

Emphasis in the early years was on research and development, as well as on the development of an ITS Strategic Plan, and the development of a national ITS architecture and related standards. Towards the end of the ISTEA term, a growing feeling developed in the U.S. that much of the required research and development had been completed, that many ITS technologies were now available, and that the primary emphasis should now be on deployment. When ISTEA expired, the U.S. Congress included significantly increased transportation funding (to $217.5 billion) in the successor bill, TEA-21, which included or authorized ITS funding in two separate categories. The first was funding of $1.3 billion for specific ITS projects, some research-oriented and some deployment-oriented, which funding could not be used for other purposes. The second category was that of regular transportation capital implementation funding. The new element was to make ITS eligible for such funding and to permit state transportation agencies to let ITS compete with other transportation needs and to make their own priority judgements.

Competition for funds is not new, but it has become increasingly acute in times of constrained budgets. Traditionally (though this is now changing somewhat), road engineers have not welcomed the allocation of funds to ITS if it meant that there would be less money for road construction or rehabilitation. They have argued that fixing roads is more important, that only new construction can actually increase capacity, and that the gains of ITS are quickly overtaken by growth in traffic (while overlooking the fact that new roads can also fill up with traffic quickly, and that ITS is a relatively low-cost "capacity extender"). Competition for funds will continue, but it is probably more likely, now that the benefits of ITS have been demonstrated, that ITS will be viewed as a legitimate claimant on transportation funds.

As noted above, the U.S. emphasis is now on deployment. While there have been significant ITS deployments in some parts of Canada, Canada as a country is not well positioned to deploy regionally or nationally integrated and intermodal systems, and has some catching up to do in terms of defining national approaches in such areas as ITS architecture, standards, and interoperability.

1.2 Principal Focus in this Report

As noted above, the primary ITS focus in this report is on road transportation and, to a lesser extent, those intermodal aspects where one of the modes involved is road transportation.

1.2.1 Key Focus Areas

Within this context, the primary focus is on:

- Key ITS application areas for Canada
- Nature of ITS "industry" and "market" in Canada
- Research and development budget levels; scale issue
- Identification of ITS research and development priorities

The first of these, key ITS application areas for Canada, is addressed in this section. The last three areas are discussed in Section 2 "Overview of Trends, Opportunities, and Issues."

Some of the identified areas of importance by the survey respondents include the following:

- Estimation of the cost of roadway congestion to national economies, and the importance of efficient transportation to the economy.
- Determination of hidden subsidies for autos.
- Health costs of auto use.
- A practical guide to ITS.
- The need for ITS planning and deployment of nationally and regionally integrated and intermodal ITS systems (covering a wide range of areas, including commercial vehicle operations, advanced traveller information systems, in-vehicle navigation systems, smart cards for transportation, use of transportation demand management to address climate change).
- The need for a strong national ITS organization, with federal funding support.
- The need to develop a Canadian ITS system architecture, and especially to determine the applicability of the U.S. ITS system architecture for Canada.
- The need for a strong national organization on ITS standards for system deployment and implementation.
- The need for the federal and provincial governments to support and fund ITS model deployments.

These listed areas are all important, both to ITS and transportation in general. It is suggested, however, that they fall more into the areas of policy, strategy, planning, funding, deployment, and marketing/advocacy than they do into research and development (and especially technological R&D).

Some survey respondents suggested specific areas of ITS R&D, as follows:

- Research into the most acceptable Canadian national ITS architecture.
- Research into necessary ITS standards, to support the system architecture and system deployment.
- Research into national ITS interoperability, in various ITS application areas, including what needs to be done to provide such interoperability, and the barriers to it.
- Identification of technical and institutional barriers to ITS deployment.

These do represent potential areas of strategic technical R&D in ITS, and are included in the sections below. The ITS application areas outlined in following sections are numbered from 1 to 6 (with further subdivisions). The strategic technical R&D areas are identified as area “0.”

1.2.2 Key ITS Application Areas for Canada

Key ITS application areas for Canada are considered to be those which currently or potentially satisfy one or more of the following criteria:

- they offer cost-effective mobility, efficiency, and safety improvements in the Canadian context, on a reasonably wide-spread basis;
- they are necessary to support/enhance Canada’s economy and industrial competitiveness;

- they can meet needs unique to Canada's geographic, climatic, environmental, social, or demographic conditions.

Key ITS application areas are not necessarily the same as key ITS R&D areas for Canada. Some degree of correlation between the two may be expected, but they are by no means identical. Some ITS applications which have significant benefits may already be relatively well-developed, not needing much additional R&D. Others may already offer significant benefits, in early-generation applications, but would benefit further from R&D which would help to refine the application or make the deployment more cost-effective. Others, not yet applied, may offer potential benefits, but may require R&D for them to be realized.

Some of the key ITS applications for Canada are considered to be the following:

1. Advanced Traffic Management Systems (ATMS)

1.1 Computerized urban traffic signal control systems, with traffic responsive control. These systems, for individual routes or for networks, vary in complexity and sophistication, from route signal progressions, to networks managed on a series of fixed timing plans for different periods of the day, to active, dynamic, real-time traffic-adaptive network signal control systems. Because there are many urban areas in Canada with signalized traffic control systems of varying size and complexity, and because their cost-effectiveness has been demonstrated, this is a key ITS application.

1.2 Freeway traffic management systems, such as COMPASS on Highway 401, or those on the expressways in Montreal. High-volume freeways in Canada continue to increase in number and extent, are linked into freeway networks, and become congested over time. These ITS systems are well proven and have demonstrated cost-effectiveness and hence are a key application.

1.3 Corridor traffic management systems, such as Toronto's Gardiner/ Lakeshore Boulevard corridor. In a sense, this is the general case, of which 1.2 is the special case. This is a definite need in major urban areas, with proven benefits, whose implementation has sometimes been hindered more by jurisdictional and institutional issues than by technical problems. This is a key ITS application in major urban areas.

1.4 Electronic Tolling and Traffic Management (ETTM), such as on Highway 407 in Ontario. With the growing move toward user-pay concepts, and public-private partnerships for highway infrastructure construction, toll highways provide a means of providing new highways earlier than would otherwise be possible. These factors, combined with the demonstrated success of electronic tolling on Highway 407, make this a key ITS application area for Canada.

1.5 Emergency notification and response systems. One of the best ways to reduce delay in a street or freeway network is to detect and remove incidents, accidents, and other emergencies quickly. This is particularly important because the disruptive effects of an incident may last much longer than the actual incident duration itself. This key ITS application supports applications 1.1 to 1.3.

1.6 Travel Demand Management systems (TDM): Ride-sharing; high-occupancy-vehicle (HOV) lanes, provisions, and services; parking management and control; road pricing). These applications are of moderate to high interest to Canada:

- Ride-sharing occurs to a significant degree, but mostly on a self-arranged basis. Techniques for automated ride matching are well established, and incentives to achieve more ride-sharing are well known, but used only to a minor degree. A significant increase in ride sharing appears to occur principally during emergencies, such as transit strikes. Moderate priority.

- High-occupancy-vehicle (HOV) lanes, provisions, and services: These have been provided in some Canadian municipalities and on some Canadian freeways, with significant potential, but little real success. In some quarters, HOV lanes have come under fire as being expensive facilities which achieve little, and then only in a narrowly defined band of operating conditions (HOV demand above that which makes the lane look empty, arousing public resentment, and below that which results in HOV lane congestion, diminishing the incremental benefit they show over regular lanes). This has led to increased interest in the U.S. in so-called HOT lanes (High-Occupancy-free, others Toll), which provide an incentive for ride sharing (free use), but allows others to use the lanes by paying a toll, thus ensuring significant lane usage, in a manner that can be fine-tuned by adjusting the toll rate. Moderate priority.

- Parking management and control: ITS can help in such applications, but this is likely to be a low-priority Canadian priority until some jurisdiction wishes to implement travel demand management in a serious way.

- Road pricing (sometimes called congestion pricing): The ITS technology of electronic tolling enables the application of road pricing in a wide variety of scenarios, to achieve travel demand management (as opposed to use of tolling to fund infrastructure), but it is likely to be a low to moderate-priority Canadian priority until some jurisdiction wishes to implement travel demand management in a serious way, including “restrictive” measures, and is willing to implement such a program.

1.7 Traffic Enforcement: Automatic camera capture and recording of violators, such as photo-radar for speed enforcement, cameras for red-light running, and for enforcement of toll highway provisions. The first two of these are safety measures, and will be of considerable interest across Canada. The third is of more specialized, but real, interest for toll road enforcement.

2. Advanced Traveller Information Systems (ATIS)

2.1 Navigation and route guidance systems, either in-vehicle or outside the vehicle, made available on a variety of media. This is of moderate interest in Canada, and principally in the major urban areas, where route and destination finding can be difficult. On an intercity basis, route finding in Canada usually is not a significant challenge. The benefits are reduced excess (out-of-the-way) travel and delay (from a system perspective), and increased comfort and convenience (from a user perspective). The cost-effectiveness of such systems has not yet been well established. Further, as they constitute consumer products, the consumer demand is also not well established in North America. (Demand is high in Japan, however.) Such systems can either be fully autonomous, providing "best route" information based on nominal network conditions, or they can be real-time systems (either one-way or interactive), using real-time traffic condition information from the infrastructure provider's traffic management centre to provide best route information based on real, current network conditions.

2.2 Road/weather information systems (RWIS). Because of the long winter season, and the variety and often unexpected nature of weather conditions in Canada, these data systems are a key ITS application for Canada, providing important information for:

- improved safety, through provision of advanced warning to motorists of adverse and unsafe road and weather conditions;
- improved road maintenance fleet operations and deployment, especially for efficient and timely snow and ice removal.

2.3 Changeable message signs (CMSs) linked to a traffic control centre. This is a key ITS technology for Canada. It is an component of many ATMS systems, but may also be used more or less on its own or with smaller systems in small, specific applications, for example:

- together with RWIS, to provide advanced warning to motorists of unsafe road and weather conditions.
- as dynamic, real-time warning signs in construction and maintenance zones, to provide greater effectiveness than static warning signs.
- together with new sensors, to provide warning of over-height vehicles in advance of low vertical clearance situations.

2.4 Information on available transit services (schedules, routes, delays, etc), made available on a variety of media. This could potentially be a moderate to high priority ITS application for Canada, as long experience in Canada and elsewhere has shown that such systems actually attract riders to transit, by providing better information and removing uncertainty about transit service and waiting times. However, higher level government support for transit (at the provincial and federal levels) has been diminishing in Canada, leaving most of the costs to be covered by the farebox or by municipal funding. Scarcity of funding generally is not conducive to the implementation of advanced systems, unless the benefits are both proven and overwhelming. For these reasons, this is considered a low priority ITS application for Canada.

3. Commercial Vehicle Operations Systems (CVO)

3.1 Commercial vehicle electronic clearance, at weigh/inspection stations or at international border crossings. This is a key ITS application for Canada, for several reasons:

- increased goods transportation efficiency, both north-south (NAFTA) and east-west within Canada.
- necessary to maintain Canadian trucking industry competitiveness within NAFTA context.
- improved trucking enforcement effectiveness and efficiency.
  longer highway life through better weight control.

There are numerous issues which need to be addressed, to arrive at the best approaches to achieve desired results (more below).

3.2 Electronic Data Interchange (EDI) on truck/container cargos. This is a supportive element for the CVO applications in 3.1, and is important in the goods distribution industry. However, it is proceeding apace, driven by efficiency considerations, and therefore is not considered a primary area of ITS R&D.

3.3 Fleet management systems, for both commercial vehicle operations, and public agency maintenance fleet operations. This is a key ITS application for Canada. Fleet management systems in the commercial sector are well developed and in relatively widespread use. Those in the public transit sector are included in 4.2 below. For public sector road maintenance operations, however, advanced fleet management systems have not been widely used, and this represents an opportunity for many public road authorities.

4. Advanced Public Transportation Systems (APTS)

4.1 Fleet management systems, including automated transit vehicle location, control (AVLC) and management systems. This is a moderate priority ITS application for Canada. A variety of such systems has been implemented in cities across Canada, and they are relatively well established. Ontario has developed standard specifications and procurement guidelines for moderate-sized cities, so that the primary barrier to implementation is that of cost.

4.2 Advanced, dynamic passenger information systems: See 2.4 above. It is repeated here for organizational reasons (that is, a transit application).

4.3 Advanced fare systems, including smart cards or other electronic fare payment. This is potentially a moderate to high priority ITS application for Canada, for transit systems of all sizes. Benefits include: reduced bus loading times, hence shorter run times (better service), more efficient use of vehicles, good financial control, automated reporting, and controlled effective fare rates when used as a pass. Systems are currently in operation in two small cities in the Greater Toronto Area.

5. Advanced Rural Transportation Systems (ARTS)

5.1 "Mayday" emergency reporting and response. This is one of the main ITS ARTS applications generally, but especially for Canada with its winter conditions, long road distances, low densities and low traffic volumes. Some technologies for this are now available (cell phones using a variety of technologies, GPS receivers), but market penetration and geographical coverage are incomplete.

5.1 Advisory information on road and weather conditions. See 2.2 and 2.3 above. It is repeated here for organizational reasons (that is, a rural ITS application).

6. Advanced Vehicle Control Systems (AVCS)

6.1 Automated Highway System (AHS). This is a low priority ITS application for Canada. The time horizon is distant, and interest has waned even in the U.S., after an enthusiastic early start. There are many unresolved issues. However, some parts of AHS are feasible such as Automated Collision Notification (ACN) and collision avoidance systems.

6.2 Intelligent Vehicle Initiative (IVI): Improved vehicle safety design (including improved vision at night or in adverse visibility conditions; dynamic cruise control; radar controlled braking; improved sensors). This is a moderate priority ITS application for Canada. The safety benefits appear to be worthwhile and of considerable interest, but most if not all of the technical development will take place outside of Canada, except for occasional niche technologies.

2. Overview Of Trends, Opportunities, And Issues

2.1 Trends Affecting ITS

2.1.1 Social Trends

The primary social trends affecting ITS include the following:

- continuing heavy reliance on the private automobile for urban and short-to-medium range intercity transportation, because of its flexibility, convenience, comfort, privacy, and generally high level of service relative to alternatives.

- growing frustration with congestion, resulting in longer and less reliable commuting times.

- continuing expansion of low-density suburban land use development, as people seek a balance between housing costs, housing "quality," and commuting distance and time.

- potential market for ITS applications and for toll roads, both of which provide better mobility, information, and safety. While some toll roads are attracting significant usage, there have also been signs of public resistance from both automobile and commercial vehicle users. The market for ITS applications was estimated 5 years ago (ITS America: ITS

Strategic Plan) at $200 billion, of which 80% would be private sector consumer products. A recent update done for US DOT has estimated the market to be over $400 billion.

- continuing trend to non-permanent employees, resulting in more part-time and contract employees, and more small, home businesses, accompanied by more telephone and internet communications (increased telecommunications and telecommuting). Somewhat counter-intuitively, such increased telecommunications have generally not led to a decrease in transportation, or only a minimal one.

2.1.2 Environmental Trends

The primary environmental trends affecting ITS include the following:

- The environment will continue to be a significant public concern, though, based on past history, its priority ranking in a list of public issues will vary, generally dropping in priority in times of economic and employment downturns.

- Air quality, particularly as it affects health, continues to be a significant environmental concern in medium-to-large urban areas, and a large part of the problem emissions comes from motor vehicles. Some provinces and cities have now introduced vehicle inspection and maintenance programs. However, the largest beneficial effect will come from continuing automotive emission reduction technology and, to some degree, alternative fuels. ITS is often viewed as a means of improving air quality, by reducing delay, smoothing traffic flow, and reducing energy consumption. While these relationships are valid, the benefits may be dissipated if the ITS-induced improvements in efficiency lead to more travel, more dispersed land use, and longer commuting distances. To ensure that ITS delivers such benefits, improved land use controls and travel demand management through road pricing (facilitated by ITS) may become necessary.

- The concern about global warming is likely to continue to grow. Together with governments in other countries, the Government of Canada is now or has recently commissioned many studies in 14 different sectors, including transportation, on what measures are available to meet its Kyoto commitments on greenhouse gas emission reductions. ITS is one of the measures being studied. Greenhouse gas emissions are almost directly related to the amount of fuel consumed, so that measures that reduce fuel consumption will serve to reduce greenhouse gases. The claimed benefits for ITS are similar to those described under air quality, and are subject to the same qualification.

2.1.3 Political Trends

The primary political trends affecting ITS include:

- the Canadian Government and several provincial governments have shown increased and high-level support for ITS in the last two years.

- the government support for ITS has stressed not only transportation objectives and benefits, but also industry and export objectives.

- constrained government budgets in Canada are resulting in government downsizing, functional off-loading to lower-tier governments and private industry, greater interest in public-private partnerships, and less emphasis on and interest in research and development.

- For jurisdictional and funding reasons, Canada up to now has not had a strong, integrated, coordinated approach to ITS strategy, funding, planning, R&D and deployment.

2.1.4 Technological Trends

The primary technological trends affecting ITS include:

- Continuing advances in electronic, computing, communications, location, and display technologies, including improved capability and speed, miniaturization, and cost reductions, will make existing ITS applications more affordable and capable, and open the door to new or previously unviable applications.

- Increasing adoption of the U.S. National ITS Architecture in North America (with some possible Canadian variants or add-ons), and technical standards, will lead to more efficient technical development, more interoperable deployments, and a more level playing field for ITS industry product suppliers. However, some ITS industry leaders today will continue to try to gain market share and have their proprietary products adopted as de facto standards.

- Increasing technological complexity will underscore the importance of good education and training in ITS, with respect to design, deployment, operations, and maintenance.

2.2 Opportunities for Public and Private Co-operation

ITS provides many opportunities for public and private co-operation:

- The old name IVHS inherently conveyed this opportunity, indeed the need, for public and private co-operation, better than the term ITS does, because it stated that for success, the vehicle and highway (and also the driver) had to work and function together as a system, and had to cooperate with each other. The vehicle is usually considered a private one (except for transit), but equally important, the vehicle designers and manufacturers, both for original equipment and for after-market products, are private corporations. On the other hand, the infrastructure providers are usually public agencies, or private agencies acting on their behalf. Consequently, it may be argued, that for many ITS applications, public-private co-operation is not only opportune, but also necessary.

- In terms of funding for ITS applications, there will also be a public-private split. If the forecasters in the U.S. ITS strategic plans are correct, this split is expected to be approximately 20% public funding and 80% private funding.

- Toll roads represent an important opportunity for public-private cooperation, whether the roads are completely privatized (owned by the private sector) or built for a public agency under a design-build or design-build-operate arrangement. ITS facilitates public-private toll road initiatives in such areas as electronic tolling, traffic management systems, and the integration of the two (electronic tolling and traffic management or ETTM).

- As governments off-load or contract out more and more of their functions, more opportunities for public-private cooperation arise. These include consulting, planning, design, construction, construction supervision, operations, and maintenance. Some or all of these may include ITS components, such as:

    - operation of traffic management and control centres;
    - provision of traffic conditions information to the public (e.g., Trafficmaster in the UK);
    - provision of traffic conditions information to a service-provider who integrates it with navigation and route guidance devices;
    - operation of CVO systems (e.g., HELP system in the U.S.).

2.3 Other Canadian ITS Issues

There are, of course, many issues. Only a few are highlighted here:

2.3.1 Nature of ITS "Industry" and "Market" in Canada

Transportation needs and ITS opportunities must both be brought together. This approach is more likely to result in identification of cost-effective solutions. In transportation, a common approach is to identify the needs and then initiate the search for solutions that will address and solve those needs. If this is done without a good knowledge and understanding of what ITS can achieve, some of the best solutions may be missed. If, on the other hand, one starts with the ITS technologies or systems, one may easily be criticized for advocating "solutions looking for a problem." The preferred approach is to start from both ends: identification of needs and problems to be solved, at one end, and identification of ITS capabilities and opportunities at the other end. These are then brought together in the middle to match needs with appropriate, cost-effective solutions.

The dual objectives of implementing good ITS applications in Canada (usually public-sector driven) and supporting the Canadian ITS industry (private sector) also suggest that the Canadian approach to ITS should be both needs- and opportunity-driven. For example, in the 1980s, significant major implementations of freeway traffic management systems, urban traffic signal control systems, and supporting ITS technologies (e.g., weigh-in-motion scales) in the Greater Toronto Area met identified transportation needs, and at the same time presented opportunities for Canadian consultants, designers, systems integrators, product developers, and suppliers, sometimes in niche areas. This platform led to important expertise bases which in turn enabled such companies to market and export their products and services outside Canada. This has happened to such an extent that some companies now export over 90% of their products and services, with only a small proportion being sold within Canada. Part of the reason for this is that government markets in Canada for such systems in the early 1990s were lean, and hence accounted for small proportions of total output. This illustrates several points, however:

- the importance of government procurement and implementation of ITS systems to meet the two dual objectives;
- the importance of procuring and using Canadian products and services to create industrial opportunities, and of providing ITS developers and suppliers with “local” national and provincial applications which they can demonstrate.
- the importance of picking your market, possibly in niche specialty applications, and not necessarily competing across the board with the industry giants.

2.3.2 Research and Development Budget Levels

The research and development budgets for ITS in the U.S., Japan, and Europe, have been very substantial for a long period of time, about 15 years. By comparison, the R&D budgets for ITS in Canada have been minuscule. For example, in many areas, the relative ratio between the U.S. and Canada is typically described as 10:1. In ITS, both R&D and deployment, the relative ratio is more like 100:1. It quickly becomes apparent that scale of effort becomes a major issue and a major consideration. It has sometimes been said the “shoestring” nature of Canadian R&D budgets forces us to husband our resources more carefully, and get more return per investment dollar spent. This may be true to some extent. On the other hand, the tiny scale of ITS R&D investment means that Canada simply cannot compete with the major players in many areas, and perhaps more importantly, these limited resources simply choke off major initiatives that Canada should undertake. Further, it is noted that transportation budgets for R&D in Canada are generally being reduced rather than increased.

Because of the relatively small scale of ITS R&D funding in Canada, several potential opportunities should be explored and pursued:

- Participation in ITS R&D programs in other countries, notably the U.S., but some possibilities also exist in Europe. This has long been a practice in some other areas, such as SHRP-CSHRP.
- Encouragement and promotion of exchange programs for technical staff, so that Canadian researchers and engineers can participate in and benefit from foreign R&D programs.

2.3.3 Identification of ITS Research and Development Priorities

The purpose of this study is to identify road transportation R&D priorities, and more specifically in this part of the study, to identify ITS R&D priorities. This poses a significant dilemma, as may be seen by considering the discussion in 2.3.2. The question is what approach to take in identifying ITS R&D priorities. The approach depends on the expected size of the R&D budget(s) available:

- If the budget can be expected to be substantial, it then makes sense to identify priority ratings (e.g., high, medium, low) without undue concern about the budget. This means that consideration can be given to both major and minor initiatives.

- On the other hand, if the expected R&D budget is small, the first approach makes little sense, as many initiatives will simply not be possible. It would seem better to approach it from the point of view of the likely available budget, and priority rate those R&D initiatives that can be undertaken within that budget.

The budget available for ITS R&D is not known, but for this discussion, it is assumed that R&D budgets for ITS in Canada will continue to be limited, possibly extremely limited. Consequently, the approach taken in identifying ITS R&D needs has tended toward the second approach rather than the first.

3. Description of Issues

The issues, together with proposed research and development needs and priorities, are summarized in the following table, Table ITS-1. To a large extent, because of the expected scale of budgets for R&D in Canada, many of the proposed R&D areas are related to what might be called "product improvement," that is, R&D on how the various ITS applications can be made more cost-effective and safe.

ITS RESEARCH AND DEVELOPMENT NEEDS

ISSUE	DESCRIPTION	IMPACT ON CANADIAN HIGHWAY TRANSPORT'	EXPECTED BENEFITS	BENEFICIARIES & PARTNERSHIP OPPORTUN-ITIES (PO)
0. ITS Policy and Strategy				
0.1 National ITS Architecture	R&D Needs: - applicability of US ITS system architecture - changes needed to create suitable Canadian architecture**.**	Will provide the system foundation for creating national & regional interoperable ITS systems **Priority: High**	More rational approach to system design and deployment; less need for costly retrofit to achieve interoperability	B: all ITS participants PO: Governments, system developers, users, and industry
0.2 National ITS Standards	R&D Needs: - identification of ITS standards necessary to support architecture - identification of ITS standards critical to system deployment - assessment of suitability of US and ISO standards for Canadian ITS - assessment of impact of existing & proposed standards on Canadian deployments and Canadian industry	Lack of standards leads to a proliferation of incompatible proprietary products, risk of high costs to captive market purchasers **Priority: High**	Level playing field for suppliers; competitive supplier sources and lower costs for purchasers; better chance to achieve interoperability	B: Purchasers, suppliers; system users

0.3 National ITS Interoperability for Various ITS Applications	R&D Needs: - identification of ITS applications where national or regional interoperability is important - research on what needs to be done to achieve interoperability - identification of barriers to interoperability and solutions to them	In some ITS areas, interoperability is very important, such as for goods movement, across borders, within jurisdictions, and intermodally, to achieve efficiency and maintain competitiveness **Priority: Medium to High**	Better transport efficiency, lower costs for shippers, carriers, and regulators.	B: shippers, carriers, regulators, intermodal ports PO: Government purchasers and regulators; carriers; shippers
0.4 Technological and Institutional Barriers to ITS Deployment in Canada	R&D Needs: - Identification of technological barriers to ITS deployment - Identification of institutional and funding barriers to ITS deployment	ITS deployment has faced various barriers in Canada which have led to under-utilization **Priority: Medium**	Greater deployment of ITS applications in Canada where cost-effective	B: All players PO: All players
1. ATMS				
1.1 Urban Traffic Signal Control Systems	a. Systems relatively mature b. R&D Needs: optimization of control; how cost-effective is adaptive control; current cost-effectiveness of various communications options	Such systems are not yet as cost-effective as they could be. **Priority: Medium to High**	Lower cost of UTSCS; reduced delay for motorists	B: urban municipalities and urban road users PO: Public clients; private suppliers and installers; possible contracting out of operation and maintenance

1.2 Freeway Traffic Management Systems	R&D Needs: - network optimization - FTMS for construction projects - light (simpler, lower cost) FTMS design - improved incident detection & response - network route diversion strategies	Improved efficiency and safety **Priority:** **- Medium** **- High** **- High** **- High** **- Medium**	Lower cost of FTMS systems; reduced delay to motorists; safer travel for motorists	B: freeway owners; freeway road users; equipment suppliers PO: Same as 1.1
1.3 Corridor (Freeway & Arterials) Traffic Management Systems (CTMS)	R&D Needs: - optimization of traffic management between freeway and adjacent arterials	Improved efficiency and safety **Priority:** **- Medium**	Same as 1.1	Same as 1.1
1.4 Electronic Tolling & Traffic Management (ETTM)	R&D Needs: - Lower cost tolling & enforcement technologies - Cost effective design & operational integration with FTMS and traffic management	Improved cost-effectiveness and traffic management **Priority:** **- High** **- Medium to high**	Lower cost of FTMS systems; reduced delay to motorists; safer travel for motorists	B: Toll system owners & operators; road jurisdictions; road users; equipment suppliers PO: Public owners; private concessionaires; private equipment suppliers & installers
1.5 Emergency Notification & Response Systems	R&D Needs: - Improved incident detection methods & algorithms - Verification of incidents & emergencies w/o need for CCTV	Improved safety and reduced delay **Priority:** **- High** **- Medium to high**	Lower cost of such systems; reduced delay to motorists; safer travel for motorists	B: Road system owners; road users PO: Public owners and private equipment & algorithm developers and suppliers, possibly part of private operation of traffic control centres

1.6 Travel Demand Management Systems	R&D Needs: - Demonstration of HOT lane concept in selected locations. - Most cost-effective ways to do road pricing	Unrestrained growth of travel demand, with heavy demands on public funding, energy, and environment **Priority:** **- Medium** **- Low to medium**, unless real interest in and commitment to road pricing develops	Lower demand on road transportation, with reduced demands for road funding; more effective use of HOV lanes; more efficient use of road facilities; reduced energy consumption and emissions	B: Society; transportation providers PO: Privatized road pricing would be a partnership possibility
1.7 Traffic Enforcement	R&D Needs: - Most cost-effective ways to use photo radar for speed enforcement - Most effective ways to use ca - mera technologies for toll road enforcement	Excessive speeds, increasing variability in speeds, and red-light running all impact safety adversely **Priority** **- Medium to high** **- Low to medium**	Improved safety for road users; better use of enforcement resources; improved enforceability in difficult situations (heavy traffic)	B: Road authorities; enforcement agencies; road users PO: Road and enforcement authorities working with equipment developers and suppliers
2. ATIS				
2.1 Navigation & Route Guidance Systems	R&D Needs: - Effectiveness & market appeal of various systems (simple to advanced) - Assessment of system benefits and individual user benefits	Increased travel distance and delay in urban areas due to poor knowledge of best route **Priority:** **- Medium** **- Medium**	Reduced travel and delay; less demand on road system; better road user comfort and convenience	B: Road authorities; road users; info service providers PO: Road authorities (w/ real time traffic info) and private service providers

2.2 Road/Weather Information Systems (RWIS)	R&D Needs: - Most effective, & most cost-effective, deployment of RWIS - How effective is RWIS in improving safety? - How effective is RWIS in improving maintenance operations?	Lack of good and extensive road & weather info impacts adversely on safety and on road maintenance operations **Priority:** **- High** **- High** **- High**	Reduced exposure to adverse road conditions; improved safety; improved road maintenance operations	B: Road authorities & their agents; road users PO: Road authorities and their agents, with information service providers
2.3 Changeable Message Signs (see also 1.2, 1.3)	R&D Needs: - How effective, and how cost-effective are CMSs in conveying necessary information for adverse weather, and for construction/maintenance operations - Best types of CMS messages, and info on public response to them	Lack of good information of road, weather, and construction conditions, which attracts attention, is readable, and comprehensible, can impact adversely on safety. **Priority:** **- High** **- High**	Reduced exposure to adverse road conditions; improved safety; improved road construction and maintenance operations	B: Road authorities & their agents; road users; equipment suppliers PO: Limited, per se
3. Commercial Vehicle Operations (CVO) Systems				

3.1 Electronic Clearance for CVs at Weigh/Inspection Stations & International Border Crossings	R&D Needs: - Measure of efficiencies provided by such systems - How can operating constraints be minimized? - Best approach: "Best" operators only vs all commercial vehicles	Enforcement efforts should be focussed on "bad" operators; delays to operators; concern over level playing field in NAFTA **Priority:** **- High** **- High** **- Medium to high**	More effective use of enforcement resources; reduced CV delay; better control of vehicle weights; less damage to road infrastructure	B: Road authorities; enforcement agencies; CV operators; manufacturers & shippers; Customs & Immigration authorities PO: Many, among public agencies and private shippers & carriers
3.3 Fleet Management Systems	R&D Needs: - What are the most cost-effective FMSs? - How can high efficiencies best be achieved?	Inefficiencies in the trucking industry and other fleet management operations (e.g., highway maintenance) **Priority:** **- Medium to high** **- Medium to high**	More efficient use and deployment of vehicle fleets	B: Commercial vehicle operators; maintenance fleet operators; FMS suppliers; shippers PO: Limited; primarily where road authorities privatize their road maintenance operations
4. APTS (Transit)				
4.1 Transit Fleet Management Systems	R&D Needs: - How effective & how cost-effective are they?	High cost of transit operations, declining public funding, stress need for operating efficiency **Priority:** **- Medium**	Efficient transit operation; lower transit costs; better service to passenger	B: Transit operators; transit users PO: Primarily where transit service is privatized
4.2 Transit Traveller Information System	See 2.4			

4.3 Advanced Transit Fare Systems (Smart Cards)	R&D Needs: - Measurement of real efficiencies achieved	Fare collection systems could provide improved efficiency and user service and convenience **Priority** **- Medium to high**	Improved fare collection efficiency & reporting; improved user service & convenience; more flexible pass systems are possible	B: Transit operators; transit users; fare system suppliers PO: Transit operators and faresystem suppliers
5. ARTS (Rural)				
5.1 Mayday emergency systems	R&D Needs: - Most effective technologies in a changing technology environment	Difficulty of motorist user reporting and emergency response on large, low density, rural Canadian highway network **Priority:** **- High**	Greater rural motorist safety and security	B: Road users PO: Road authorities and system suppliers
5.2 RWIS Advisory System	See 2.2 and 2.3			
6. AVCS				
6.2 Advanced Vehicle Safety Systems	R&D Needs: - Effectiveness & cost-effectiveness of vehicle safety technologies - Market appeal of vehicle safety technologies	Still too many road user deaths and injuries on Canadian roads **Priority:** **- Medium** **- Low to medium**	Improved road user safety	B: Road users; vehicle and system suppliers PO: Vehicle regulatory and safety authorities; vehicle and system manufacturers and suppliers

4. Description Of R&D Projects

4.1 Descriptive Names of R&D Projects

The ITS R&D projects identified in Section 3, in Table 1, have been given descriptive names for identification purposes, and are listed below along with their proposed priorities (H = high; M = medium; L = low).

0-1	ITS-General	Canadian National Architecture	H
0-2	ITS-General	ITS Standards	H
0-3	ITS-General	National ITS Interoperability (various ITS application areas)	M-H
0-4	ITS-General	Technical and Institutional Barriers to ITS Deployment	M
1-1	ITS-ATMS	Urban Traffic Signal Control Systems: Optimization & Cost-effectiveness of Control	M-H
1-2	ITS-ATMS	Urban Traffic Signal Control Systems: Assessment of Communication Options	M-H
1-3	ITS-ATMS	FTMS Network Optimization	M
1-4	ITS-ATMS	FTMS for Construction Projects	H
1-5	ITS-ATMS	Light FTMS Design	H
1-6	ITS-ATMS	FTMS Incident Detection & Response	H
1-7	ITS-ATMS	FTMS Network Route Diversion Strategies	M
1-8	ITS-ATMS	Optimization of Corridor Traffic Management Systems	M
1-9	ITS-ATMS	Lower Cost Electronic Tolling Technologies	H
1-10	ITS-ATMS	Integration of Electronic Tolling with Traffic Management	M-H
1-11	ITS-ATMS	Incident Detection & Response (Non-freeway)	H
1-12	ITS-ATMS	HOT Lanes	M
1-13	ITS-ATMS	Road Pricing for Transportation Demand Management	L-M
1-14	ITS-ATMS	Photo Radar for Speed/Red-Light-Running Enforcement	M-H
1-15	ITS-ATMS	Toll Road Enforcement	L-M
2-1	ITS-ATIS	Route Guidance Effectiveness	M
2-2	ITS-ATIS	Route Guidance System and User Benefits	M
2-3	ITS-ATIS	Cost-effective Road/Weather Information Systems	H
2-4	ITS-ATIS	RWIS Safety Effectiveness	H
2-5	ITS-ATIS	RWIS Maintenance Effectiveness	H
2-6	ITS-ATIS	CMS Effectiveness (Weather and Construction)	H
2-7	ITS-ATIS	CMS Messages	H
3-1	ITS-CVO	Commercial Vehicles Operations (CVO) Efficiency	H
3-2	ITS-CVO	Minimization of CVO Operating Constraints	H
3-3	ITS-CVO	Best Approach to CVO Participation	M-H
3-4	ITS-CVO	Effective CV Fleet Management Systems	M-H
3-5	ITS-CVO	Achieving High CVO Efficiency through Fleet Management	M-H
4-1	ITS-APTS	Effectiveness of Transit Fleet Management Systems	M
4-2	ITS-APTS	Advanced Transit Fare Systems (Smart Cards)	M-H
5-1	ITS-ARTS	Effective Mayday Emergency Systems	H
6-1	ITS-AVCS	Effective Vehicle Safety Technologies	M
6-2	ITS-AVCS	Market Appeal of Vehicle Safety Technologies	L-M

This is an extensive list of potential and worthwhile technological R&D areas in ITS. All of them would be worthy of directed effort.

4.2 Suggested ITS Research & Development Projects

To provide focus for this study, the following six high priority projects were selected from the above list, and are proposed as being the most important to Canada on a national basis. There are other projects designated as high priority in the table, but these six have been selected on the basis of the prioritization process given in Part A, Section 5.1, and on the basis of the following criteria:

* They form the foundation upon which ITSs in Canada can be designed and implemented.
* They contribute to interoperability among jurisdictions.
* They address needs which are found across Canada, in all jurisdictions in Canada.
* They address situations and circumstances unique to Canada or parts thereof.
* They contribute to Canadian government-identified core businesses, including efficient highway management and planning, infrastructure and user safety, and efficient private fleet operations and efficient public regulation and enforcement.
* They help meet primary transportation objectives of mobility, efficiency, and safety.
* They support economic development, trade and tourism.

a) Canadian National ITS Architecture (0-1)

Problem Description: The R&D needs include (1) a detailed review of the applicability of the US ITS System Architecture to Canadian needs, and (2) determination of the changes, if any, needed to create a suitable Canadian ITS System Architecture.

Proposed Solution: Commissioning of a study or studies by consultants, with the participation of interested stakeholders, to do this research, and to develop a draft Canadian ITS System Architecture for review. (Transport Canada has initiated this work by funding of a preliminary study.)

Expected Benefits: This work is necessary to provide the system foundation for creating national and regional interoperable ITSs. The benefits are that a national ITS architecture will provide a rational approach to system design and deployment, and this will lead to less need for costly retrofit to achieve interoperability. It will also reduce uncertainty for system suppliers, and, by providing multiple competitive sources for ITS technologies, should reduce costs to purchasers. Almost all ITS participants will benefit.

Partnership Opportunities: All ITS participants have to work together for this to be successful: governments, system deployers, system users, and ITS hardware and software suppliers.

Resources Required: Estimated $300,000 - $500,000 (development of the US ITS System Architecture cost over $20 million).

b) ITS Standards (0-2)

Problem Description:	The R&D needs include (1) identification of ITS standards necessary to support the ITS system architecture; (2) identification of ITS standards critical to system deployment; (3) assessment of suitability of US and ISO standards for Canadian ITS applications; (4) assessment of the impact of existing or proposed standards on Canadian deployments and Canadian industry.
Proposed Solution:	(1) Commissioning of a study or studies by consultants, with the participation of interested stakeholders, to do this research, and to make recommendations on the needs identified above; (2) participation in US and ISO standards committees on ITS at a sufficient level of depth and expertise to make Canadian views and positions known (the Canadian ITS community does now participate in these activities, but on a very thin resource base).
Expected Benefits:	Lack of standards leads to a proliferation of incompatible proprietary products, and risk of high costs to captive market purchasers. Standards create a level playing field for suppliers, competitive supplier sources and lower costs for purchasers, and better opportunities to achieve interoperability.
Partnership Opportunities:	Yes; purchasers and suppliers in particular should be (and are, internationally) involved in standards development activities.
Resources Required:	Estimated \$50,000 - \$150,000 per year.

c) FTMS for Construction Projects (1-4)

Problem Description:	For various reasons, collision rates in roadway work zones are higher than normal roadway sections. The most frequent collision types are side-swipe and rear-end collisions, often due to driver inattention and failure to recognize the characteristics of the work zone.
Proposed Solution:	The need is to identify the best use of ATMS/FTMS technologies in effective communication with drivers in work zones with the objective of improved safety. These technologies involve monitoring of traffic conditions, use of changeable message signs or other signs to communicate conditions to the drivers, and rapid response to any incidents that occur. Some work has already been done by various jurisdictions. There is need for further demonstration projects and trials to determine what works most effectively in various situations, and for a central repository, assessment, and dissemination of information.
Expected Benefits:	Reduced delay to motorists, and improved safety for motorists and construction workers.
Partnership Opportunities:	Yes; road jurisdictions, contractors, and equipment suppliers.

Resources Required: Estimated $75,000 - $150,000 per demonstration.

d) Incident Detection & Response (freeway and non-freeway) (1-6, 1-11)

Problem Description: Even though collision rates are declining, the absolute number of incidents/collisions continues to rise. Each one, particularly in congested urban areas, takes its toll in death/injury/property damage and increased travel delay. There is a need to minimize damage and travel delay through enhanced use of ITS traffic management systems.

Proposed Solution: The need is to identify the best use of low-cost ATMS/FTMS technologies to identify incidents automatically, and respond to them and remove them as quickly as possible. These technologies involve monitoring of traffic conditions, use of changeable message signs or other signs to communicate conditions to the drivers, and rapid response to any incidents that occur. The solution requires (1) development of improved incident detection methods and algorithms, and (2) development of techniques for the verification of incidents and emergencies without requiring the use of CCTV. Some work has already been done by various jurisdictions. There is need for further demonstration projects and trials to determine what works most effectively in various situations.

Expected Benefits: Reduced delay to motorists, and improved safety for motorists, and lower cost of such systems.

Partnership Opportunities: Yes; road jurisdictions, academia, contractors, and equipment suppliers.

Resources Required: Estimated $250,000 - $500,000.

e) Cost-Effective Road/Weather Information Systems (2-3)

Problem Description: Lack of good and extensive road and weather information impacts adversely on safety and on the effectiveness and efficiency of winter road maintenance operations. The R&D needs are (1) to determine the most effective, and most cost-effective deployment of RWIS; (2) to determine the effectiveness of RWIS in improving winter road safety; and (3) to determine the effectiveness of RWIS in improving winter maintenance operations.

Proposed Solution: Systematic regional deployments of RWISs in various parts of Canada, to determine what degree of complexity and system weather station density is most cost-effective. Some work has already been done by various jurisdictions. There is need for further demonstration projects and trials to determine what works

	most effectively in various situations, and for central data repository and dissemination.
Expected Benefits:	Reduced exposure to adverse road conditions; improved motorist safety; improved winter road maintenance operations.
Partnership Opportunities:	Yes; road jurisdictions, maintenance contractors, and equipment suppliers.
Resources Required:	Estimated $300,000 - $500,000 per regional demonstration.

f) Commercial Vehicles Operations (CVO) Efficiency (3-1)

Problem Description:	CVO ITSs have now been in operation for several years, particularly at state/provincial weight/inspection stations. The more complex streamlining of commercial vehicle processing at international border crossings (vital for NAFTA) has been demonstrated, but is not yet ready for full deployment. It is necessary to evaluate their effectiveness and cost-effectiveness in terms of efficiencies realized by (1) trucking fleets, (2) regulatory and enforcement agencies; (3) border crossing agencies (facility owner, Customs, Immigration), to determine how operating constraints can be minimized, and to refine the deployment approaches. This should include consideration of whether only the "best" truck operators should be included as participants in such a system, or all commercial vehicles.
Proposed Solution:	A systems analysis of required functions and controls, together with development of a range of system designs, demonstration-type deployments, and evaluation.
Expected Benefits:	More level playing field in NAFTA; enforcement efforts could be more effective (focussed on "bad" operators); reduced commercial vehicle delay and higher productivity; better control of vehicle weights; less damage to road infrastructure.
Partnership Opportunities:	Yes; road jurisdictions, enforcement agencies, commercial vehicle firms and operators, manufacturers and shippers, Customs and Immigration authorities, equipment suppliers.
Resources Required:	Varies with location and traffic volume; could range from $500,000 - $2,500,000 per regional demo.

I/ WINTER MAINTENANCE OPERATIONS

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1. Introduction

Extensive winter maintenance operations are undertaken every year by, or on behalf of, transportation authorities to keep the highway system serviceable in winter conditions, and to maintain target levels of service. Significant resources are expended in conducting winter maintenance operations, and they represent a large component of the operating and capital budgets of most highway authorities. The quality and consistency of winter maintenance operations have also a significant impact on user costs including costs of delays and accidents.

Winter maintenance activities encompass a wide range of snow and ice control operations. The selection of the most appropriate method(s) depend on many factors, such as the local conditions, the temperature, the target level of service, and the weather conditions.

Often, winter maintenance operations start before the winter with pro-active measures, such as the erection of snow fences to reduce snow drifting. With respect to the operations taken during the winter, the most common operating approach is to wait until the onset of a storm, or until it has started, and then to undertake one or more of the following operations:

Plowing
Plowing is done to remove snow, ice or other materials, such as slush, from the pavement.

Applying de-icing chemicals
De-icing chemicals are applied with the objective of eventually producing a bare pavement surface. Salt is the most common de-icing chemical used at present. Most commonly, salting is done immediately after the road has been plowed with the purpose of weakening the ice-pavement bond so that subsequent plowing operations are more effective at reaching bare pavement.

Applying abrasives
Sand or other abrasives are applied to produce a short-term increase in traction. Abrasive materials are applied in conditions where the temperature is too cold for the available de-icing chemicals to be effective, and/or where the target level of service is not necessarily to produce a bare pavement surface.

2. Overview of Trends

a) Rationalization of Service Providers and Cost Reduction

In the current climate of fiscal restraint, authorities responsible for winter maintenance are faced with significantly reduced budgets. Because winter maintenance operations consume a large part of many highway authorities' budgets, there is growing focus on increasing cost-effectiveness of winter maintenance operations.

One of the most important results of these pressures is that an increasing portion of winter maintenance operations is being contracted out to the private sector. In the past, only relatively basic services were contracted out (e.g., snowplow operations). Now, there is a trend towards contracting out a greater portion of winter maintenance operations, including the management of the operation (e.g., as evidenced by the Area Maintenance Contracts recently awarded by the Ontario Ministry of Transportation). In addition, there is a trend towards transferring highway infrastructure from provincial to municipal jurisdiction.

b) Environmental Damages and Costs

The environmental damages caused by salt, as well as the associated mitigation costs such as those incurred from contaminated groundwater supplies, have been rising rapidly in recent years. Pressure is also being exerted by Environment Canada, which included salt on its Environmental Priority Substance List. As a result, an Action Report is being developed by Environment Canada, to be tabled in early 2000, that will recommend the environment-related status of salt.

Environmental concerns have led to increasing interest, on the part of highway authorities, in alternative de-icing chemicals, and/or in methods to minimize salt usage, including anti-icing snow and ice control methods.

3. Research Needs and Opportunities

The highest priority issues are considered ones related to:
- Performance standards and monitoring
- Alternative de-icing chemicals and minimizing environmental damage.

Other issues include:
- Operations analysis and defining the overall benefits achieved from technology improvements
- Better technology transfer and dissemination of information
- Miscellaneous issues

3.1 Performance Standards and Monitoring

The current trends towards contracting out winter maintenance services, and downloading responsibilities onto the municipalities, has brought into focus a number of information gaps and uncertainties. The most important issues in this area are listed below:

a) What is the standard now?

Winter maintenance standards used to date are subjective, and objective performance standards are not yet available. Typically, most highway authorities have used qualitative standards based on the road class (which is related to the traffic volume), the pavement surface condition (e.g., bare, centre-bare, etc.), and the length of time required to achieve the desirable condition after the end of inclement weather (a storm).

In practice, these standards have often been exceeded with the result that the public has become accustomed to a higher level of service. This has, de facto, created a higher standard which is not well-defined, but is expected by the public.

There is a need for harmonization since standards vary between provinces across Canada, and between provincial ministries and municipalities.

b) What should the standard be?

The principal issues here are the degree to which the public benefits from a given level of service versus the costs that are incurred. This is a very broad topic that encompasses many technical, legal, financial and political issues. On the technical side, there is a need to benchmark the benefits with the level of service.

c) How should the standard be defined and monitored?

A wide range of parameters and methods can be used to define a standard. However, there are no standardized quantitative measures available for defining or monitoring quality of winter maintenance operations. Although the lack of standards has been brought into focus by the current trend towards contracting out winter maintenance operations, it is also of concern in cases where the highway authorities undertake operations themselves or are evaluating new winter maintenance technologies.

Standards for winter maintenance operations may include the following parameters:

- The surface condition and the time within which it is to be achieved (e.g., Bare pavement within 30 minutes after the start of a storm, etc.)
- The surface condition that is to be maintained during the storm
- The pavement friction level that is to be achieved within a given time after the start of a storm, and the pavement friction that is to be maintained during a storm
- The time to recover from a storm
- The "design storm" – this is very important to define. Is the performance standard to be achieved for all storms, or are some storms considered to be so severe that the standard does not apply?
- Chloride loading – should part of the standard be to minimize chloride loading to the environment?
- Accidents and delays - should part of the standard be to minimize accidents and delays?
- A "resource-based" approach – for example, a standard could be written in the form of the number of snowplows that are to be on the road (for a given network) within a certain time after the storm has commenced.

3.2 Alternative De-Icing Chemicals and Minimizing Environmental Damage

De-icing chemicals and methods, and their use in practice, are summarized in Table 1 according to:

- the type of de-icing chemical,
- the form of the chemical, and

- how the chemical is used (e.g., de-icing or anti-icing).

Table 1 De-Icing Chemical and Usage

De-Icing Chemical	Form of Chemical	Usage	
		De-Icing	**Anti-Icing**
Salt	Dry in particles	Common practice	Limited tests done
	Liquid	Limited tests done	Limited tests done
	Pre-wetted	Limited tests done	Limited tests done
Alternatives	Dry in particles or flakes	Limited tests done (depending on de-icer being considered)	Limited tests done (depending on de-icer being considered)
	Liquid	Limited tests done (depending on de-icer being considered)	Limited tests done (depending on de-icer being considered)
	Pre-wetted	Limited tests done (depending on de-icer being considered)	Limited tests done (depending on de-icer being considered)

Many factors affect the most suitable usage of de-icing chemicals, such as:
- the current and forecast pavement temperature
- the current and forecast precipitation
- the traffic volume
- the road condition (covered with ice, packed snow, etc.)
- the target level of service.

Strategies for minimizing de-icer usage and environmental damage include:

a) Using salt more efficiently

The potential approaches include:
- Applying salt in liquid or pre-wetted form, as opposed to dry form, which is the approach not commonly used at present
- Using salt in an anti-icing mode vs a de-icing mode
- Timing salt applications for maximum advantage (e.g., to take advantage of traffic patterns, expected storm patterns, exposure to sunlight, etc.)
- Varying the salt application rate.

b) Using alternative de-icing chemicals

Alternative de-icing chemicals can offer the following additional advantages:
- They may be more environmentally friendly than salt

- They are effective at lower temperatures than salt. It is generally recognized that the minimum practical operating temperature for salt is about –12° C to –15° C.
- They may require less material to be applied than salt.

However, currently-available alternative de-icing chemicals are more costly than salt.

The most critical research needs in this area are:

- To define the operating envelope where each approach and each chemical is most suited.
- To quantify the advantages and disadvantages for each case.

3.3 Operations Analysis and Defining the Overall Benefits Achieved from Technology Improvements

Winter maintenance operations are extensive, making it difficult to evaluate the benefits achieved from a specific technology improvement in relation to the overall system cost. The "theoretical" benefits achieved from a specific technology improvement may not be realised in practice because highway authorities have extensive infrastructure and require significant resources and fixed assets for its maintenance.

There is a need to better understand the cost-effectiveness of specific technology improvements, and to use this knowledge to focus research into the areas that have the biggest overall impact. Winter maintenance research tends to be too narrowly focussed, and should also address broader issues..

3.4 Better Technology Transfer and Dissemination of Information

Currently, the testing and research that is conducted is fragmented as many highway authorities and organizations carry out evaluations on a relatively informal basis. The information obtained usually does not get widely disseminated between highway authorities and, at times, the information does not get transferred within the highway authorities to field personnel.

Improved information transfer will avoid duplication, and foster further improvements, as highway authorities and the industry will be able to learn from the experiences of others. It is also important to maintain a network of contacts for personnel specializing in winter maintenance operations. The following approaches are recommended to improve communications and technology transfer:

(a) Organize a Winter Maintenance Conference or Workshop
While there are several conferences dealing with winter maintenance, such as the Eastern and Western Snow Conferences, SWIFT, and the APWA conference, none of these is focussed on winter maintenance problems for roads in Canada. An annual winter maintenance conference, or workshop, that is focussed on roads for Canadian highway authorities, should be organized.

(b) Establish a Website
Prepare and maintain a website where information is posted and updated. The University of Iowa currently maintains a "Snow and Ice" list which helps to provide a network of contacts.

This institution is currently in the process of establishing a "Winter Maintenance Strategies" course over the Internet at its website.

3.5 Miscellaneous Issues

a) Development of Standardized Testing Approaches and Comparison Methods

Currently, testing is carried out relatively informally. Furthermore, the tests are often carried out using different test approaches and the results are evaluated using different methods of comparison. This makes it difficult to compare or evaluate the results from different testing programs. This situation could be improved if commonly-accepted test approaches and methods of comparison were available. It is also recommended that dedicated test sites be established where the required testing infrastructure is readily available. It is noted that Ontario Ministry of Transportation has already established a dedicated test site near Barrie, Ontario, with its Maintenance 2001 Project.

b) Automatic Vehicle Locators

Do they help and are they worth the money? What is the optimum amount of information to be obtained from Automatic Vehicle Locators?

c) Characteristics of winter maintenance sands

It was generally believed that sufficient information is now available to define sand performance. However, a need exists for better technology transfer.

d) Reducing animal kills

Further developments are required. This is an area where some testing is currently underway.

e) Reducing or preventing the amount of snow that accumulates on highway signs

A solution to this problem would provide significant benefits.

f) Providing winter maintenance information to the public

This issue encompasses also legal and political aspects. The technical issues include

- What information be provided
- Cost of providing information
- Timeliness and reliability of information.

g) Snowplows

Snowplough technology is relatively stable. Research needs have lessened because of the following reasons:

- a large amount of practical experience has been built to date, and a significant amount of testing has been done.
- Snowplow manufacturers and suppliers are competitive and engaged in competitive research.

h) Snowdrifting

There is a large amount of practical experience, and a significant amount of testing has been done to date. Also, SHRP has recently issued comprehensive guidelines on snowdrifting. The main task is to provide effective technology transfer.

4. Recommended Research Projects

The following six projects were identified as high priority projects according to the criteria formulated in Section A.

a) Defining current winter maintenance standards
b) Defining the target standard
c) Monitoring compliance with standards
d) Large-scale implementation and evaluation of anti-icing strategies and road weather information systems (RWIS)
e) Minimizing salt applications
f) Alternative de-icers.

a) Defining Current Winter Maintenance Standards

Project Description:	To define the standard of service that is actually being provided to the public at present.
Proposed Solution:	Detailed recording of the chronology of winter storms, storm conditions, the winter maintenance operations undertaken, and the results achieved. The surface condition achieved should contain information defining when and where a surface condition was "lost" (e.g., bare pavement becoming re-covered with ice or packed snow, etc). The work should be carried out for a range of geographic areas, and for roads under the jurisdiction of both the municipalities and the provincial ministries.
Expected Benefits:	A baseline for the provision of services. This is fundamental from many angles, including contracting out services, transferring infrastructure to the municipalities, and evaluating technologies within the agencies.
Partnership Opportunities:	Provincial and municipal agencies and the industry need to work together. It is noted that a study of this type is currently being carried out by the MTO in co-operation with the Minnesota Department of Transportation.
Resources Required:	Estimated $ 50,000 to $ 200,000, depending on the number of sites, and presuming that the participating provincial and municipal authorities will collect the required data without charge.

b) Defining the Target Standard

Problem Description:	The target level of service should be based on engineering and economic principles. There is a need to establish the relationship between the specific winter maintenance operations and the benefits achieved.
Proposed Solution:	Investigate the relationship between the winter maintenance operations undertaken (e.g., the type of operation – plowing, sanding, applying de-icing chemicals), the timing of the operations, the pavement surface condition achieved (e.g., bare pavement, centre-bare, etc), and user costs (traffic delays, accidents, traffic volumes).
Expected Benefits:	A technical basis for establishing quantitative standards which are required for contracting out services and for evaluating technologies within the highway agencies.
Partnership Opportunities:	Partnership with provincial and municipalities agencies.
Resources Required:	Estimated $ 50,000 to $ 100,000, depending on the scope and number of sites. It is assumed that the participating road authorities will collect the required data without charge.

c) Monitoring Compliance with Standards

Project Description:	Together with establishing standards and target levels of performance, it is also necessary to establish methodology for monitoring compliance with the standards.
Proposed Solution:	Due to the complexity of this project, it is recommended that the project be undertaken in phases. Phase 1 should document the approaches in the current technology and develop terms of reference for the subsequent phases
Expected Benefits:	The monitoring methods used are essential to ensure that value-for-money is realized from winter maintenance operators.
Partnership Opportunities:	The most significant opportunities for partnership are with the industry and other highway agencies, including Transportation Research Board (TRB), which is in the process of formulating a National Cooperative Highway Research Program proposal with similar objectives.

Resources Required: Phase 1 estimated $ 50,000. Later phases estimated $ 100,000 to $ 500,000 depending on scope and results of Phase 1.

d) Large-Scale Implementation and Evaluation of Anti-Icing Strategies and Road Weather Information Systems (RWIS)

Project Description: A version of this project has been already described in Chapter H, Traffic Management and ITS as Project ***e*** (Cost-Effective Road/Weather Information Systems). The only difference between the versions is that in this version the project objective is more specific in seeking to link RWIS with specific winter maintenance activities.

Proposed Solution: It is well known that accurate and timely forecasts are a fundamental requirement for successfully implementing an anti-icing strategy. . There is a need for further demonstration projects and trials to determine what works most effectively in various situations.

Expected Benefits: Reduced exposure to adverse road conditions; improved motorist safety; improved winter road maintenance operations.

Partnership Opportunities: Road jurisdictions, maintenance contractors, and equipment suppliers.

Resources Required: Estimated $300,000 - $500,000 per regional demonstration.

e) Minimizing Salt Applications

Project Description: The current trends in this area are for using liquid or pre-wetted applications, and/or for using variable application rates. Although some testing has already been carried out, more information is still required to fully define the operating envelope (where each application is most suitable), and the costs and benefits for different applications under various conditions.

Proposed Solution: Additional field testing studies need to be carried out.

Expected Benefits: Reduced salt application rates resulting in cost savings and lessening environmental impact.

Partnership Opportunities: Yes; road jurisdictions, maintenance contractors, and equipment suppliers.

Resources Required: Estimated at $ 50,000 to $75,000.

f) Alternative De-Icers

Project Description:	The objective is to investigate the operating envelope for alternative de-icers under field conditions.
Proposed Solution:	The project should include consolidation of available information and field testing. Limited evaluation results should be supplemented with testing in areas with different climatic conditions.
Expected Benefits:	A better understanding of the operating envelopes of alternative de-icing chemicals leading to cost savings and lessening environmental impact.
Partnership Opportunities:	Road jurisdictions, chemical and equipment suppliers, and maintenance contractors, and other organizations such as the Insurance Corporation of BC.
Resources Required:	State-of-the-art review and technology transfer estimated at \$25,000; field testing estimated at \$ 300,000 to \$500,000.