Estimation of Investment Requirements to Preserve the Canadian Roadway Infrastructure

D.J. Swan
Applied Research Associates Inc.
5401 Eglinton Avenue West, Suite 204, Toronto, ON, Canada, M9C 5K6
Tel: (416) 621-9555, fax: (416) 621-4917, email: djswan@ara.com

Jerry J. Hajek
Applied Research Associates Inc.
5401 Eglinton Avenue West, Suite 204, Toronto, ON, Canada, M9C 5K6
Tel: (416) 621-9555, fax: (416) 621-4917, email: hajek1@rogers.com

David K. Hein
Presenting Author
Applied Research Associates Inc.
5401 Eglinton Avenue West, Suite 204, Toronto, ON, Canada, M9C 5K6
Tel: (416) 621-9555, fax: (416) 621-4917, email: dhein@ara.com

Bruno Jacques
Transport Canada
Place de Ville (ACAB), Ottawa, ON, Canada, K1A 0N5
Tel: (613) 990-5340, fax: (613) 957-3280, email: jacqueb@tc.gc.ca

Paper prepared for presentation
at the Pavement Preservation/Preserving the Economy session
of the 2007 Annual Conference of the
Transportation Association of Canada
Saskatoon, Saskatchewan

ABSTRACT

What are the main components of the Canadian road network and what do they cost over their life-cycle? What is the total annualized cost of building and maintaining a provincial highway or a municipal arterial road in different parts of the country? What portion of road infrastructure costs should be attributed to trucks? This paper provides answers to these questions using the results from a recent study sponsored by Transport Canada. The objective of the study was to estimate the representative annualized capital and maintenance costs for Canadian provincial, territorial, and municipal roads, and allocate them to cars, trucks, and buses. The study was part of the Transport Canada Full Cost Investigation Project currently underway.

The paper describes procedures for estimating annualized life-cycle costs of roads in different geographical regions of Canada and for different road functional classes. The entire Canadian road network was classified into 14 geographical regions, and the road network in each region was divided into 14 road functional categories. This classification resulted in 196 representative road sections. There were 14 geographical regions because some of the Provinces were subdivided into two regions and the Territories were combined into one region. Total annualized capital and maintenance life cycle costs per kilometre of roadway were estimated for each of the 196 representative road segments. Annualized cost estimates and road inventory data were based on extensive surveys of federal, provincial, territorial, and municipal agencies. Survey responses were obtained from nearly all senior Canadian transportation agencies and from 15 representative municipalities. The estimation of annualized costs for the individual representative road segments was facilitated by a computational model. The model utilized 90 separate cost items to estimate the annualized costs for each representative road segment.

Cost allocation analysis further assigned the total annualized life-cycle costs to cars, trucks, and busses using the incremental method. The cost allocation percentages depend on road functional classification. For example, about 70 percent of all road infrastructure costs for provincial rural freeways in Southern Ontario were allocated to trucks, whereas only about 6 percent of all costs for municipal rural local roads were allocated to trucks.

BACKGROUND

The Full Cost Investigation Project was initiated by Transport Canada in 2004 with the assistance of representatives from provincial and local transportation agencies. The purpose of the Full Cost Investigation Project is to estimate the full of constructing and maintaining the transportation system in Canada, as well as to estimate social costs generated by transportation activities in Canada [1].

The study is focused on four primary modes of transportation across Canada:

- Road
- Air
- Rail
- Marine

The purpose of the project described in this paper was to help evaluate the costs of the four primary modes of transportation. The objective is to make meaningful comparisons among modes. This will aid in the selection between transportation modes, such as between the same origin and destination for a given product, for freight, or for a given itinerary for passengers. The results of the project could help guide transportation policy in Canada including an objective of estimating cost burden assumed by users. The concept of user pricing encompasses the cost to move people, goods, and raw materials across and within Canada.

Because of the complexity of the task of estimating full cost transportation for the four primarily transportation modes, the project has been divided into smaller, more manageable components. This paper outlines two of the steps carried out to estimate the costs of road infrastructure in Canada: (a) Estimation of roadway costs by functional classification described in Reference 2, and (b) Allocation of the estimated costs to cars, trucks, and buses described in Reference 3.

ESTIMATION OF ROADWAY COSTS BY FUNCTIONAL CLASSIFICATION

The estimation of road infrastructure costs was accomplished using the following steps:

1. The entire public road infrastructure in Canada, consisting of more than 650,000 two-lane equivalent km of roads, was divided into 196 functional categories of roads. Each functional category was represented by a one-km long representative road segment.
2. Each representative road segment was broken down into representative cost components based on type of infrastructure (pavements, bridges, and all other) and type of costs (initial, rehabilitation, and maintenance).
3. Representative cost components were broken down into representative cost elements. Unit costs and quantities were estimated for each element using extensive surveys.
4. Costs estimated for the individual elements were aggregated in terms of the representative components, the representative road segments, and the extent of each functional category of roads.

Representative Road Segments

Representative road segments were developed by classifying the entire network by geographical regions, jurisdictions, design features, and road functional classes. The classification schema used is shown in Figure 1.

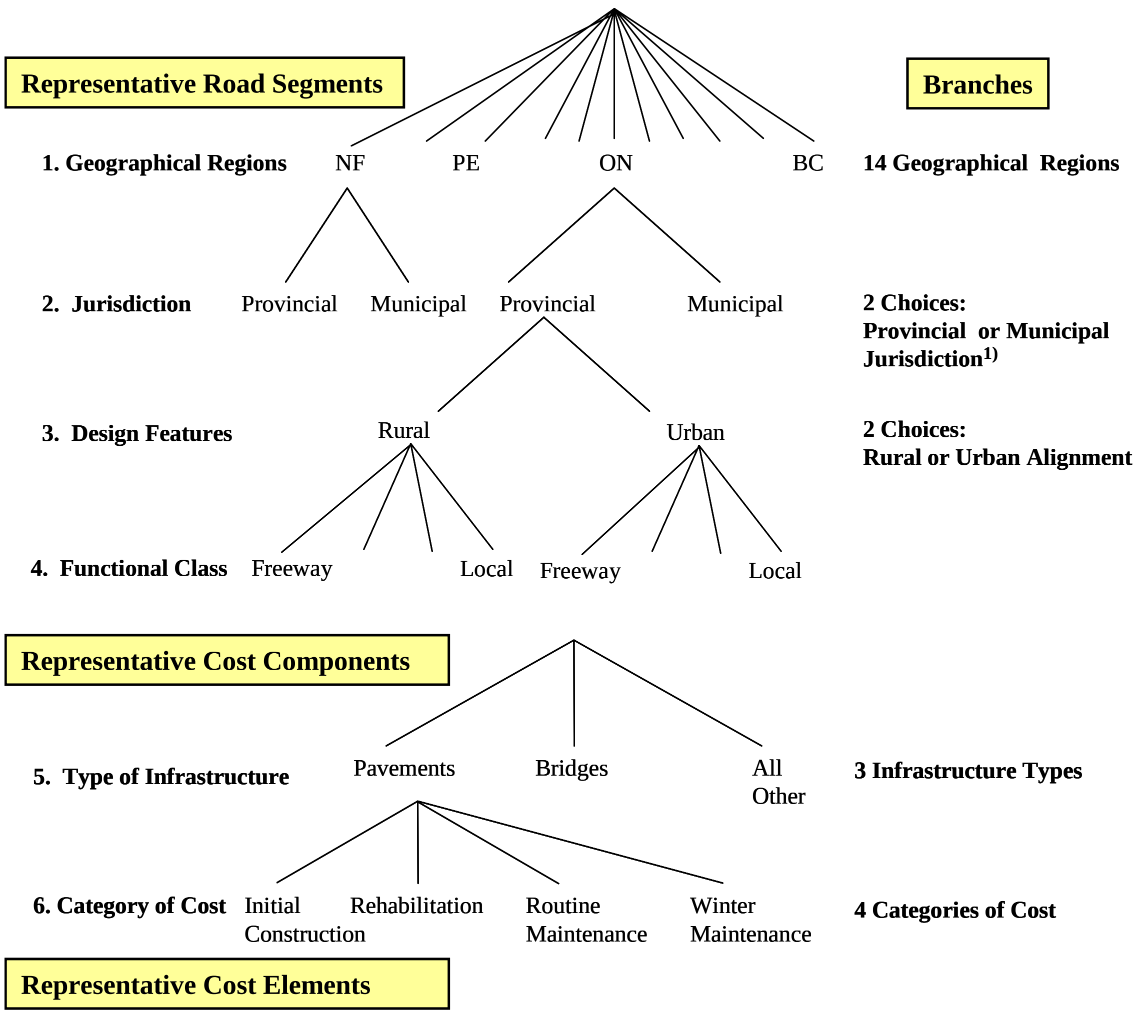

Figure 1. Classification schema.

Classification by Geographical Region

Classification by the geographical region was necessary to account for the differences in road infrastructure costs due changes in geographical location, environmental conditions, traffic flow, and road design features. For example, it is typically more expensive to construct a road through the mountainous areas of British Columbia than across the Prairie Provinces. The classification recognizes all ten Provinces and one combined "territory." To account for environmental and other differences that exist within a single province, Québec, Ontario, and British Columbia were each subdivided into two regions. Consequently, there were 14 geographical regions.

Classification by Jurisdiction

Classification by jurisdiction divided roads into provincial roads and municipal roads. This division was necessary because municipal roads have typically higher construction costs (for example because of smaller contracts and higher traffic volumes) and, in many situations, different road design features, e.g., closed drainage systems. Federal and territorial roads were combined with the provincial roads.

Classification by Design Features

Classification by design features divided roads into rural and urban. Rural and urban roads differ mainly by the following design features:

Rural – Road has open roadside ditches without curb-and-gutter. Road may have rural road design features even if it is located within municipal boundaries and is classified as a municipal road.

Urban – Road has predominantly an urban alignment, including curb-and-gutter and a closed drainage system. Road is considered to be urban when more than 50 percent of its alignment is urban.

Classification by Road Functional Class

Classification by road functional class was necessary because of the differences in design features such as pavement and shoulder width and road design speed. The following classification was used for provincial roads:

Freeway – A divided highway with full control of access.

Arterial – A two-lane or a multi-lane road that carries significant volumes of long distance traffic at high speeds. There is a high degree of access control.

Collector – A two-lane or a multi-lane road that balances traffic flow needs with access. Access to the road is governed by traffic flow considerations and by safety concerns.

Local – A two-lane or a multi-lane road that primarily provides access to local land users. Access to the highway is controlled by safety concerns.

The following classification was used for municipal roads:

Arterial – Resembles a highway going through a municipality.

Collector – Feeds traffic from an arterial to the local roads or vice-versa.

Local – All other roadways that are not residential streets, and arterials or collector roads.

Residential – Residential roads and streets provide direct access to residences and were not included in the study.

The classification schema resulted in a total of 14 representative segments in each of the 14 geographical region. Considering that there were 14 regions, the total number of representative segments was 196.

Representative Cost Components

Each representative segment was divided into representative cost components by the type of road infrastructure (pavements, bridges, and all other infrastructure components) and the type of costs (initial, rehabilitation, and maintenance) as shown in Figure 1.

Type of Road Infrastructure

Road infrastructure was divided into three infrastructure types: pavements, structures, and all other infrastructure component.

Pavements **–** Pavements included all pavement layers above the subgrade soil.

Bridges **–** The category of bridges included bridges and large culverts, road tunnels, large retaining walls, and large snow sheds.

All Other Infrastructure Component **–** All other infrastructure component included all components that were not a pavement or a structure such as earth work, culverts, drainage systems, landscaping and fencing, lighting, and safety and traffic control appurtenances.

Types of Costs

The following four types of costs were established in view of the budgeting and asset management practices of Canadian transportation agencies (Figure 2).

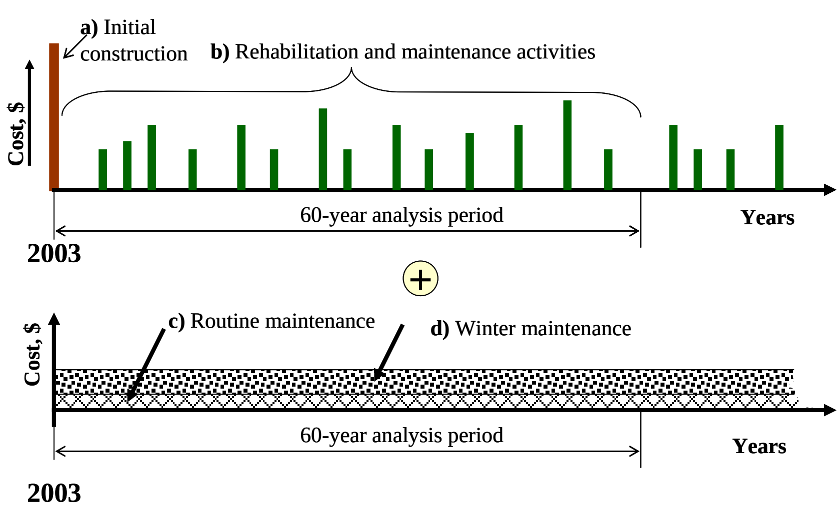

Figure 2. Cost streams used to estimate total cost.

Initial Construction Costs **–** Initial construction costs include costs incurred during the initial construction of the road infrastructure. Initial construction costs were estimated separately for the three road infrastructure components.

Rehabilitation and Maintenance (R & M) Cost **–** Rehabilitation and maintenance costs include all expenditures that provide a measurable and lasting improvement (improvement lasting more than a year) in the condition of a road infrastructure asset. Typically, rehabilitation and maintenance costs are considered by transportation agencies to be capital costs. Rehabilitation and maintenance costs were estimated separately for the three road infrastructure components.

Routine Maintenance Cost **–** Routine maintenance costs include expenditures that do not increase asset value. Typically, routine maintenance costs are considered by transportation agencies to be operating costs. Routine maintenance costs included minor repairs such as filling of potholes, minor guide rail repairs, minor bridge repairs, cutting grass, maintenance of the right-of-way, and the removal of debris. Routine maintenance costs were estimated as a combined cost for all three road infrastructure components.

Winter Maintenance Costs **–** The cost of winter maintenance includes the cost of the field operations for snow removal and ice control and the costs of all other associated and supporting activities and facilities [4]. Winter maintenance costs are considered to be operating costs and were estimated as a combined cost for all three infrastructure components.

Representative Cost Elements

Representative cost components were further subdivided into representative cost elements. For example, in the case of the representative cost component *initial pavement costs*, representative elements included the type and thickness of individual pavement and shoulder layers, the extent of subgrade improvements, the length of subdrains, and the length of closed drainage system.

Cost Estimation Methodology

Cost estimates were based on unit costs and quantities obtained for the representative cost elements. Consequently, the total cost estimates were based on hundreds of data elements. To ensure that the estimates were as accurate as possible, an extensive survey of federal, provincial, and municipal transportation agencies was carried out. Detailed survey responses were obtained from nearly all Canadian senior transportation agencies and from 15 municipal agencies.

In addition to the agency surveys, data and information were also obtained through extensive review of contract drawings, engineering manuals, guidelines and specifications, literature review [5, 6, 7, 8], internet searches of databases posted by Canadian federal, provincial, and municipal transportation agencies, and consultations with experts.

To the extent possible, unit costs and quantities obtained through surveys were left unchanged. In some situations, the values were adjusted by engineering judgment to take into account costs and quantities reported by adjacent jurisdictions. If specific quantities and unit cost data could not be generated by surveys or by documentation reviews, quantities and unit costs were estimated by engineering judgment using a team approach.

Cost estimation was facilitated by a computational model. The model combined hundreds of data elements in terms of unit costs and quantities, and yielded estimated costs for all representative cost components in all geographical regions. All estimated data elements used in the model are well-defined and can be changed by the user if better estimates become available. Because the total cost estimates are based on hundreds of data elements, the overall cost estimates should remain reliable even if the estimates for some of the data elements are off.

Estimated costs were expressed in terms of equivalent uniform annual costs calculated using a 6 percent discount rate and assuming a 60-year analysis period. The costs include overhead costs (planning, engineering, construction supervision, quality assurance and building detours and temporary bridges), but do not include the cost of land. Initial costs of bridges and all other road infrastructure were adjusted to reflect the infrastructure age.

Results of Cost Estimates by Functional Class

Example results of the estimated annualized costs are given for Southern Ontario in Table 1. The table contains nine individual data tables. Eight of the tables correspond to the eight types of costs and the last table provides total costs. Similar tables were developed for all 14 geographical regions.

The following observations are based on the results presented in Table 1.

- Initial construction costs dominate the total costs. For example, the pavement initial construction costs alone represent 37 percent of coats (
- Figure 3).
- All costs tend to increase with the higher functional class of the road. This is expected because, for example, arterial roads are built and maintained using higher standards than collector roads.
- Municipal roads have typically lower costs than the corresponding provincial roads. Municipal roads typically follow the existing terrain and municipalities tend to be located on terrain suitable for building roads.
- In general, urban roads have higher costs than the corresponding rural roads. For example, urban roads have more expensive drainage systems, tend to have more bridges per given road length, and have higher routine and winter maintenance costs.
- Winter maintenance costs are typically higher than routine maintenance costs. The winter maintenance costs are generally at par with the pavement maintenance and rehabilitation costs.

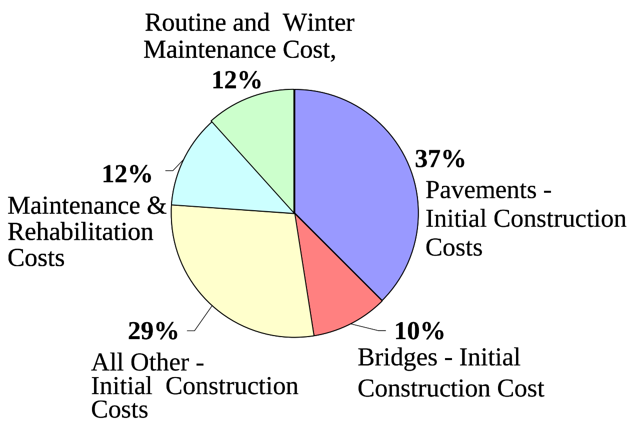

Figure 3. Distribution of the cost for provincial rural arterial roads in Southern Ontario.

Estimated costs of the type presented in Table 1 can be used to compare costs of preserving road infrastructure in different geographical regions, and to compare the model costs with actual expenditures. In an ideal situation, if the model overestimates provincial expenditures, it means that the province is renewing its road infrastructure at a lower renewal rate than that assumed by the model. On the other hand, if the model underestimates the reported expenditures, it means that the province is renewing its road infrastructure at a higher rate than that assumed by the model.

Table 1. Example of cost reporting sheet, Southern Ontario

1. Pavements - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 27,580	$ 11,092		
Arterial	$ 16,828	$ -	$ 13,671	$ 17,002
Collector	$ 15,216	$ 16,764	$ 11,183	$ 14,277
Local	$ 9,781	$ -	$ 9,096	$ 11,077

2. Pavements - Maintenance and Rehabilitation Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 3,026	$ 2,090		
Arterial	$ 3,954	$ -	$ 2,881	$ 2,881
Collector	$ 3,754	$ 3,464	$ 2,155	$ 2,155
Local	$ 2,854	$ -	$ 2,035	$ 2,035

3. Bridges - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 11,172	$ 13,407		
Arterial	$ 10,055	$ 10,055	$ 5,638	$ 5,638
Collector	$ 8,938	$ 11,172	$ 5,012	$ 6,265
Local	$ 5,586	$ 3,910	$ 626	$ 1,253

4. Bridges - Maintenance and Rehabilitation Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 545	$ 654		
Arterial	$ 436	$ 436	$ 245	$ 245
Collector	$ 315	$ 394	$ 218	$ 273
Local	$ 164	$ 115	$ 27	$ 55

5. All Other Road Infrastructure - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 34,479	$ 35,742		
Arterial	$ 24,993	$ 27,637	$ 17,116	$ 20,065
Collector	$ 16,267	$ 23,503	$ 12,741	$ 18,862
Local	$ 8,629	$ 12,569	$ 7,587	$ 12,848

6. All Other Road Infrastructure - M&R Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 389	$ 1,439		
Arterial	$ 449	$ 1,012	$ 459	$ 1,104
Collector	$ 461	$ 1,076	$ 493	$ 1,190
Local	$ 442	$ 1,150	$ 492	$ 1,283

7. Routine Maintenance Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 1,925	$ 2,063		
Arterial	$ 1,788	$ 1,925	$ 1,788	$ 1,925
Collector	$ 1,650	$ 1,788	$ 1,650	$ 1,788
Local	$ 1,513	$ 1,650	$ 1,513	$ 1,650

8. Winter Maintenance Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 3,300	$ 3,300		
Arterial	$ 2,750	$ 3,025	$ 2,475	$ 2,750
Collector	$ 2,200	$ 2,750	$ 1,925	$ 2,200
Local	$ 2,200	$ 2,750	$ 1,375	$ 1,925

Total Roadway Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 82,417	$ 69,787		
Arterial	$ 61,253	$ 44,091	$ 44,274	$ 51,612
Collector	$ 48,802	$ 60,911	$ 35,377	$ 47,009
Local	$ 31,169	$ 22,145	$ 22,752	$ 32,126

Note:
All costs reported in this table are equivalent uniform annual costs (based on 6 percent discount rate and 60-year analyses period) reported for one one-km-long traffic lane. The reporting units are Canadian dollars for 2003.

COSTS ALLOCATION BY VEHICLE TYPE

The objective of typical highway cost allocation studies is to allocate road costs to the categories of highway users who are responsible for them. Consequently, highway cost allocations studies are typically carried out by jurisdictions which adhere to the user-pay policy [9, 10, 11]. The user-pay policy states that users should pay in proportion to the road costs for which they are responsible.

The cost allocation was carried out for all annualized cost estimates prepared for the 196 representative road segments and 8 types of costs described previously. The cost allocation procedure is described in Reference 3. The results were expressed as percentages of annualized costs allocated to cars, trucks, and buses. The vehicle types used in this study were defined as follows.

Cars or light vehicles (motorcycles, passenger cars and light trucks)

In terms of regulations, cars and light vehicles are defined as vehicles with a Gross Vehicle Weight (GVW), or registered GVW, of 4,500 kg or less. However, Canadian transportation agencies typically classify vehicles by appearance. The category of light vehicles includes motorcycles, passenger cars, all other two-axle, four-tire vehicles. Light vehicles pulling trailers of any kind are also classified as light vehicles. In this paper, light vehicles are referred to as cars.

Trucks

Typically, trucks are defined as vehicles with GVW exceeding 4,500 kg which are not buses. Canadian transportation agencies classify and report trucks as vehicles with six-or-more tires which are not buses. This definition of trucks was used in this study.

Buses

For classification purposes in the field, transportation agencies define buses as vehicles manufactured to carry passengers which have at least six tires. The majority of buses on Canadian roads are probably school buses.

Commercial Vehicles

Trucks and buses combined are called commercial vehicles (CV).

Allocation Methodology

The cost allocation methodology was based on the incremental method. The incremental method allocates road infrastructure costs of successively heavier or larger vehicles in increments that correspond to the increasing costs of providing the road infrastructure for these vehicles. For example, for the initial pavement construction, the first increment represents the cost of providing pavement size and thickness (pavement widths and shoulder widths and pavement structure) considered to be adequate for cars only. The first increment is called the base case. The cost for the base case is a common responsibility of all vehicles and is assigned to all vehicle classes on the basis of each class’s share of vehicle kilometres of travel adjusted for the vehicle size.

The second increment represents the additional cost of increasing the pavement area and pavement thickness to accommodate commercial vehicles (trucks and buses). This additional cost was assigned to commercial vehicles only. The cost allocation between cars and commercial vehicles represented the first step in the cost allocation process. In the second step, the costs allocated to commercial vehicles were divided between trucks and buses. The schema of the cost allocation methodology is shown in Figure 4.

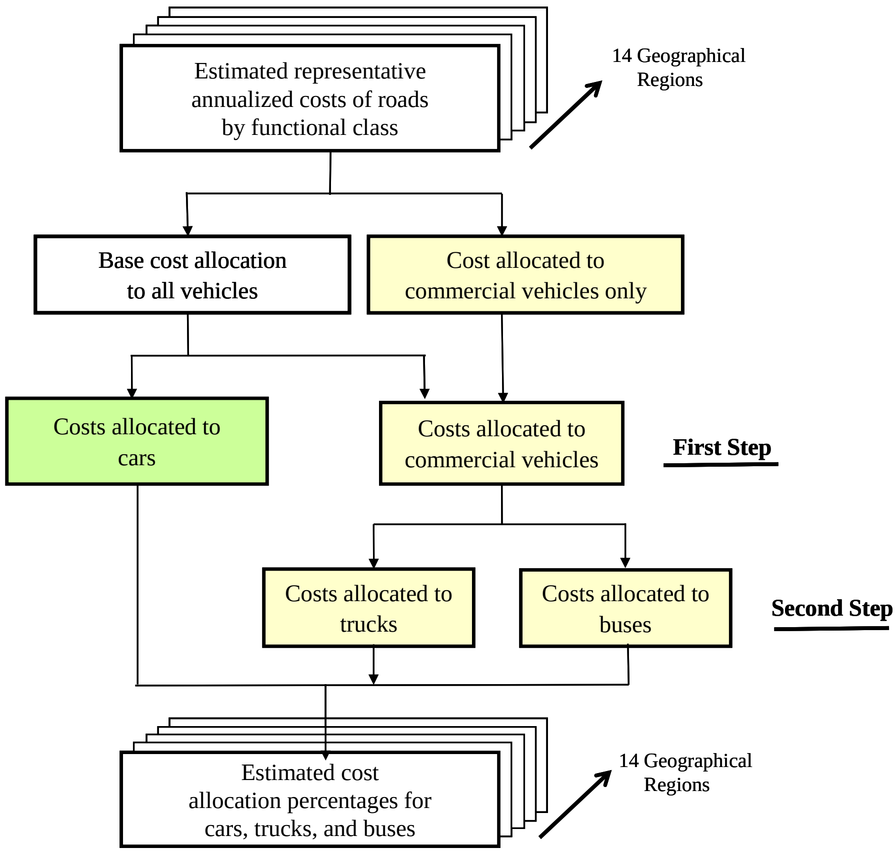

Figure 4. Cost allocation methodology.

Cost Allocation Between Cars and Commercial Vehicles

Cost allocation estimates between cars and commercial vehicles were carried out separately for eight individual cost types as outlined in Table 2.

Allocation of Initial Construction Costs

According to the schema shown in Figure 5, the total annualized cost of the initial construction for roadways, pavements and bridges was allocated three ways:

- Costs of the base case were allocated to both cars and CV.
- Costs of the additional roadway width, pavement width, and bridge deck area required for CV, were allocated to CV only.

- Costs of the alignment changes, and additional pavement and bridge structures required for CV, were allocated to CV only.

Table 2. Proposed cost allocation between cars and commercial vehicles for all cost types

Cost type	Cost item	Cost allocation procedure
Initial roadway construction	Additional road width required to for CV	All to CV
	Alignment and other changes required for CV	All to CV
	Base case allocation	To cars and CV
Initial pavement construction	Additional pavement width required for CV	All to CV
	Additional pavement structure required for CV	All to CV
	Base case allocation	To cars and CV
Initial Bridge construction	Additional bridge deck area required for CV	All to CV
	Additional bridge structure required for CV	All to CV
	Base case allocation	To cars and CV
R&M costs for road infrastructure (without pavements and bridges)		Same split as for initial construction
R&M costs for pavements	R&M due to the additional area required for CV	All to CV
	R&M due to traffic loads	All to CV
	R&M due to the environment	To cars and CV
R&M costs for bridges		Same split as for initial construction
Cost of routine maintenance		To cars and CV
Cost of winter maintenance		To cars and CV

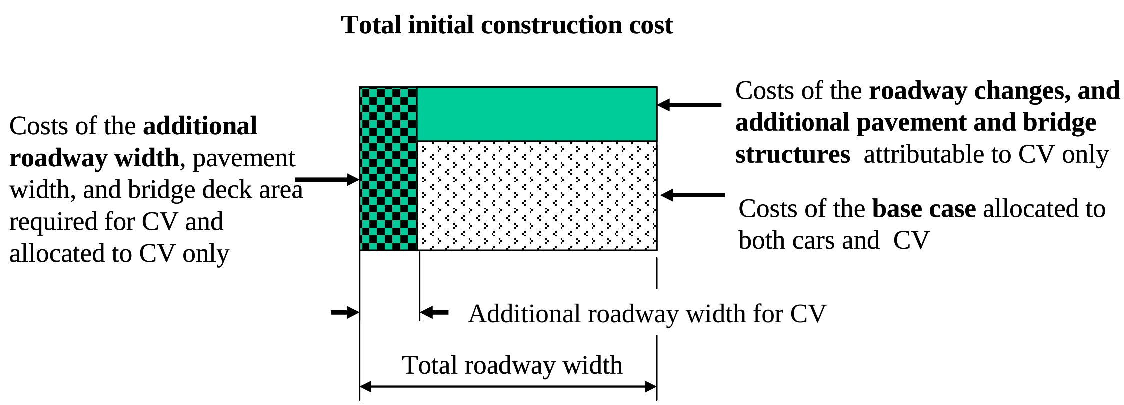

Figure 5. Allocation of initial road construction costs.

Cost of Base Case

The base case assumes a roadway width, pavement structural capacity, and bridge strength that are judged to be appropriate to accommodate a traffic flow containing cars and associated supporting vehicles. The associated supporting vehicles include emergency response vehicles (e.g., ambulances and emergency-response buses), vehicles required to provide routine and winter maintenance (e.g., high-speed snow plows), and vehicles required for maintenance and rehabilitation operations (e.g., trucks for the transportation of paving materials, trucks for the transportation of construction equipment such as hot-mix pavers, and bucket-trucks used for bridge inspections). It is expected that associated supporting vehicles will use the base case roadway only when necessary for the preservation of the roadway itself. For bridges, a base case bridge design vehicle would probably be a fully loaded 4-axle dump truck. In addition, the base case bridge structure should withstand wind and seismic loads, and scouring forces of water flows.

Base case costs were allocated by considering the usage of the representative roadway segments by cars and CV, and by considering the impact of cars and commercial vehicles on the capacity of the road to carry vehicles. This capacity was expressed in terms of Passenger Car Equivalent (PCE) factors. Several recent cost allocation studies have used different PCE factors to represent different types of commercial vehicles [12, 13], and this approach was also used in this study.

<u>Costs of the additional roadway width, pavement width, and bridge deck area required for CV</u>

The additional roadway width, pavement width, and bridge deck area was estimated by subtracting the width deemed to be required to accommodate car-only traffic from the typical roadway width. These estimates were carried out for all 196 representative roadway segments.

<u>Costs for Roadway Changes and Pavement and Bridge Strengthening</u>

Alignment changes and road features attributable to commercial vehicles include items such as the requirement for gentle longitudinal gradients, truck climbing lanes, extra pavement and shoulder width on turning ramps and at intersections, and extra length of acceleration and deceleration ramps.

The cost of the additional pavement structure required to accommodate CV was calculated as the difference in costs between the cost of the original pavement structure for all vehicles and the cost of the pavement structure designed to accommodate cars only. Pavement structures designed for cars only were expected to accommodate also the associated supporting traffic and to withstand commensurable environmental exposure such as freeze-thaw cycles. Specific pavement structures for cars were developed for each of the 14 road functional classes in all 14 categories of roads.

The cost of the additional bridge structure required to accommodate CV was estimated using engineering judgement and ranged from 1 to 8 percent of the total bridge cost required for the base scenario.

Allocation of Rehabilitation and Maintenance Costs

The allocation of rehabilitation and maintenance (R&M) costs for the roadways and bridges was done in the same proportion as that established for the allocation of the initial construction costs for roadways and bridges (Table 2). The allocation of R&M costs for pavements was done according to the cost allocation schema shown in Figure 6.

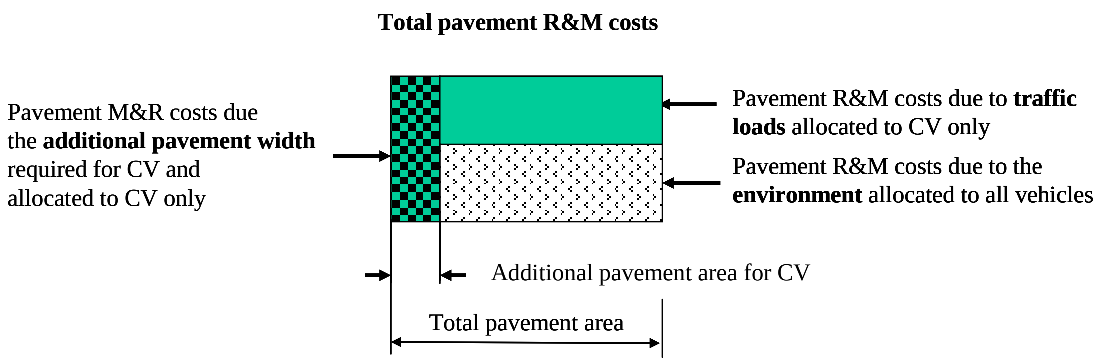

Figure 6. Allocation of pavement rehabilitation and maintenance costs.

The proportion of the total R&M costs attributed to the traffic loads was estimated using the results of a recent study carried out by Laval University [13], and engineering judgement. The results of the Laval study, obtained from Reference 13 are summarized in Table 3 in terms of the traffic damage index. The traffic damage index, multiplied by 100 is equal to the percentage of R&M costs allocated to pavement damage due to traffic loads, and thus allocated to CV only.

Table 3. Traffic damage indices for Canadian conditions

Highway classification	Subgrade soil type			
	Fine grained			Coarse
	Wet-freeze environment		Dry-freeze environment	Average conditions
	High frost	Low frost	High frost	
Major highways	0.65	0.70	0.50	0.80
Other highways	0.60	0.65	0.45	0.70
Local roads	0.55	0.60	0.45	0.60
Municipal roads	0.55	0.60	0.45	0.60

Allocation of Routine Maintenance and Winter Maintenance Costs

The cost of routine and winter maintenance was distributed between cars and commercial vehicles according to the usage of the road capacity using estimated traffic volumes and Passenger Car Equivalents.

Allocation of Costs of CV Between Trucks and Buses

The overall share of costs attributed to buses is typically quite small because the bus volumes are small. The review of the Canadian Long-Term Pavement Performance (C-LTPP) traffic database [16] indicated that bus volumes seldom exceed one percent of the total traffic volume and five percent of the total CV traffic volume. However, on some municipal urban arterial and collector roads with transit bus routes, buses may constitute the majority of commercial traffic. For this reason, the cost allocation between trucks and buses was carried out for two cases:

- Overall case where the allocation was based on average bus volumes.
- Segment-specific case where the allocation was carried out for a specific road segment in a specific municipality.

Only the overall results are reported in this paper. Considering similarities in size and axle weights between trucks and buses, overall allocation of costs between trucks and buses was based on their respective volumes.

Results of Cost Allocation

The computational model developed for the calculation of representative annualized costs was expanded to include the estimation of cost allocation for cars, trucks, and buses. A cost allocation reporting sheet, corresponding to the cost reporting sheet (Table 1), was created for each of the 14 geographical regions. An example of the cost allocation reporting sheet is shown in Table 4. The results shown in Table 4 are for Southern Ontario and include cost allocation percentage for only three of the eight types of costs.

The cost allocation percentages given in Table 4 are the percentages of the representative annualized costs. For example, referring to Table 4, 49.9 percent of the total cost for provincial rural collector highways in Southern Ontario was attributed to cars, 48.6 percent to trucks, and 1.5 percent to buses. The addition of the allocation percentages for cars, trucks, and buses always equals 100 percent.

Because the cost allocation percentages are very sensitive to the intensity of use (to the proportions of cars, trucks and buses), road functional classes serving traffic with high percentage of trucks have high allocation rates for trucks. For example, 68.7 percent of all costs for provincial rural freeways in Southern Ontario were allocated to trucks. Trucks on provincial rural freeways represent 25 percent of all vehicles [2]. On the other hand, only 5.9 percent of all costs for municipal rural local roads in Southern Ontario were allocated to trucks. Trucks on municipal rural local roads represent only 2 percent of all vehicles [2]. Moreover, trucks using local roads tend to be much smaller than trucks using rural freeways.

CONCLUSIONS

The procedure established for estimating the representative annualized capital and maintenance costs by functional class, and for allocating these costs to cars, trucks, and buses provides a reliable, high level estimates for planning and policy purposes.

Ideally, all Canadian provincial and territorial transportation agencies, as well as Canadian municipal transportation agencies, should use a similar definition of road functional classes. The uniform definition of road functional classes would facilitate the planning and management of the road network and would also facilitate transfer of knowledge and experience regarding road infrastructure management across Canada.

The accuracy of the cost estimates, and also the accuracy of the cost allocation estimates, can be improved by modeling the road network using a larger number of representative road segments than the 196 segments used in this study. There are more than 200,000 two-lane equivalent kilometres of federal, provincial, and territorial roads, and more than 650,000 two-lane equivalent kilometres of municipal roads (not including residential streets) in Canada.

Table 4. Example of cost allocation sheet, Southern Ontario

Pavements - Initial Construction Costs

Functional Class	Provincial						Municipal					
	Rural			Urban			Rural			Urban		
	C %	T %	B %	C %	T %	B %	C %	T %	B %	C %	T %	B %
Freeway	20.6	77.8	1.6	25.4	72.4	2.2						
Arterial	32.9	65.3	1.8	47.9	48.8	3.3	50.4	45.3	4.3	55.2	35.9	9.0
Collector	42.2	56.0	1.7	51.6	44.5	3.9	55.7	39.0	5.3	54.9	30.0	15.0
Local	49.5	48.5	2.0	58.2	35.6	6.3	95.9	3.5	0.6	60.1	29.9	10.0

Pavements - Maintenance and Rehabilitation Costs

Functional Class	Provincial						Municipal					
	Rural			Urban			Rural			Urban		
	C %	T %	B %	C %	T %	B %	C %	T %	B %	C %	T %	B %
Freeway	12.0	86.2	1.8	15.2	82.3	2.5						
Arterial	11.8	85.9	2.4	14.8	79.9	5.3	11.8	80.4	7.7	13.8	68.9	17.2
Collector	15.6	81.9	2.5	19.2	74.3	6.5	16.4	73.6	10.0	18.4	54.4	27.2
Local	16.3	80.4	3.3	20.1	67.9	12.0	19.7	68.3	12.0	21.1	59.2	19.7

The sub-tables for other types of costs (e.g., initial construction costs for bridges) are not included in this example of the cost allocation sheet

Winter Maintenance Costs

Functional Class	Provincial						Municipal					
	Rural			Urban			Rural			Urban		
	C %	T %	B %	C %	T %	B %	C %	T %	B %	C %	T %	B %
Freeway	49.2	49.8	1.0	58.8	39.9	1.2						
Arterial	64.8	34.3	0.9	81.1	17.7	1.2	80.5	17.8	1.7	88.7	9.0	2.3
Collector	77.4	21.9	0.7	88.9	10.2	0.9	90.0	8.8	1.2	94.0	4.0	2.0
Local	88.1	11.5	0.5	95.4	3.9	0.7	95.9	3.5	0.6	96.0	3.0	1.0

Total Road Costs

Functional Class	Provincial						Municipal					
	Rural			Urban			Rural			Urban		
	C %	T %	B %	C %	T %	B %	C %	T %	B %	C %	T %	B %
Freeway	29.9	68.7	1.4	37.9	60.2	1.9						
Arterial	41.7	56.8	1.6	56.9	40.4	2.7	55.5	40.6	3.9	61.5	30.8	7.7
Collector	49.9	48.6	1.5	63.2	33.9	2.9	63.6	32.0	4.4	66.2	22.5	11.3
Local	58.5	39.8	1.7	70.8	24.8	4.4	93.1	5.9	1.0	72.1	20.9	7.0

Legend:
C %: Percentage of costs allocated to cars (light vehicles)
T %: Percentage of costs allocated to trucks
B %: Percentage of costs allocated to buses

Cost allocation estimates are very sensitive to the proportion of cars, trucks, and buses in the traffic flow. Better traffic data is the key to improving cost allocation estimates. This would require obtaining additional traffic data from provincial and municipal transportation agencies.

The annualized cost estimates and cost allocation estimates can easily be updated when better data and information become available using the computational model.

ACKNOWLEDGEMENTS

The authors acknowledge the guidance received from the members of the Full Cost Investigation Task Force, particularly from Mr. Amarjit Chadha, Manitoba Department of Transportation and Government Services, Ms. Susi Derrah, New Brunswick Department of Transportation, and Mr. Andrew Liu and Mr. Wayne Gienow, Saskatchewan Highways and Transportation, and Mr. Pascal Mongeau from Transport Canada. We are grateful to all federal, provincial, territorial, and municipal representatives who responded to surveys and provided data and information. The contribution of Mr. Jeff Harris, formally with Transport Canada, is also gratefully acknowledged.

REFERENCES

1. *Interim Estimates of the Financial Costs and Revenues Associated with the Provision of Road Infrastructure in Canada, 2000*. Full Cost Investigation Project, Transport Canada, Economic Analysis, November 2004.

2. Applied Research Associates, *Estimation of the Representative Annualized Capital and Maintenance Costs of Roads by Functional Class*, Final Report prepared for Transport Canada, March 2006, http://www.tc.gc.ca/pol/en/aca/fci/menu.htm

3. Applied Research Associates, *Estimation of Road Cost Allocation between Light Vehicles and Heavy Vehicles in Canada*, Final Report prepared for Transport Canada, February 2007.

4. Conger, S.M., *Winter Highway Operations*, NCHRP Synthesis 344, Transportation Research Board, Washington, D.C., 2005.

5. Washington State Department of Transportation, *Highway Construction Cost Comparison Survey,* April 2002.

6. Agrawal, A.C., Hajek, J.J. et al, *Impact on the Highway Infrastructure of Existing and Alternative Vehicle Configurations and Weight Limits*, Technical Report and General Report, Ministry of Transportation of Ontario, 1201 Wilson Ave., Downsview, Ont., M3M 1J8, May 1997.

7. Cambridge Systematics, *Highway Economic Requirements System, HERS Technical Report*, U.S. Department of Transportation, Federal Highway Administration December 2000.

8. Alam, M., Timothy D., and Sissel, S., *Development of Highway Improvement Capital Cost Table for System-Wide Cost-Benefit and Life Cycle Cost Analysis of Highway Investment Need*, paper presented at the 2005 Annual Meeting of the Transportation Research Board, Washington, D.C., January 2005.

9. Carey, J., *1999 Update of the Arizona Highway Cost Allocation Study*, Final report prepared for Arizona Department of Transportation, August 1999.

10. Oregon Department of Transportation, *2003 Oregon Highway Cost Allocation Study*, Oregon Department of Administrative studies, May 2003.

11. Virginia Department of Transportation, *Vehicle Cost Responsibility Study (SJR 121)*, Joint Legislative Audit and Review Commission, January 1991.

12. US Department of Transportation, FHWA, *1997 Federal Highway Cost Allocation Study: Final Report*, 1997.

13. Cambridge Systematics, Inc., *Minnesota Truck Size and Weight Project*, http://www.dot.state.mn.us/information/truckstudy/.

14. Dore, G., et al, *Estimation of the Relationship of Road Deterioration to Traffic and Weather in Canada*, Report prepared for Transport Canada, http://www.tc.gc.ca/pol/en/aca/fci/menu.htm.

15. Transport Canada, *Allocation Option*s, March 2006, http://www.tc.gc.ca/pol/en/aca/fci/menu.htm.

16. Hajek, J,J., *Traffic Data Processing and Assurance (DEPA)*, Final Report, prepared for Transportation Association of Canada, Canadian Strategic Highway Research Program (C-SHRP), Ottawa, Ontario, January 2006.