DIRECTIONS

THE FINAL
REPORT OF
THE ROYAL
COMMISSION
ON NATIONAL
PASSENGER
TRANSPORTATION

Volume 4

DIRECTIONS

THE FINAL

REPORT OF

THE ROYAL

COMMISSION

ON NATIONAL

PASSENGER

TRANSPORTATION

Volume 4

The opinions expressed in Volumes 3 and 4 are those of the authors of the individual studies and do not necessarily reflect the views of the Royal Commission.

We gratefully acknowledge permission granted to reprint previously published and unpublished material by the following: Academic Press, Inc.; American Economic Association; American Telephone and Telegraph Company; Pierre Berton; The Brookings Institution; Charles River Associates Incorporated; Federal Reserve Bank of Boston; Federal Reserve Bank of Chicago; Federal Reserve Bank of Cleveland; Bill Freedman; George W. Hilton; The Institute of Economic Affairs; Institute for Research on Public Policy; John Deutsch Institute, Queen's University; Alfred E. Kahn; Frank S. Koppelman; Douglass Lee; McGraw-Hill, Inc.; Northwestern University Press; Oceana Publications, Inc.; Organisation for Economic Co-operation and Development; Oxford Review of Economic Policy; Oxford University Press; Pergamon Press Ltd.; T.D. Regehr; Transportation Association of Canada; Transportation Research Board, National Research Council; The University of Chicago Press; University of Toronto Press; George W. Wilson; Clifford Winston; The World Bank.

CANADIAN CATALOGUING IN PUBLICATION DATA

Canada. Royal Commission on National Passenger Transportation

Directions: the final report of the Royal Commission on National Passenger Transportation.

Issued also in French under title: Directions.
To be complete in 4 v.
Chairman: Louis D. Hyndman
ISBN 0-660-14092-6 (set of 4 v.)
ISBN 0-660-14545-6 (v. 1 and 2)
DSS cat. no. Z1-1989/1-1992E (set of 4 v.)
DSS cat. no. Z1-1989/1-1992-1-2E (v. 1 and 2)

1. Transportation — Canada — Passenger traffic. 2. Transportation — Passenger traffic — Government policy — Canada. 3. Transportation — Passenger traffic — Environmental aspects — Canada. 4. Carriers — Government policy — Canada. I. Hyndman, Louis D. II. Title. III. Title: the final report of the Royal Commission on National Passenger Transportation.

HE199.9C35 1992 388'.042'0971 C92-099717-1

CONTENTS

PREFACE

Volumes 3 and 4 present a selection of research studies prepared for the Royal Commission by its Research Division staff and by various authors under contract. Volume 3 includes: historical overviews and general surveys related to transportation objectives; studies on subsidies, pricing and competition; and a discussion of institutional issues. Volume 4 includes: applied analyses related to determining the cost of transportation; industry studies of the air, bus and rail modes; and studies on travel demand, taxation and technology.

The historical overviews comprise two studies. The first, by D.R. Owram, entitled "Icons and Albatrosses: Passenger Transportation as Policy and Symbol in Canada," examines the evolution of transportation in Canada, with particular emphasis on rail and roads. The second, by George W. Wilson, entitled "U.S. Intercity Passenger Transportation Policy, 1930–1991: An Interpretive Essay," provides a survey and a critique of U.S. transportation policy over the last 60 years.

Two of the general surveys, namely, that by Robin Boadway, entitled "The Role of Equity Considerations in the Provision and Pricing of Passenger Transportation Services," and that by David W. Slater, entitled "Transportation and Economic Development: A Survey of the Literature," discuss issues related to the inclusion of equity or economic development as objectives for a passenger transportation system.

The studies that discuss subsidies, pricing and competition issues include those by Trevor D. Heaver, entitled "Subsidies in Canadian Passenger Transportation"; David Gillen and Tae Hoon Oum, entitled "Transportation Infrastructure Policy: Pricing, Investment and Cost Recovery"; John Blakney, entitled "Competition Policy and Canadian Passenger Transportation"; and Keith Acheson and Don McFetridge, entitled "Controlling Market Power in Weakly Contestable Canadian Airline Markets." Federal-provincial institutional issues are discussed in two papers by Patrick J. Monahan, entitled "Constitutional Jurisdiction Over Transportation: Recent Developments and Proposals for Change" and "Transportation Obligations and the Canadian Constitution."

The applied analyses in Volume 4 include three studies on the cost of transportation. These are "Transportation Infrastructure Costs in Canada" by Ashish Lall; "Road Costs" by Fred P. Nix, Michel Boucher and Bruce Hutchinson; and "Environmental Damage from Transportation" by VHB Research & Consulting Inc. Of the industry studies, that by Steven A. Morrison, entitled "Deregulation and Competition in the Canadian Airline Industry," and that by Ron Hirshhorn, entitled "The Effects of U.S. Airline Deregulation: A Review of the Literature," relate to the air mode. The bus mode is addressed in "An Analysis of the Canadian Intercity Scheduled Bus Industry" by Richard Lake, L. Ross Jacobs and S. T. Byerley. The rail mode is addressed in the study by Charles Schwier and Richard Lake, entitled "VIA Rail Services: Economic Analysis," while airports are considered in "Airport Investment and Pricing Policies" by A. Cubukgil, S. Borins and M. Hoen.

Volume 4 concludes with studies on three further topics. Travel demand is addressed in two studies. The paper by Eric J. Miller and Kai-Sheng Fan, entitled "Travel Demand Behaviour: Survey of Intercity Mode-Split Models in Canada and Elsewhere," is a general survey of demand modelling. It is complemented by Richard Laferrière's study, entitled "Price Elasticities of Intercity Passenger Travel Demand," which calculates various elasticities of travel demand from several models on comparable bases. The impact of taxes on the cost competitiveness of Canadian intercity passenger transportation carriers, both intermodally and with U.S. carriers, is addressed in "Differential Taxation of Canadian and U.S. Passenger Transportation" by Ken McKenzie, Jack Mintz and Kim Scharf. Finally, a discussion of general technology issues and of prospective technology relevant to Canadian intercity passenger transportation modes over the next 25 years is provided in "Notes on Intercity Passenger Transportation Technology" by Richard Lake.

The contribution of those who participated in the editing and translation of all of the four volumes of this report was acknowledged at the beginning of Volume 1. In addition, the Royal Commission staff was ably assisted in the editing of Volumes 3 and 4 by PMF Editorial Services Inc.

11

TRANSPORTATION INFRASTRUCTURE COSTS IN CANADA

Ashish Lall*
September 1990

I. INTRODUCTION

In the mid-1970s, various studies produced by the Research Branch of the Canadian Transport Commission (CTC) examined the costs and revenues of road, rail, air and marine modes of transportation.

These studies covered the period 1955 to 1968. The capital stock estimates in the various studies were based on historical investment series which went as far back as the late 19th century. An attempt was made to incorporate not only the direct costs and revenues relevant to the various modes, but also to account for the costs of licensing, economic regulation and justice.

In 1982, Transport Canada produced a study that extended the work of the CTC studies to cover the period 1969 to 1979. Although the general methodology was similar to that of the CTC studies, careful examination shows that some data and/or methodology changes have been made.

The Transport Canada study derived a measure of cost recovery for each mode and therefore was able to cast light on the contribution to each mode from the public purse. The scope of the study was restricted to infrastructure provided by the government. In the case of the air mode, for example, the costs and revenues were related to civil aviation services and did not

* Research Division, Royal Commission on National Passenger Transportation.

include carrier information. The rail mode was the only exception: both infrastructure costs, which are borne by the carrier, and operating costs were included.

The Transport Canada study examined costs on the basis of cash flow, book value and inflation adjustments. The cash flow analysis treated all costs as current costs. The book-value method classified operating and maintenance (O&M) costs as current costs, and capital costs were allocated over the service life of the assets. The book-value analysis derived gross and net capital stocks for the different modes based on investment at historical nominal cost. These historical cost measures were adjusted for inflation in the inflation-adjusted analysis.

The following three sections on road costs, civil aviation costs, and rail costs and revenues attempt to update the Transport Canada study. They, however, do not include any indirect costs such as those of regulation and justice, nor do they attempt to include revenues (with the exception of rail).

The Transport Canada study and its predecessors were based on detailed information collected from a variety of sources. The following sections rely primarily on Statistics Canada data. Some information is also derived from the tables in the CTC and Transport Canada studies. Any inconsistencies between the two sources affect the current study. This leads to inherent biases in the capital stock estimates that can only be rectified by collecting historical data on investment expenditure.

Tables 1 and 2 present some comparative results for the three modes under consideration. The constant-dollar, cash-flow analysis shows a decline in O&M costs for all three modes. Real total costs have also declined for the rail mode. Over the period 1983 to 1986, the real net capital stock of the air and rail modes has increased at an annual rate of 9.46 percent and 6.22 percent respectively. Although the real net capital stock of the road mode registers a decline, this does not suggest that road infrastructure is deteriorating in Canada; the growth rate of the net stock of roads is quite sensitive to the method of depreciation, and pavement life.

Table 1
Modal Costs in Millions of 1986 $

	Cash flow (current $)		Cash flow (1979 $)		Book value (current $)		Inflation adj. (1979 $)		Inflation adj. (current $)	
	O&M	TC	O&M	TC	NCS	TC	NCS	TC	NCS	TC
Air	949	1,374	627	978	2,087	1,358	2,017	951	2,435	1,340
Rail	6,106	7,286	4,030	4,829	10,559	7,805	9,348	5,067	13,733	7,634
Road	2,848	7,856	1,881	5,136	34,099	9,088	33,360	6,868	51,348	10,525

Table 2
Annual Average Compound Growth Rates (%), 1983–1986

	Cash flow (current $)		Cash flow (1979 $)		Book value (current $)		Inflation adj. (1979 $)		Inflation adj. (current $)	
	O&M	TC	O&M	TC	NCS	TC	NCS	TC	NCS	TC
Air	-0.54	3.96	-3.21	2.98	16.80	3.34	9.46	0.32	8.42	1.58
Rail	1.14	0.84	-1.54	-1.77	9.50	2.52	6.22	-0.12	8.19	2.41
Road	-0.64	4.06	-3.30	1.83	6.73	3.72	-0.10	-0.74	1.72	1.34

Notes: **O&M — Operating and maintenance expenditure**
TC — Total cost
NCS — Net capital stock

The Estimates version of the air data is reported here.
Road data are for the case of 20-year, straight line depreciation.

As noted in the text, air and road estimates are for infrastructure costs/capital whereas rail estimates are for total costs/capital.

II. Road Costs in Canada, 1980–1988

BACKGROUND AND PURPOSE

One of the most widely quoted studies of road costs and revenues is by Haritos.[1] This study covered the period 1955 to 1968. It was updated by Transport Canada in the form of a multimodal study in 1982,[2] to cover the period 1969 to 1979. The Transport Canada study (henceforth referred to as the TC study) attempted to derive a cost-recovery index on an industry-wide basis for the rail, road, marine and air modes of transport.

Haritos included those infrastructure costs and revenues that are attributable to users of each mode. The costs included the following categories:

- infrastructure costs;
- administration, O&M costs;
- costs of safety including regulation, courts, police, search and rescue;
- costs of economic regulation (CTC/National Transportation Agency [NTA] costs); and
- costs of licensing and registration, etc.

The purpose of this section is to update the road-cost estimates computed in the TC study. Unfortunately, the lack of data does not permit as detailed an analysis.

DATA AND METHODOLOGY

Data on road expenditures by various levels of government are available from a variety of sources (see Appendix 1). None of the listed sources were used in this study, either because of inconsistencies in the data or because information was not available for the entire period being studied.

The data used here are from Statistics Canada,[3] and include capital and O&M expenditures on roads by all levels of government. Consolidated Government Expenditure on Roads is taken to represent the total expenditure on roads.[4] The total value of construction (new and repair) work purchased by all levels of government is taken to represent capital expenditure on roads. This includes expenditures on highways, roads, streets, bridges, trestles, culverts, overpasses and viaducts. O&M expenditures are then derived as a residual.

As is discussed later, the information utilized in this analysis contains some margin of error compared to other sources; in general, it overestimates road expenditures. It is assumed that costs of courts, police, etc., are included in the residual measure of O&M expenditures. For the purposes of this analysis, some adjustments are made to the data prior to use. Although some of these adjustments are no doubt arbitrary or naïve, the nature of the information restricts choice to that between equally arbitrary alternatives. The adjustments made to the data are described below.

Data on total expenditures on roads are available for the period 1978 to 1985. Information on total expenditures on transportation and communications is available for the period 1978 to 1988. It is assumed that the road expenditures' share of transportation and communications costs is constant over the period 1985 to 1988. The 1985 share (66.28 percent) is used to derive road expenditures for the period 1986 to 1988. O&M expenditures are derived by subtracting capital expenditures from total road expenditures.

Haritos classified road maintenance costs as those that are attributable to users and those that are attributable to non-users. He determined that 92 percent of maintenance costs are attributable to users. Non-users bear some of the snow ploughing and other road costs.[5] Following this procedure, the O&M expenditures derived residually are reduced by 8 percent. These adjusted O&M expenditures are added to capital expenditures to derive the adjusted total expenditures on roads.[6]

The TC study divided capital expenditures into those associated with land or right-of-way, and other capital expenditures. Calculations from the TC study showed that, over the period 1970 to 1979, the share of expenditures on land accounted for an average of 3.76 percent of total capital expenditures. It is assumed that this share prevails over the period 1980 to 1988. In this manner, capital expenditures are divided between land costs and other.

The TC study covered the period 1969 to 1979. Data obtained for this study commenced in 1978. The information for the two overlapping years is not included here; however, it can be used to check the integrity of the information used here. Some data on total expenditures on roads are also available in a paper by Hicks.[7] These are also utilized for checking purposes. Column 2 of Table 3 presents the data utilized in this analysis; column 3 is taken from the paper by Hicks; and column 4 shows the ratio of column 2 to column 3.

Table 4 shows a comparison of the data used here with that used in the TC study.[8] If the information used by Hicks and Transport Canada is "the truth," then the data utilized in this analysis are within 10 percent of "the truth."

Table 3
TOTAL EXPENDITURES ON ROADS
(THOUSANDS OF CURRENT $)

Year	RCNPT	Hicks	RCNPT/Hicks
1978	4,953,486	4,705,301	1.05
1979	5,312,560	5,043,199	1.05
1980	5,982,627	5,673,594	1.05
1981	6,658,200	6,229,165	1.07
1982	7,356,303	6,670,693	1.10
1983	6,955,382	6,650,257	1.05
1984	7,283,913	7,061,900	1.03

Table 4
ROAD EXPENDITURES
(THOUSANDS OF CURRENT $)

Capital Expenditures on Roads			
Year	**RCNPT**	**TC Study**	**RCNPT/TC Study**
1978	2,833,759	3,178,000	0.89
1979	3,170,272	3,222,000	0.98
Road Operating and Maintenance Expenditures			
Year	**RCNPT**	**TC Study**	**RCNPT/TC Study**
1978	2,119,727	1,974,000	1.07
1979	2,142,288	2,004,000	1.07
Total Expenditures on Roads			
Year	**RCNPT**	**TC Study**	**RCNPT/TC Study**
1978	4,953,486	5,152,000	0.96
1979	5,312,560	5,226,000	1.02

The calculation of depreciation for the years 1980 to 1988 requires knowledge of past nominal investments. Haritos used the straight line method of depreciation and assumed a road life of 20 years. This implies that the calculation of depreciation expenses in 1980 will require knowledge of the depreciation expenses from 1961 to 1980. For the period 1961 to 1968, real investment is derived from gross capital stocks.[9] This is converted to a nominal series using the Highway Construction Price Index.[10]

A nominal investment series for the period 1970 to 1979 is derived from the gross capital stocks reported in the TC study.[11] For the year 1969, total investment is available; this, however, has to be broken down to exclude land. This is accomplished by applying the share of land in 1970 to total investment in 1969.[12] Depreciation expenses carried forward from the past can then be derived from the nominal investment series for the period 1961 to 1979 by using a 20-year road life. In the inflation-adjusted analysis, this exercise is conducted at 1979 prices.

The cash-flow analysis treats all costs as current costs and, in this case, total costs are merely the sum of capital and O&M costs. The book-value analysis forms gross capital stocks of land and other capital. This is nothing but the cumulative nominal investment in each type of capital. Following Haritos, roads are assumed to have a useful life of 20 years, and the straight line method of depreciation is used.[13] Land is not depreciated. Subtracting the accumulated depreciation in any year from the gross capital stock in that year yields the net stock or the book value of the assets. Following Haritos, the cost of capital is obtained by multiplying the net stock by the prime lending rate.[14] Total cost is the sum of O&M expenditures, depreciation and the cost of capital.

The inflation-adjusted analysis follows the same method as the book-value analysis. The difference lies in the fact that all expenditures are deflated to remove the effects of inflation.[15] The expenditures on land and O&M are deflated using the implicit Gross Domestic Product (GDP) deflator.[16] Other capital expenditures are deflated using the Highway Construction Price Index.[17] Following the TC study, a six percent cost of capital is used in the inflation-adjusted analysis.

The inflation-adjusted analysis is also presented in "current" terms. This amounts to a revaluation of the constant dollar magnitudes in current-year dollars. The gross and net capital stocks, the stock of land, and depreciation expenses derived in the inflation-adjusted analysis (at 1979 prices) are inflated to current-year dollars using the price deflators described above. The cost of capital is assumed to be 6 percent of the inflated net stock. Total annual costs are derived as the sum of depreciation, the cost of capital and O&M expenditures.

RESULTS

The results are presented in the tables below. Table 5A presents the cash-flow analysis in current and 1979 dollars. The book-value analysis is presented in Table 5B. Table 5C presents the inflation-adjusted analysis in 1979 dollars. These results are then inflated and presented in Table 5D.

The real annual total costs of road infrastructure (1979 dollars) in 1988 were about $166 million lower compared to 1980. Though the stock of right-of-way or land has been increasing, the real book-value of other capital in 1988 was approximately $15 million lower than that in 1980. In real terms, there was a deterioration in road infrastructure in Canada over the period 1980 to 1988.

Table 5A
ROAD INFRASTRUCTURE: CASH-FLOW ANALYSIS

Year	Annual Expenditures					
	Millions of current $			Millions of 1979 constant $		
	O&M	Capital	Total	O&M	Capital	Total
1980	2,521	3,462	5,983	2,280	3,062	5,342
1981	2,891	3,767	6,658	2,359	2,817	5,176
1982	3,238	4,118	7,356	2,431	2,937	5,368
1983	2,904	4,052	6,955	2,077	2,785	4,861
1984	3,238	4,046	7,284	2,245	2,669	4,914
1985	2,990	5,097	8,086	2,021	3,230	5,251
1986	2,848	5,008	7,856	1,881	3,256	5,136
1987	2,931	5,126	8,057	1,853	3,428	5,280
1988	3,048	5,362	8,410	1,852	3,496	5,348

Table 5B
Road Infrastructure: Book-Value Analysis
(Millions of current $)

Year	Capital stock			Annual costs			
	Gross	Net	Land	O&M	Depre-ciation	Cost of capital	Total costs
1980	39,627	22,209	1,873	2,521	1,620	3,165	7,305
1981	43,252	24,058	2,015	2,891	1,777	4,641	9,309
1982	47,216	26,074	2,170	3,238	1,948	4,122	9,308
1983	51,115	27,862	2,322	2,904	2,111	3,112	8,127
1984	55,009	29,489	2,474	3,238	2,267	3,556	9,061
1985	59,914	31,931	2,666	2,990	2,463	3,378	8,831
1986	64,734	34,099	2,854	2,848	2,652	3,587	9,088
1987	69,667	36,182	3,047	2,931	2,850	3,445	9,226
1988	74,827	38,277	3,248	3,048	3,065	4,145	10,258

Table 5C
Road Infrastructure: Inflation-Adjusted Analysis
(Millions of 1979 constant $)

Year	Capital stock			Annual costs			
	Gross	Net	Land	O&M	Depre-ciation	Cost of capital	Total costs
1980	90,414	33,962	4,720	2,280	2,808	2,038	7,126
1981	93,115	33,806	4,835	2,359	2,857	2,028	7,244
1982	95,936	33,722	4,952	2,431	2,905	2,023	7,359
1983	98,612	33,461	5,060	2,077	2,937	2,008	7,021
1984	101,175	33,078	5,166	2,245	2,946	1,985	7,176
1985	104,276	33,214	5,295	2,021	2,964	1,993	6,978
1986	107,407	33,360	5,420	1,881	2,986	2,002	6,868
1987	110,713	33,646	5,542	1,853	3,020	2,019	6,892
1988	114,086	33,947	5,664	1,852	3,072	2,037	6,960

Table 5D
Road Infrastucture: Inflation-Adjusted Analysis
(Millions of current $)

Year	Capital stock			Annual costs			
	Gross	Net	Land	O&M	Depre-ciation	Cost of capital	Total costs
1980	102,329	38,437	5,217	2,521	3,178	2,306	8,005
1981	124,956	45,366	5,926	2,891	3,834	2,722	9,447
1982	134,792	47,381	6,596	3,238	4,082	2,843	10,162
1983	143,713	48,764	7,076	2,904	4,281	2,926	10,110
1984	153,694	50,248	7,451	3,238	4,475	3,015	10.728
1985	164,980	52,550	7,833	2,990	4,690	3,153	10,832
1986	165,322	51,348	8,209	2,848	4,595	3,081	10,525
1987	165,210	50,207	8,767	2,931	4,507	3,012	10,450
1988	174,531	51,933	9,322	3,048	4,699	3,116	10,863

The following addendum to this analysis examines the effects of changes in pavement life on capital stock and road costs. The issue of the appropriate rate of depreciation is particularly contentious in the case of roads and highways. This is because decay depends not only on the initial thickness of the road and on the amount and type of vehicular traffic, but also on climatic conditions.

ADDENDUM: SENSITIVITY OF ROAD COSTS TO PAVEMENT LIFE

Methodology and Results

This addendum includes an examination of the impact on road costs of a change in the rate and method of depreciation. Tables 5A through 5D used the 1979 capital stock benchmarks from the TC study. Roads were assumed to have a life of 20 years and the straight line method of depreciation was used. In this addendum, the following version of the perpetual inventory method[18] is used to construct capital stocks for the period 1956 to 1988:

$$K_{it} = I_{it} + (1 - \delta_i)K_{it\text{-}1}$$

where I_{it} is nominal investment in year t for capital category i; K_{it} is the capital stock in year t for capital category i; and δ_i is the depreciation rate for capital category i. The depreciation expense in year t is then $K_{it\text{-}1}*\delta_i$. The derivation of the investment series and investment in land was discussed earlier.[19] The 1955 benchmark capital stock reported in the work by Haritos[20] is used. The capital stocks are first constructed at 1968 prices and later converted to 1979 prices.

Net capital stocks are constructed for varying road lives. These are 20 years, 25 years, 27 years, 30 years, 33.3 years and 45 years.[21] A life of approximately 12.4 years (depreciation rate 8.0679 percent) is also used. The present discounted value[22] (PDV) of the depreciation stream generated by a dollar's worth of investment depreciated (exponential decay) at this rate is identical to the PDV of the depreciation stream generated by a dollar's worth of investment, assuming a life of 20 years, using the straight line method of depreciation.

The results of the inflation-adjusted analysis[23] are reported in Tables S-1 to S-6. Table S-1 shows that unlike total cost, the net capital stock is quite sensitive to both the rate and method of depreciation. All results reported under the column heading of (SL 20) are reproduced from Table 5C in the main text. Table S-2 shows that the real total cost of road infrastructure has increased by approximately $250 million over the period 1980 to 1988. The net capital stock no longer shows the deterioration encountered earlier.

One should not expect any changes in the gross capital stock and the stock of land. Unfortunately, changes do occur because investment data are derived from tables of two different studies. It is clear that there have been some changes in methodology between the work of Haritos and the TC study.[24] Unless pre-1955 data are collected, such biases cannot be removed. Another source of bias in these results is the use of the 1955 benchmark. Prior to 1955, the straight line method of depreciation was used by Haritos, and the road life was assumed to be 20 years. The sensitivity exercise changes these assumptions in 1956.

Clearly, the results of this study, due to their dependence on earlier work, are constrained by the assumptions of that work. The availability of a consistent historical investment series would help produce a clearer picture of the stock of road infrastructure in Canada.

Table S-1
1988 Ratios with Respect to the Base Case of 20 Years

	(SL 20)	(12.4)	(25)	(27)	(30)	(33.3)	(45)
Ratio of road life	*	0.62	1.25	1.35	1.50	1.67	2.25
Ratio of net capital stock	0.72	0.73	1.13	1.17	1.22	1.28	1.41
Ratio of depreciation expenditure	1.33	1.18	0.90	0.86	0.81	0.76	0.62
Ratio of cost of capital	0.72	0.73	1.13	1.17	1.22	1.28	1.41
Ratio of total cost	0.99	0.95	1.02	1.02	1.03	1.03	1.04

Note: * not comparable

Table S-2
Road Infrastucture: Inflation-Adjusted Analysis (20-Year Life)
Method of Depreciation: Exponential Decay
(Millions of 1979 constant $)

Year	Capital stock			Annual costs			
	Gross	Net	Land	O&M	Depre-ciation	Cost of capital	Total costs
1980	73,296	41,028	3,410	2,280	2,004	2,462	6,746
1981	75,997	41,678	3,525	2,359	2,051	2,501	6,911
1982	78,818	42,415	3,642	2,431	2,084	2,545	7,059
1983	81,494	42,970	3,751	2,077	2,121	2,578	6,776
1984	84,057	43,385	3,856	2,245	2,149	2,603	6,997
1985	87,157	44,316	3,986	2,021	2,169	2,659	6,849
1986	90,289	45,231	4,110	1,881	2,216	2,714	6,810
1987	93,595	46,276	4,232	1,853	2,262	2,777	6,891
1988	96,968	47,335	4,354	1,852	2,314	2,840	7,006

Table S-3
ROAD INFRASTUCTURE: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Net Capital Stock for Varying Asset Lives							
	(SL 20)	(12.4)	(20)	(25)	(27)	(30)	(33.3)	(45)
1980	33,962	31,639	41,028	45,029	46,326	48,027	49,636	53,709
1981	33,806	31,788	41,678	45,929	47,312	49,127	50,849	55,217
1982	33,722	32,044	42,415	46,913	48,381	50,311	52,144	56,811
1983	33,461	32,135	42,970	47,712	49,265	51,310	53,256	58,224
1984	33,078	32,105	43,385	48,367	50,003	52,162	54,221	59,494
1985	33,214	32,615	44,316	49,533	51,252	53,524	55,695	61,272
1986	33,360	33,115	45,231	50,683	52,485	54,871	57,155	63,041
1987	33,646	33,749	46,276	51,961	53,847	56,348	58,746	64,946
1988	33,947	34,400	47,335	53,256	55,226	57,843	60,357	66,876
Growth rate(%):	-0.005	1.05	1.79	2.10	2.20	2.32	2.44	2.74

Note: Growth rate is the average annual compound rate over the period 1980–1988.

Table S-4
ROAD INFRASTUCTURE: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Depreciation Expenditures for Varying Asset Lives							
	(SL 20)	(12.4)	(20)	(25)	(27)	(30)	(33.3)	(45)
1980	2,808	2,518	2,004	1,754	1,669	1,555	1,444	1,154
1981	2,857	2,553	2,051	1,801	1,716	1,601	1,489	1,194
1982	2,905	2,565	2,084	1,837	1,752	1,638	1,525	1,227
1983	2,937	2,585	2,121	1,877	1,792	1,677	1,564	1,262
1984	2,946	2,593	2,149	1,908	1,825	1,710	1,598	1,294
1985	2,964	2,590	2,169	1,935	1,852	1,739	1,627	1,322
1986	2,986	2,631	2,216	1,981	1,898	1,784	1,671	1,362
1987	3,020	2,672	2,262	2,027	1,944	1,829	1,715	1,401
1988	3,072	2,723	2,314	2,078	1,994	1,878	1,762	1,443

Table S-5
ROAD INFRASTUCTURE: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Cost of Capital for Varying Asset Lives							
	(SL 20)	(12.4)	(20)	(25)	(27)	(30)	(33.3)	(45)
1980	2,038	1,898	2,462	2,702	2,780	2,882	2,978	3,223
1981	2,028	1,907	2,501	2,756	2,839	2,948	3,051	3,313
1982	2,023	1,923	2,545	2,815	2,903	3,019	3,129	3,409
1983	2,008	1,928	2,578	2,863	2,956	3,079	3,195	3,493
1984	1,985	1,926	2,603	2,902	3,000	3,130	3,253	3,570
1985	1,993	1,957	2,659	2,972	3,075	3,211	3,342	3,676
1986	2,002	1,987	2,714	3,041	3,149	3,292	3,429	3,782
1987	2,019	2,025	2,777	3,118	3,231	3,381	3,525	3,897
1988	2,037	2,064	2,840	3,195	3,314	3,471	3,621	4,013

Table S-6
ROAD INFRASTUCTURE: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Total Cost for Varying Asset Lives							
	(SL 20)	(12.4)	(20)	(25)	(27)	(30)	(33.3)	(45)
1980	7,126	6,697	6,746	6,736	6,729	6,717	6,703	6,657
1981	7,244	6,819	6,911	6,916	6,914	6,908	6,899	6,866
1982	7,359	6,918	7,059	7,083	7,086	7,087	7,085	7,066
1983	7,021	6,590	6,776	6,816	6,824	6,832	6,836	6,832
1984	7,176	6,764	6,997	7,055	7,070	7,085	7,096	7,108
1985	6,978	6,568	6,849	6,928	6,948	6,971	6,989	7,020
1986	6,868	6,499	6,810	6,903	6,928	6,957	6,981	7,025
1987	6,892	6,549	6,891	6,998	7,027	7,063	7,092	7,150
1988	6,960	6,639	7,006	7,126	7,160	7,201	7,236	7,308

Table S-7
DATA TABLE
(MILLIONS IN 1968 $)

Year	Real Investment and Deflators			
	Land	Capital	Capital deflator	Land deflator
1956	15	274	1.027	0.747
1957	21	336	0.954	0.763
1958	22	314	0.861	0.777
1959	24	405	0.863	0.793
1960	27	529	0.850	0.803
1961	33	633	0.767	0.803
1962	26	677	0.797	0.817
1963	27	742	0.851	0.833
1964	32	872	0.899	0.857
1965	34	1,000	0.979	0.883
1966	39	987	1.054	0.927
1967	43	955	1.014	0.967
1968	38	855	1.000	1.000
1969	42	1,029	1.046	1.047
1970	42	1,033	1.093	1.093
1971	49	1,241	1.179	1.130
1972	49	1,260	1.239	1.193
1973	52	1,283	1.395	1.297
1974	57	1,173	1.871	1.487
1975	56	1,140	2.093	1.633
1976	53	1,090	2.183	1.773
1977	55	1,128	2.337	1.887
1978	64	1,207	2.528	1.997
1979	56	1,132	2.738	2.197
1980	54	1,075	3.099	2.428
1981	53	987	3.675	2.692
1982	53	1,030	3.847	2.926
1983	50	977	3.991	3.072
1984	48	936	4.160	3.168
1985	59	1,132	4.332	3.249
1986	57	1,144	4.215	3.327
1987	55	1,207	4.086	3.475
1988	56	1,232	4.189	3.615

III. Rail Costs and Revenues, 1982–1987

BACKGROUND AND PURPOSE

The purpose of this section is to update the estimates of rail costs and revenues computed in the TC study. The TC study updated the Haritos study done at the CTC.[25] The methodology of these studies, as mentioned earlier, was to look at rail costs on a cash-flow, book-value and an inflation-adjusted basis.

Canadian railways are under a statutory obligation to submit annual reports to the National Transportation Agency (NTA), copies of which are also submitted to the Chief Statistician. The non-confidential information is published by Statistics Canada. The TC study, and that preceding it, relied on the annual reports for their data.

In 1981, changes in the Uniform Classification of Accounts caused data consistency problems for the early 1980s. Prior to 1982, Statistics Canada did not publish railway property accounts.[26] Along with the accounting changes, the data in this study, which are more aggregative in nature, may make it difficult to draw comparisons with earlier work. The basic methodology employed here, however, is taken from the TC study.

DATA AND METHODOLOGY

Data on rail revenues and expenditures were obtained from Statistics Canada publications.[27] Revenues include all rail revenues except government payments. O&M expenditures are derived by deducting depreciation expenses and taxes other than income taxes from total rail expenses.[28] Investment expenditures are classified into those on Land, Way and Structure (W&S) and Machinery and Equipment (M&E). These were obtained from the property accounts.[29]

This information is sufficient to derive the results of the cash-flow analysis in current dollars. The cash-flow analysis treats all costs as current costs; therefore, total costs are merely the sum of taxes other than income tax, capital costs and O&M costs. A revenue-to-expense ratio is easily derived.

The constant dollar version of the cash-flow analysis requires adjustment for inflation. Government payments, revenues, taxes other than income tax, O&M expenditures and expenditures on land are deflated by using the implicit GDP deflator.[30] Expenditures on way and structures are deflated by the implicit price index for total railway construction. Expenditures on machinery and equipment are deflated by the price index for capital expenditure on machinery and equipment by the railway transport industry.[31]

The book-value analysis necessitates the construction of capital stock series. This requires an investment series, a capital stock benchmark and knowledge of the decay rate of the assets. The 1982 net book values of W&S capital and M&E capital are used as the respective capital stock benchmarks for that year.[32] The 1982 end-of-year balance of land is used as the benchmark capital stock for land.[33] The depreciation rates used are 3 percent (exponential decay) for W&S capital and 6 percent (exponential decay) for M&E capital.[34] To construct capital stocks for the period 1983 to 1987, the same version of the perpetual inventory method is used here as in the addendum to Section II:

$$K_{it} = I_{it} + (1 - \delta_i)K_{it-1}$$

where I_{it} is nominal investment in year t for capital category i; K_{it} is the capital stock in year t for capital category i; and δ_i is the depreciation rate for capital category i. The depreciation expense in year t is $K_{it-1}*\delta_i$. Following the TC study, the cost of capital is obtained by multiplying the net capital stock by the prime lending rate.[35] Total cost is the sum of O&M expenditures, depreciation, the cost of capital and taxes.

The inflation-adjusted analysis follows the same method as the book-value analysis. The difference lies in the fact that all expenditures are deflated to remove the effects of inflation. The ratio of inflation-adjusted to book-value net capital stock is calculated from the TC study for the year 1979 for each type of capital.[36] The same ratio is assumed to prevail in the year 1982. This ratio is then applied to the 1982 benchmark capital stocks used in the book-value analysis to derive those for the inflation-adjusted analysis. Following the TC study, a 6 percent cost of capital is used in the inflation-adjusted analysis.

The inflation-adjusted analysis is also presented in "current" terms. This amounts to a revaluation of the constant dollar magnitudes in current-year dollars. The net capital stocks, depreciation expenses,[37] taxes, O&M expenses and revenues derived in the inflation-adjusted analysis (at 1982 prices) are inflated to current-year dollars, using the price deflators described above. The cost of capital is assumed to be 6 percent of the inflated net stock.

RESULTS

The results are presented below in Tables 6 to 10. Each table presents results for VIA Rail, Class I railways (CN, CP and VIA), Class II/III railways and all Canadian railways (sum of Class I and Class II/III). Government payments, which comprise maritime freight, eastern grain and flour, branch-line, intercity passenger, commuter service and other payments, are not included in the calculation of the revenue-to-expense ratio.

Table 7 shows that in real terms there has been a decline of $315 million in government payments to Canadian railways as a whole; with CN and CP accounting for over $300 million. This sharp drop is almost entirely due to the drop in branch-line payments to the railways since 1984. In 1987, Class I railways were able to cover all their costs without relying on government payments. Compared to 1982, VIA's cost recovery is unchanged in 1987. Canadian railways as a whole, however, increased their revenue-to-expense ratio from 0.79 to 0.96. Not only have revenues increased over this six-year period by $577 million, but O&M expenditures have declined by about $350 million.

Table 9 shows that, in real terms, the net total capital stock of Canadian railways has increased by more than $2 billion over the period 1982 to 1987. Most of this increase is accounted for by way-and-structures capital. The M&E stock of VIA registers a decline of about $25 million. The revenue-to-expense ratio has increased from 0.85 in 1983 to 0.91 in 1987 for Canadian railways.

Table 6
RAIL CASH-FLOW ANALYSIS (CURRENT $)

VIA RAIL: CASH-FLOW ANALYSIS
(MILLIONS OF CURRENT $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay-ments
	O&M	Land	W&S	M&E	Taxes	Total expend-itures			
1982	576	0.362	2	12	3	593	157	0.27	449
1983	588	0.003	9	3	7	607	173	0.29	451
1984	543	0.000	4	3	3	552	175	0.32	398
1985	672	0.026	56	2	7	737	200	0.27	524
1986	624	0.080	16	30	5	676	202	0.30	462
1987	639	-0.001	64	35	6	743	193	0.26	517

CLASS I RAILWAYS: CASH-FLOW ANALYSIS
(MILLIONS OF CURRENT $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay-ments
	O&M	Land	W&S	M&E	Taxes	Total expend-itures			
1982	5,150	7	480	262	153	6,052	4,750	0.79	982
1983	5,420	20	697	204	157	6,499	5,501	0.85	955
1984	5,859	11	615	224	165	6,875	6,378	0.93	574
1985	5,735	6	778	423	182	7,124	6,319	0.89	682
1986	5,637	6	634	228	196	6,701	6,282	0.94	615
1987	5,700	9	478	28	195	6,411	6,551	1.02	673

Table 6 (cont'd)
RAIL CASH-FLOW ANALYSIS (CURRENT $)

CLASS II/III RAILWAYS: CASH-FLOW ANALYSIS
(MILLIONS OF CURRENT $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay-ments
	O&M	Land	W&S	M&E	Taxes	Total expend-itures			
1982	525	1.94	51	42	11	632	537	0.85	32
1983	481	0.76	51	63	10	606	541	0.89	30
1984	519	0.89	517	31	11	1,080	659	0.61	28
1985	467	1.30	77	21	11	577	656	1.14	12
1986	469	0.35	91	13	11	585	638	1.09	35
1987	487	1.65	455	24	11	978	643	0.66	33

CANADIAN RAILWAYS: CASH-FLOW ANALYSIS
(MILLIONS OF CURRENT $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay-ments
	O&M	Land	W&S	M&E	Taxes	Total expend-itures			
1982	5,675	9	531	305	164	6,683	5,288	0.79	1,014
1983	5,901	20	748	267	168	7,105	6,042	0.85	985
1984	6,378	12	1,132	255	176	7,954	7,037	0.88	602
1985	6,202	7	854	444	193	7,701	6,975	0.91	694
1986	6,106	6	725	242	207	7,286	6,921	0.95	650
1987	6,187	11	933	52	206	7,389	7,194	0.97	706

Notes: Following the TC study, the revenue/expense ratio is calculated here. There is no presumption as to what its value should be, especially in the case of the cash-flow analysis.

As mentioned in endnote 29, capital expenditures for 1987 are not comparable to those in previous years.

Table 7
Rail Cash-Flow Analysis (Constant $)

VIA Rail: Cash-Flow Analysis
(millions of 1979 constant $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay- ments
	O&M	Land	W&S	M&E	Taxes	Total expend- itures			
1982	433	0.272	2	8	2	445	118	0.27	337
1983	421	0.002	6	2	5	434	124	0.29	323
1984	377	0.000	3	2	2	383	122	0.32	276
1985	454	0.017	39	1	5	500	135	0.27	354
1986	412	0.053	11	21	3	447	133	0.30	305
1987	404	-0.001	44	24	4	474	122	0.26	327

Class I Railways: Cash-Flow Analysis
(millions of 1979 constant $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay- ments
	O&M	Land	W&S	M&E	Taxes	Total expend- itures			
1982	3,866	5	365	180	115	4,531	3,566	0.79	737
1983	3,877	14	523	134	112	4,661	3,935	0.84	683
1984	4,063	8	448	146	114	4,780	4,423	0.93	398
1985	3,878	4	542	283	123	4,830	4,272	0.88	461
1986	3,721	4	432	155	129	4,441	4,147	0.93	406
1987	3,603	6	323	19	124	4,075	4,141	1.02	425

Table 7 (cont'd)

Rail Cash-Flow Analysis (Constant $)

Class II/III Railways: Cash-Flow Analysis
(Millions of 1979 constant $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay- ments
	O&M	Land	W&S	M&E	Taxes	Total expend- itures			
1982	394	1.46	39	29	8	472	403	0.85	24
1983	344	0.55	38	41	7	432	387	0.90	22
1984	360	0.61	377	20	8	766	457	0.60	20
1985	316	0.88	53	14	8	391	444	1.13	8
1986	309	0.23	62	9	7	388	421	1.09	23
1987	308	1.04	308	16	7	640	406	0.64	21

Canadian Railways: Cash-Flow Analysis
(Millions of 1979 constant $)

Year	Annual Expenditures						Annual revenues	Revenue/ expense ratio	Gov't pay- ments
	O&M	Land	W&S	M&E	Taxes	Total expend- itures			
1982	4,260	7	404	209	123	5,003	3,970	0.79	761
1983	4,221	15	561	175	120	5,092	4,322	0.85	705
1984	4,423	9	825	166	122	5,546	4,880	0.88	418
1985	4,193	5	596	297	131	5,222	4,716	0.90	469
1986	4,030	4	494	164	137	4,829	4,568	0.95	429
1987	3,911	7	631	36	130	4,714	4,547	0.96	446

Table 8
Rail: Book-Value Analysis (Current $)

VIA Rail: Book-Value Analysis
(millions of current $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	5	291	295	0.36	576	—	47	3	—	157	—
1983	13	277	290	0.36	588	18	32	7	645	173	0.27
1984	16	263	279	0.36	543	17	34	3	596	175	0.29
1985	72	249	320	0.39	672	16	34	7	730	200	0.27
1986	85	264	350	0.47	624	17	37	5	684	202	0.30
1987	147	283	430	0.47	639	18	41	6	704	193	0.27

Class I Railways: Book-Value Analysis
(millions of current $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	4,344	1,912	6,256	147	5,150	—	989	153	—	4,750	—
1983	4,911	2,001	6,913	167	5,420	245	772	157	6,595	5,501	0.83
1984	5,379	2,106	7,485	178	5,859	267	903	165	7,194	6,378	0.89
1985	5,995	2,403	8,398	184	5,735	288	888	182	7,094	6,319	0.89
1986	6,449	2,487	8,936	190	5,637	324	940	196	7,097	6,282	0.89
1987	6,733	2,366	9,099	200	5,700	343	866	195	7,105	6,551	0.92

Table 8 (cont'd)

RAIL: BOOK-VALUE ANALYSIS (CURRENT $)

CLASS II/III RAILWAYS: BOOK-VALUE ANALYSIS
(MILLIONS OF CURRENT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	674	276	950	51	525	—	150	11	—	537	—
1983	705	322	1,027	52	481	37	115	10	643	541	0.84
1984	1,201	334	1,535	53	519	40	185	11	756	659	0.87
1985	1,241	335	1,576	54	467	56	167	11	701	656	0.94
1986	1,295	328	1,623	54	469	57	171	11	708	638	0.90
1987	1,711	332	2,044	56	487	59	195	11	751	643	0.86

CANADIAN RAILWAYS: BOOK-VALUE ANALYSIS
(MILLIONS OF CURRENT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	5,018	2,188	7,206	198	5,675	—	1,139	164	—	5,288	—
1983	5,616	2,324	7,940	219	5,901	282	887	168	7,238	6,042	0.83
1984	6,580	2,440	9,019	231	6,378	308	1,088	176	7,950	7,037	0.89
1985	7,236	2,737	9,974	238	6,202	344	1,055	193	7,794	6,975	0.89
1986	7,744	2,815	10,559	245	6,106	381	1,111	207	7,805	6,921	0.89
1987	8,445	2,698	11,143	256	6,187	401	1,061	206	7,855	7,194	0.92

Table 9

RAIL: INFLATION-ADJUSTED ANALYSIS (CONSTANT $)

VIA RAIL: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	5	269	273	1.10	433	—	16	2	—	118	—
1983	11	255	266	1.10	421	16	16	5	458	124	0.27
1984	13	241	255	1.10	377	16	15	2	409	122	0.30
1985	52	228	280	1.12	454	15	17	5	491	135	0.28
1986	61	235	296	1.17	412	15	18	3	449	133	0.30
1987	103	244	347	1.17	404	16	21	4	444	122	0.27

CLASS I RAILWAYS: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	4,571	1,766	6,336	448	3,866	—	380	115	—	3,566	—
1983	4,957	1,794	6,750	462	3,877	243	405	112	4,638	3,935	0.85
1984	5,256	1,832	7,088	470	4,063	256	425	114	4,859	4,423	0.91
1985	5,640	2,006	7,646	474	3,878	268	459	123	4,727	4,272	0.90
1986	5,903	2,040	7,943	478	3,721	290	477	129	4,616	4,147	0.90
1987	6,049	1,937	7,986	484	3,603	300	479	124	4,506	4,141	0.92

Table 9 (cont'd)
RAIL: INFLATION-ADJUSTED ANALYSIS (CONSTANT $)

CLASS II/III RAILWAYS: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	709	255	964	156	394	—	58	8	—	403	—
1983	726	281	1,007	156	344	37	60	7	449	387	0.86
1984	1,081	284	1,365	157	360	39	82	8	488	457	0.94
1985	1,102	281	1,383	158	316	49	83	8	456	444	0.97
1986	1,131	273	1,404	158	309	50	84	7	451	421	0.93
1987	1,405	273	1,678	159	308	50	101	7	465	406	0.87

CANADIAN RAILWAYS: INFLATION-ADJUSTED ANALYSIS
(MILLIONS OF 1979 CONSTANT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	5,279	2,021	7,300	604	4,260	—	438	123	—	3,970	—
1983	5,682	2,075	7,757	619	4,221	280	465	120	5,086	4,322	0.85
1984	6,337	2,116	8,453	627	4,423	295	507	122	5,348	4,880	0.91
1985	6,742	2,287	9,029	632	4,193	317	542	131	5,183	4,716	0.91
1986	7,034	2,314	9,348	636	4,030	339	561	137	5,067	4,568	0.90
1987	7,454	2,210	9,664	643	3,911	350	580	130	4,971	4,547	0.91

Table 10
Rail: Inflation-Adjusted Analysis (Current $)

VIA Rail: Inflation-Adjusted Analysis
(thousands of current $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	6	391	398	1.47	576	—	24	3	—	157	—
1983	15	389	403	1.54	588	23	24	7	642	173	0.27
1984	18	370	388	1.59	543	22	23	3	591	175	0.30
1985	74	340	415	1.66	672	22	25	7	726	200	0.28
1986	90	346	436	1.78	624	22	26	5	678	202	0.30
1987	152	359	512	1.86	639	23	31	6	698	193	0.28

Class I Railways: Inflation-Adjusted Analysis
(thousands of current $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	6,005	2,572	8,577	597	5,150	—	515	153	—	4,750	—
1983	6,607	2,737	9,344	646	5,420	338	561	157	6,476	5,501	0.85
1984	7,212	2,812	10,023	678	5,859	364	601	165	6,989	6,378	0.91
1985	8,090	2,995	11,085	702	5,735	389	665	182	6,971	6,319	0.91
1986	8,665	3,005	11,670	725	5,637	424	700	196	6,958	6,282	0.90
1987	8,944	2,850	11,794	766	5,700	440	708	195	7,044	6,551	0.93

Table 10 (cont'd)

RAIL: INFLATION-ADJUSTED ANALYSIS (CURRENT $)

CLASS II/III RAILWAYS: INFLATION-ADJUSTED ANALYSIS
(THOUSANDS OF CURRENT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	931	371	1,302	207	525	—	78	11	—	537	—
1983	967	428	1,396	218	481	51	84	10	626	541	0.86
1984	1,483	436	1,919	226	519	55	115	11	700	659	0.94
1985	1,581	420	2,000	233	467	72	120	11	670	656	0.98
1986	1,660	402	2,063	239	469	73	124	11	677	638	0.94
1987	2,077	402	2,479	251	487	74	149	11	720	643	0.89

CANADIAN RAILWAYS: INFLATION-ADJUSTED ANALYSIS
(THOUSANDS OF CURRENT $)

Year	Capital Stock				Annual Costs					Annual revenues	Revenue/cost ratio
	Net W&S stock	Net M&E stock	Net capital stock	Land stock	O&M	Depreciation	Cost of capital	Taxes	Total costs		
1982	6,936	2,943	9,879	804	5,675	—	593	164	—	5,288	—
1983	7,574	3,165	10,740	865	5,901	389	644	168	7,102	6,042	0.85
1984	8,695	3,248	11,943	904	6,378	418	717	176	7,690	7,037	0.92
1985	9,670	3,415	13,085	935	6,202	461	785	193	7,641	6,975	0.91
1986	10,326	3,407	13,733	964	6,106	497	824	207	7,634	6,921	0.91
1987	11,022	3,252	14,274	1,017	6,187	514	856	206	7,764	7,194	0.93

IV. Civil Aviation Costs in Canada, 1980–1988

BACKGROUND AND PURPOSE

This section updates the estimates of civil aviation costs computed in the TC study. The data and methodology used in the TC study are based on earlier work done at the CTC.[38] Both studies used detailed information to arrive at their results but, unfortunately, similar data are no longer available. This work utilizes aggregative information from alternative sources. The results are therefore not strictly comparable to those of the TC or earlier studies.

DATA AND METHODOLOGY

Data on civil aviation expenditures are available in the Public Accounts, the Estimates and from Statistics Canada. Consolidated Government Expenditure on the air mode is taken to represent the total expenditure on civil aviation.[39] Some adjustments are made to this series prior to use.[40] Data on total expenditures on the air mode are available for the period 1978 to 1985. Those on total expenditures on transportation and communications are available for the period 1978 to 1988. It is assumed that the air mode's share of expenditures on transportation and communications is constant over the period 1985 to 1988. The 1985 share (10.25 percent) is used to derive total expenditures on civil aviation for the period 1986 to 1988.

Federal government expenditures on civil aviation are reported on an annual basis in the Public Accounts and the Estimates. These are reported as being spent by Transport Canada. The Estimates show not only estimated expenditures, but also report actual expenditures with a two-year lag. Capital and O&M expenditure[41] data are obtained from the Estimates.[42]

The information in the Estimates is not entirely consistent over the sample period because of organizational and other changes in Transport Canada. In general, the data represent expenditures on revolving fund airports, federally dependent and other airports, aviation and navigation, and regulation and administration. These classifications, however, change over the sample. It should also be mentioned that the costs of regulation by the CTC/NTA are not included in this study, nor are those of the Aviation Safety Board and the Civil Aviation Tribunal.[43]

Two alternative sets of information are used here. Total expenditures are available from Statistics Canada, and capital expenditures are available from the Estimates. O&M expenditures can then be derived as a residual. Alternatively, both capital and O&M expenditures as reported in the Estimates can be used. Total expenditures are simply the sum of these two categories. One would expect the total expenditures reported by Statistics Canada to exceed those reported in the Estimates because the former are expenditures by all three levels of government, whereas the latter are merely federal government expenditures. This, however, is not the case since Statistics Canada re-classifies the data reported in the Estimates and the Public Accounts into transportation and non-transportation expenditures. Table 11 shows the difference in the data from the two sources.

Table 11
Annual Expenditures on Air Infrastructure
Ratio of Data from the Estimates to Statistics Canada Data

Year	O&M	Total
1980	1.29	1.24
1981	1.30	1.23
1982	1.26	1.21
1983	1.23	1.18
1984	1.20	1.13
1985	1.08	1.05
1986	1.14	1.10
1987	1.08	1.05
1988	1.10	1.07

As already noted, the TC study covers the period 1969 to 1979. Data obtained for the air mode commence in 1978. Although the information for the two overlapping years is not incorporated in this study, it can be used to check the integrity of the information used here.

Table 12 shows data obtained from the Estimates and from Statistics Canada (SC) and compares both sources to the information reported in the TC study (TC). A ratio of data from each source to that reported in the TC study[44] is also reported.

Table 12
AIR INFRASTRUCTURE: EXPENDITURES
(THOUSANDS OF CURRENT $)

Total Expenditures on Air Infrastructure					
Year	Estimates	SC	TC	Est./TC	SC/TC
1978	725,471	601,836	651,000	1.11	0.92
1979	733,803	581,165	603,000	1.22	0.96

Air Infrastructure Operating and Maintenance Expenditures					
Year	Estimates	SC	TC	Est./TC	SC/TC
1978	570,704	447,069	490,000	1.16	0.91
1979	648,525	495,887	515,000	1.26	0.96

Air Infrastructure Capital Expenditures			
Year	Estimates	TC	Est./TC
1978	154,767	161,000	0.96
1979	85,278	88,000	0.97

To recapitulate, capital expenditure data are taken from the Estimates. O&M expenditure data are available from two sources, the Estimates and Statistics Canada. Hence, this study provides one estimate of capital stock and two estimates of the total costs of civil aviation services provided from the public purse.

The TC study classifies capital expenditures into that on land and that on other capital. The data available for the current study do not permit this classification. It is assumed that there is no investment in land over the period 1980 to 1988. This assumption may not be entirely unrealistic since the TC study shows that the stock of land is constant over the period 1976 to 1979.[45]

The results of the cash-flow analysis are presented below in Tables 13A and 13B. The former uses Statistics Canada data and the latter uses data from the Estimates. Both current and constant dollar magnitudes are presented. Capital expenditures are deflated using an investment price deflator for air transport.[46] O&M expenditures are deflated using the implicit GDP deflator.[47]

Table 13A
AIR INFRASTRUCTURE: CASH-FLOW ANALYSIS
ANNUAL EXPENDITURES — STATISTICS CANADA DATA

Year	(millions of current $)			(millions of 1979 constant $)		
	O&M	Capital	Total	O&M	Capital	Total
1980	548	119	667	496	119	615
1981	636	171	807	519	155	674
1982	731	171	902	549	143	691
1983	782	255	1038	560	205	765
1984	832	460	1292	577	353	929
1985	846	445	1291	572	361	933
1986	829	425	1254	547	352	899
1987	874	412	1286	553	351	903
1988	894	448	1342	543	402	945

Table 13B
AIR INFRASTRUCTURE: CASH-FLOW ANALYSIS
ANNUAL EXPENDITURES — THE ESTIMATES DATA

Year	(millions of current $)			(millions of 1979 constant $)		
	O&M	Capital	Total	O&M	Capital	Total
1980	710	119	828	642	119	761
1981	825	171	996	673	155	828
1982	921	171	1092	691	143	834
1983	965	255	1220	690	205	895
1984	999	460	1459	693	353	1045
1985	914	445	1360	618	361	979
1986	949	425	1374	627	352	978
1987	942	412	1354	596	351	946
1988	983	448	1432	598	402	999

The cash-flow analysis treats all costs as current costs. Total costs are the sum of capital and O&M costs. The book-value analysis requires the construction of a gross capital stock series. This is nothing but cumulative nominal investment. Subtracting the accumulated depreciation in any year from the gross capital stock in that year yields the net stock or the book value of the assets.

The TC study used the straight line method of depreciation. Calculation of depreciation for the years 1980 to 1988 requires knowledge of depreciation rates and of past nominal investments. The TC study derived its capital stocks from highly disaggregated information on investment and depreciation. This paper utilizes a single investment series. Implied in the TC study was some composite depreciation rate for aggregate investment. Since it is not possible to infer the composite decay rate, alternative measures have to be employed. Transport Canada provided estimates of composite depreciation rates for airports (4.5 percent) and aviation (6.7 percent). This analysis uses an average of the two rates (5.6 percent) as the decay rate for civil aviation capital. The implied asset life is approximately 18 years. Depreciation expenses in 1980 will therefore depend on investments made in the 18 years prior to 1980.

Nominal total investment for the period 1954 to 1968 is available from the CTC study on air infrastructure.[48] Investment for the period 1969 to 1979 is reported in the TC study.[49] Calculation of depreciation also requires knowledge of investment in land, since land is not depreciated. Real investment in land (in 1968 dollars) for the period 1955 to 1968 is calculated by taking first differences of the stock of land reported in the CTC study.[50] The implicit GNE deflator is used to convert real investment to nominal investment.[51] Nominal investment in land for the period 1970 to 1979 is derived in a similar manner since the TC study reports the nominal stock of land for the period 1969 to 1979.[52] This leaves the year 1969. It is assumed that the 1970 share of land in total investment (about 42 percent) prevailed in the previous year.

Investment in "other" capital is derived by subtracting the nominal investment in land from nominal total investment. A depreciation rate of 5.6 percent is used.[53] The depreciation expense in 1980 includes depreciation over the period 1963 to 1980. Since the composite depreciation rate of the TC study may differ from the one used here, there is an inherent bias in our results.

Following the TC study, the cost of capital is obtained by multiplying the net stock by the prime lending rate.[54] Total cost is the sum of O&M expenditures, depreciation and the cost of capital.

The inflation-adjusted analysis follows the same method as the book-value analysis. The difference lies in the fact that all expenditures are deflated to remove the effects of inflation. As mentioned earlier, O&M expenditure is deflated using the implicit GDP deflator, and capital expenditure is deflated using the investment price deflator for air transport. Following the TC study, a 6 percent cost of capital is used in the inflation-adjusted analysis.

The inflation-adjusted analysis is also presented in "current" terms. This amounts to a revaluation of the constant dollar magnitudes in current year dollars. The gross and net capital stocks and depreciation expense derived in the inflation-adjusted analysis (at 1979 prices) are inflated to current-year dollars, using the price deflators described above. The cost of capital is assumed to be 6 percent of the inflated net stock. Total annual cost is the sum of depreciation, the cost of capital and O&M expenditures.

RESULTS

The results of the cash-flow analysis were presented earlier in Tables 13A and 13B. It is clear that irrespective of the data source, real expenditures on civil aviation have increased in Canada over the period 1980 to 1988. The Statistics Canada data show a somewhat larger increase in total costs. Real capital expenditure has nearly doubled in the nine-year period. According to the Statistics Canada data, real O&M expenditures are higher by about $50 million in 1988 compared to 1980. The data from the Estimates, however, register a decline of about $40 million.

The results of the book-value analysis are shown in Table 14. The nominal stock of capital has more than doubled over the period 1980 to 1988. Irrespective of the data source, the total annual costs in 1988 are found to exceed those in 1980 by over $500 million. The Statistics Canada data register a higher increase.

In a recent discussion paper,[55] Transport Canada reported the net book value of civil aviation infrastructure as being $2,278 million in 1987-88. It is interesting to note that this paper found the net capital stock to be $2,289 million for the same year.

Tables 15A and 15B present the results of the inflation-adjusted analysis. Table 15A shows that, in real terms, the net stock of capital has increased by about $830 million over the sample. The real total costs in 1988 exceed those in 1980 by about $75 million. The Statistics Canada data, however, show an increase that is more than twice that shown by the data from the Estimates.

Table 14
Air Infrastructure: Book-Value Analysis
(millions of current $)

Year	Capital Stock		Annual Costs					
	Gross	Net	O&M SC	O&M Est.	Depre-ciation	Total cost of capital	Total costs SC	Total costs Est.
1980	2,248	1,001	548	710	96	143	786	948
1981	2,419	1,069	636	825	103	206	945	1,134
1982	2,589	1,129	731	921	111	178	1,020	1,210
1983	2,845	1,261	782	965	123	141	1,046	1,228
1984	3,305	1,575	832	999	146	190	1,168	1,335
1985	3,750	1,852	846	914	169	196	1,211	1,279
1986	4,175	2,087	829	949	189	220	1,238	1,358
1987	4,586	2,289	874	942	210	218	1,302	1,370
1988	5,035	2,505	894	983	232	271	1,397	1,487

Table 15A
Air Infrastructure: Inflation-Adjusted Analysis
(millions of 1979 constant $)

Year	Capital Stock		Annual Costs					
	Gross	Net	O&M SC	O&M Est.	Depre-ciation	Total cost of capital	Total costs SC	Total costs Est.
1980	4,364	1,482	496	642	147	89	732	878
1981	4,519	1,486	519	673	152	89	760	914
1982	4,662	1,474	549	691	154	88	791	934
1983	4,867	1,518	560	690	161	91	811	941
1984	5,220	1,697	577	693	174	102	853	969
1985	5,581	1,868	572	618	190	112	874	920
1986	5,932	2,017	547	627	203	121	871	951
1987	6,283	2,149	553	596	218	129	900	943
1988	6,685	2,315	543	598	235	139	917	972

Table 15B

AIR INFRASTRUCTURE: INFLATION-ADJUSTED ANALYSIS

(MILLIONS OF CURRENT $)

Year	Capital Stock		Annual Costs					
	Gross	Net	O&M SC	O&M Est.	Depre-ciation	Total cost of capital	Total costs SC	Total costs Est.
1980	4,345	1,475	548	710	147	89	784	945
1981	4,975	1,635	636	825	167	98	901	1,090
1982	5,587	1,766	731	921	185	106	1,022	1,212
1983	6,063	1,891	782	965	200	113	1,096	1,278
1984	6,810	2,214	832	999	227	133	1,192	1,359
1985	6,882	2,304	846	914	234	138	1,218	1,287
1986	7,163	2,435	829	949	245	146	1,220	1,340
1987	7,372	2,521	874	942	256	151	1,282	1,350
1988	7,462	2,585	894	983	262	155	1,311	1,401

Appendix 1

DATA SOURCES FOR ROAD COSTS IN CANADA

1) Transport Canada, *Annual Report of the Interdepartmental Highway Committee,* Vol. 1. 1987-88. IHC Secretariat, Highway Branch, Transport Canada. This report provides federal highway expenditures for the period 1975-76 to 1987-88.

2) Council of Ministers Responsible for Transportation and Highway Policy, *National Highway Policy Study For Canada — Steering Committee Report on Phase 2.* National Highway Policy Steering Committee. (November 1989). Appendix C of this report provides data on national highway system revenues and expenditures by federal and provincial governments for the period 1983-84 to 1987-88.

3) Transport Canada reports:

   a) *Government Expenditures on Transportation by Province 1985/86–1988/89.* Transport Canada (TP 7064-E). March 1990.
   b) *Government Expenditures on Transportation by Province 1983/84–1986/87.* Transport Canada (TP 7064). March 1988.
   c) *Government Expenditures on Transportation by Province 1981/82–1984/85.* Transport Canada (TP 7064). 1985.
   d) *Federal and Provincial Government Transportation Expenditures by Province 1974/75–1981/82.* Transport Canada (TP 2726). November 1982.

   These reports provide federal and provincial expenditures on all the modes of transportation.

4) The Roads and Transportation Association of Canada also collects data on highway expenditures; however, it cannot provide data from the mid-1970s on.

5) "National and Provincial Economic Impact of National Highway Policy — Final Report." Prepared for Roads and Transportation Association of Canada by Informetrica Ltd., November 1989. (Mimeographed). This report contains data on investment in highways by level of government in 1989 dollars for the period 1961 to 1987.

6) Statistics Canada has published the following Service Bulletins:

a) Catalogue No. 53-006, July 1984, 13, No. 3.
b) Catalogue No. 53-002, February 1986, 2, No. 3.
c) Catalogue No. 53-002, January 1987, 3, No. 2.
d) Catalogue No. 53-002, November 1987, 3, No. 5.

These Service Bulletins contain data on federal and provincial expenditures on roads for some years between 1981-82 and 1985-86. Haritos had drawn the majority of his data from a Statistics Canada publication: *Road and Street Length and Financing* (Catalogue No. 53-201). The last year for which data are available from this source is 1976. The survey was then cancelled and nothing has replaced it.

APPENDIX 2

DATA TABLES

Table A-2.1
(MILLIONS OF 1968 $)

Year	Gross capital stock	Real investment	Deflator	Nominal investment
1955	4,398	—	—	—
1956	4,672	274	1.027	281
1957	5,008	336	0.954	321
1958	5,322	314	0.861	270
1959	5,727	405	0.863	350
1960	6,256	529	0.850	450
1961	6,889	633	0.767	485
1962	7,566	677	0.797	540
1963	8,308	742	0.851	632
1964	9,180	872	0.899	784
1965	10,180	1,000	0.979	979
1966	11,167	987	1.054	1,041
1967	12,122	955	1.014	969
1968	12,977	855	1.000	855

Notes: 1) Column 2, Gross capital stock is reproduced from Haritos (1973), Table II-1, p. 148.

2) The deflator in column 4 is the Highway Construction Price Index, Base 1971.

Table A-2.2
(MILLIONS OF CURRENT $)

Year	Gross capital stock	Nominal investment	Stock of land	Investment in land	Total capital expenditure
1969	14,603	—	892	—	1,120
1970	15,732	1,129	938	46	1,174
1971	17,195	1,463	993	55	1,518
1972	18,757	1,562	1,052	59	1,621
1973	20,547	1,790	1,119	67	1,857
1974	22,742	2,195	1,203	84	2,279
1975	25,129	2,387	1,295	92	2,479
1976	27,508	2,379	1,389	94	2,474
1977	30,144	2,636	1,493	104	2,740
1978	33,196	3,052	1,620	127	3,178
1979	36,295	3,099	1,743	123	3,222

Notes: **1) Column 2, Gross capital stock and column 4, Stock of land are reproduced from *Transport Costs and Revenues in Canada* (1982), Table 4.3, p. 33.**

2) The last column is reproduced from *Transport Costs and Revenues in Canada* (1982), Table 4.1, p. 30.

Table A-2.3

Year	Construction Price Index			Implicit GDP deflator		Prime lending rate
	Base 71	Base 81	Spliced Base 79	Base 81	Base 79	
1960	72.1	—	0.311	—	—	—
1961	65.0	—	0.280	—	—	—
1962	67.6	—	0.291	—	—	—
1963	72.2	—	0.311	—	—	—
1964	76.2	—	0.328	—	—	—
1965	83.0	—	0.357	—	—	—
1966	89.4	—	0.385	—	—	—
1967	86.0	—	0.370	—	—	—
1968	84.8	—	0.365	—	—	—
1969	88.7	—	0.382	—	—	—
1970	92.7	—	0.399	—	—	—
1971	100.0	—	0.431	—	—	—
1972	105.1	—	0.453	—	—	—
1973	118.3	—	0.509	—	—	—
1974	158.7	—	0.683	—	—	—
1975	177.5	—	0.764	—	—	—
1976	185.1	—	0.797	—	—	—
1977	198.2	—	0.854	—	—	—
1978	214.4	—	0.923	74.2	0.909	—
1979	232.2	—	1.000	81.6	1.000	—
1980	262.8	—	1.132	90.2	1.105	14.25
1981	311.6	100.0	1.342	100.0	1.225	19.29
1982	329.3	104.7	1.405	108.7	1.332	15.81
1983	346.3	108.6	1.457	114.1	1.398	11.17
1984	374.0	113.2	1.519	117.7	1.442	12.06
1985	379.8	117.9	1.582	120.7	1.479	10.58
1986	—	114.7	1.539	123.6	1.515	10.52
1987	—	111.2	1.492	129.1	1.582	9.52
1988	—	114.0	1.530	134.3	1.646	10.83

Notes:

1) Column 2 shows the "Old" Highway Construction Price Index, Base 1971.

2) Column 3 shows the "New" Highway Construction Price Index, Base 1981.

3) Column 4 shows the Spliced Index, Base 1979.

Appendix 3

DATA

Total revenue is the total operating revenue (rail)

O&M expenditure is derived as follows:

Total Rail Expenses

Less:

Track and roadway depreciation

Buildings depreciation

Signals, communications and power depreciation

Special W&S depreciation

Locomotives depreciation

Freight cars depreciation

Passenger cars depreciation

Intermodal equipment depreciation

Work equipment and roadway machines depreciation

Other equipment depreciation

Special equipment depreciation

Taxes, other than income

Way and structures capital comprises the following:

Track and roadway

Buildings and related machinery and equipment

Signals, communications and power

Terminals and fuel stations

Machinery and equipment capital comprises the following:

Rolling stock-revenue services

Intermodal equipment

Work equipment and roadway machines

Other equipment

Table A-3.1

Year	W&S deflator	M&E deflator	Capital deflator	GDP deflator	Prime rate
1982	1.314	1.457	1.363	1.332	15.81
1983	1.333	1.526	1.391	1.398	11.17
1984	1.372	1.535	1.419	1.442	12.06
1985	1.434	1.493	1.453	1.479	10.58
1986	1.468	1.473	1.464	1.515	10.52
1987	1.479	1.471	1.470	1.582	9.52

APPENDIX 4

DATA TABLES

Table A-4.1
DEFLATORS

Year	Implicit GDP deflator	Capital deflator
1979	1.000	1.000
1980	1.105	0.996
1981	1.225	1.101
1982	1.332	1.198
1983	1.398	1.246
1984	1.442	1.305
1985	1.479	1.233
1986	1.515	1.207
1987	1.582	1.173
1988	1.646	1.116

Table A-4.2
DATA USED IN CALCULATING PAST DEPRECIATION
(MILLIONS OF $)

Year	Total investment current $	Investment in land 1968 $	Investment in land current $	Implicit GNE deflator	Capital deflator
1963	38	7	6	0.843	0.390
1964	42	3	2	0.864	0.404
1965	40	3	3	0.892	0.423
1966	51	2	2	0.931	0.450
1967	45	5	4	0.968	0.480
1968	59	3	3	1.000	0.482
1969	68	—	29	—	0.511
1970	90	—	38	—	0.504
1971	127	—	53	—	0.543
1972	100	—	13	—	0.568
1973	286	—	93	—	0.605
1974	253	—	26	—	0.650
1975	151	—	39	—	0.705
1976	121	—	18	—	0.783
1977	198	—	0	—	0.815
1978	161	—	0	—	0.897
1979	88	—	0	—	1.000

ENDNOTES

1. Haritos, Z. *Rational Road Pricing Policies in Canada* (Ottawa: Canadian Transport Commission, 1973).

2. Transport Canada, *Transport Costs and Revenues in Canada* (The TC study) Ottawa, July 1982).

3. Some of the data were obtained by a special request from Statistics Canada.

4. Statistics Canada, *Consolidated Government Finance* (Ottawa, December 1987), Catalogue No. 68–202. (Data for more recent years were obtained by special request from Statistics Canada.)

5. See Haritos, *Rational*, Table 6.1, p. 48.

6. Henceforth, any reference to total road expenditures is a reference to this adjusted total.

7. See Table 4 in B. E. Hicks, *RTAC Road Infrastructure Study*, in Proceedings of 23rd Annual Meetings of the Canadian Transportation Research Forum (Saskatoon: University of Saskatchewan Printing Services, 1988), pp. 526–36.

8. Table 4.1 in Transport Canada, *Transport Costs*.

9. From Table II-1 in Appendix 2 in Haritos, *Rational*.

10. See Table A-2.1, Appendix 2.

11. From Table 4.5 in Transport Canada, *Transport Costs and Revenues*.

12. See Table A-2.2, Appendix 2 of this paper.

13. The methodology used in the TC study was used by Haritos in an earlier work in 1973 which covers the period 1955 to 1968. The 1973 piece used a road life of 20 years, as confirmed in Table II.1 of that work. The 1982 TC study makes the same assumption but the tables in that study seem to indicate asset lives of 25 to 27 years depending on the year.

14. Statistics Canada, *Canadian Economic Observer, Historical Statistical Supplement 1990/91* (Ottawa, July 1991), Catalogue No. 11-210.

15. The deflators are reported in Table A-2.3, Appendix 2.

16. Statistics Canada, *National Income and Expenditure Accounts, The Annual Estimates* (Ottawa, December 1989), Catalogue No. 13-201.

17. This is taken from Statistics Canada, *Construction Price Statistics* (Ottawa, August 1990), Catalogue No. 62-007. For the period 1981 to 1988, the new index (base 1981) is used; for the years prior to 1981, the old index (base 1971) is spliced with the new index.

18. The implied depreciation method is exponential decay.

19. Real investment in land for the period 1956 to 1968 was converted to nominal terms, using the implicit GNE deflator. Then the nominal series for the period 1956 to 1988 was deflated by the implicit GDP deflator. The real investment series and the deflators are reported in the Addendum to Section II, Table S-7.

20. The benchmarks (in millions of 1968 constant dollars) are $2,580 and $541 for capital and land respectively. See Table II-1, Appendix 2, in Haritos, *Rational.*

21. The depreciation rate is merely the inverse of the asset life.

22. Using a discount rate of 6 percent.

23. As before, a 6 percent cost of capital is used.

24. For the period 1956 to 1968, the gross capital stock and the stock of land valued in 1968 dollars are similar to those reported by Haritos. This is not the case for the remainder of the period. Unless there was a dramatic increase in road investment in 1969, the TC study is not entirely consistent with the earlier work of Haritos.

25. Z. Haritos, *National Railroad System Annual Costs and Revenues 1956-1970,* (Ottawa: Canadian Transport Commission, Economics Branch, 1973). See also Z. Haritos, "Transport Costs and Revenues in Canada," *Journal of Transport Economics and Policy* 9, 1 (January 1975).

26. These accounts provide investment expenditure data.

27. Statistics Canada, *Railway Transport in Canada: General Statistics* (Ottawa, 1982-1986), Catalogue No. 52-215; and *Rail in Canada* (Ottawa, 1987), Catalogue No. 52-216.

28. Details are reported in Appendix 3.

29. The additions to each category of capital are taken to represent investment expenditures. For 1987, additions are not reported, so the difference between the end-of-year balance and the beginning-of-year balance is taken to represent investment expenditure. This introduces a bias in investment expenditures in 1987 since, unlike other years, retirements are, in effect, netted from gross additions in that year.

30. See Table A-3.1, Appendix 3. The source is Statistics Canada, *National Income and Expenditure Accounts.*

31. Both indexes are reported in Table A-3.1, Appendix 3. The source is Statistics Canada, *Price Indexes for Capital Expenditures on Plant and Equipment (1986=100) — By Industry —Manufacturing and Non-Manufacturing Industries 1926-1990* (Ottawa, 1990), PUB 11.

32. This is taken from the accumulated depreciation accounts reported by Statistics Canada.

33. This value is taken from the property accounts published by Statistics Canada.

34. D. W. Caves and L. R. Christensen, "Productivity in Canadian Railroads, 1956-1975," CTC Research Report No. 10-78-16 (Ottawa: Canadian Transport Commission, 1978).

35. Statistics Canada, *Canadian Economic Observer.*

36. The ratios for 1979 are 1.38, 1.35 and 4.05 for W&S capital, M&E capital and land respectively.

37. Since depreciation expenses include those on W&S and M&E, the implicit price index for capital expenditures (total components) for the railway transport industry is used as a deflator. See Table A-3.1, Appendix 3, capital deflator.

38. Z. Haritos and J. D. Gibberd, *Civil Aviation Infrastructure Annual Costs and Revenues 1954-1968* (Ottawa: Canadian Transport Commission, Economics Branch, 1972). See also Haritos, "Transport Costs and Revenues in Canada."

39. Statistics Canada, *Consolidated Government Finance.*

40. The sum of $649,785,000 is deducted from the expenditures on the air mode in 1980. This amount is a deletion in accordance with the *Adjustments of Accounts Act*; details are available on page 29-11 of the *Public Accounts of Canada* for the fiscal year 1980-81.

41. Part III of the Estimates reports expenditures of revolving fund airports in the section on the Airports Authority Group. Further details are also provided toward the end of the document under the heading of Supplementary Information. The data used in this section are not taken from the Supplementary Information because the operating expenses reported therein include depreciation and certain other items.

42. For more recent years this information is reported in Part III of the Estimates for Transport Canada.

43. This information can be incorporated at a later stage.

44. From Table 2.1 in Transport Canada, *Transport Costs and Revenues.*

45. According to the TC study, the stock of land in current dollars is $421 million over the period 1976 to 1979. In constant 1979 dollars it is $949 million.

46. See Table A-4.1, Appendix 4. The source is Statistics Canada, *Price Indexes for Capital Expenditures on Plant and Equipment.*

47. See Table A-4.1, Appendix 4. The source is Statistics Canada, *National Income and Expenditure Accounts.*

48. See Table 12 in Haritos and Gibberd (1972).

49. See Table 2.1 in Transport Canada, *Transport Costs and Revenues in Canada.*

50. See Table 2 in Haritos and Gibberd, *Civil Aviation Infrastructure.*

51. Haritos and Gibberd use the GNE deflator to deflate investment in land.

52. See Table 2.2 in Transport Canada, *Transport Costs and Revenues in Canada.*

53. See Table A-4.2, Appendix 4 for details on the data.

54. Statistics Canada, *Canadian Economic Observer.*

55. Transport Canada, *Proposed New Cost Recovery Policy: Phase II Discussion Paper* (Ottawa, April 1990), TP 10041.

12

ROAD COSTS

Fred P. Nix, Michel Boucher* and Bruce Hutchinson**
November 1991

SUMMARY

This report describes a preliminary costing study for federal, provincial and territorial roads. It is "preliminary," as more work is required to firm up the data needed for costing purposes: vehicle populations, vehicle characteristics, road costs in individual provinces, etc. Further, where allocation techniques are used, they are, for the most part, borrowed from other studies. No attempt is made to relate the estimated costs to road prices or taxes.

The first step was to assemble information developed by the Transportation Association of Canada (TAC) on road lengths and annual costs. This was then substantially modified both to correct errors and to produce a cost profile of Canadian roads satisfying an analysis of optimal pavement strength. The third step was to develop a profile of vehicles and traffic conditions. More research is required in this area before a precise calculation of road costs is possible. The final step was to calculate road costs.

Road costs were calculated in two ways. First, the methodologies used in studies in the United States, the United Kingdom and Australia were modified to the extent possible and married to the Canadian data. Further, an exploratory Canadian procedure was developed (although not fully tested).

* École nationale d'administration publique, Université du Québec, Sainte Foy, Quebec.
** Faculty of Engineering, Department of Civil Engineering, University of Waterloo.

The results of these allocations are interesting, but not robust enough to base strong conclusions about the appropriate allocation of costs in Canada. Second, an attempt was made to estimate a cost function and develop marginal pavement costs for a standard axle load. (Other aspects of the marginal cost of road use were not investigated.) This attempt uses typical construction costs in Southern Ontario and a model of pavement performance also based on Ontario roads. It is difficult to extend the analysis to other provinces in the absence of appropriate models of pavement deterioration.

A summary of some of the estimates is contained in the table. Only two vehicle classes are shown: the car, and the large truck where "large" means a registered weight of 4.5 tonnes or more. For the first three allocation methodologies shown, costs are an average of all federal, provincial and territorial roads. Municipal or urban roads were not included within the scope of this research.

Summary of (Selected) Road-Cost Estimates

Methodology	Costs per kilometre (1989 cents)		Comment
Cost-allocation methods	**Auto**	**Truck**	
1. U.S. 1982 FHWA	0.5	6.1	• On-going maintence excluded
2. U.K. DoT	1.0	14.2	• Environmental factors excluded
3. Australian	1.9	7.5	• Judged to be most appropriate method for Canadian conditions
4. Exploratory methodology			
– freeways	0.5	2.0	Assumptions require testing; better data would improve the results.
– high-volume highway	0.8	3.0	
– low-volume highway	5.2	14.7	
Marginal pavement cost			
– high-volume freeway	0.0	0.8	May be problems estimating MC for roads with little truck traffic.
– high-volume highway	0.0	7.1	
– low-volume highway	0.0	112.5	

The costs shown under the fourth allocation methodology, the "exploratory" one developed here, are for the road classes indicated. Marginal pavement costs, which are only estimated for intercity paved highways, are shown for three levels of traffic volume which, in this context, means the number of annual axle loads. For the lowest-volume roads — technically, those with less than 15,000 standard axle loads annually — marginal costs are very high (75 cents per standard axle load). It may be, however, that the model of pavement performance used to calculate this is not particularly accurate at these low levels.

In undertaking this work, three issues were addressed:

1) Have pavements been designed with sufficient strengths? In the United States, recent research suggests that pavements are too thin and, as a result, have had to be resurfaced sooner than planned. The consequence is that road costs for heavy trucks are higher than they otherwise would be. (Thicker or stronger pavements mean lower costs for a given axle load.) No evidence has been found to indicate that the same is true in Canada.

2) Are governments spending enough on the roads to prevent unnecessary and costly deterioration? An argument has been made in Canada that the infrastructure is crumbling and governments are falling behind in the amount they spend on roads. The consequence, the argument goes, is that, in the long run, taxpayers will have to foot the bill for an expensive rehabilitation program. If all of this is true, there are significant ramifications for a road costing exercise (costs would be much higher than those developed from actual expenditure data).

This "infrastructure is crumbling" argument is complex and not all aspects are investigated here. It may be that a road left to deteriorate will cost more in the long run than a road which is well maintained throughout its lifetime. This has not been investigated.

What this research has investigated, however, is whether the "infrastructure is crumbling" thesis is based on facts. After adjusting for problems in TAC's data — apparent adding mistakes and the failure to distinguish between *preserving* and *preserving and upgrading* roads — the calculations suggest that the annual expenditures required to maintain the existing roads are approximately $4 billion. This is just about the amount governments are spending. The conclusion, therefore, is that the data do not support the thesis that roads are falling apart. This investigation has nothing to do with a related argument heard recently that governments should spend more on roads to increase capacity. Capacity issues are not addressed in this study.

3) What are the relative contributions of axle loads and environmental factors to pavement deterioration? The answer to this question has a significant bearing on a costing study as it determines the costs allocated to large trucks with heavy axle loads. While there is no simple answer applicable to all roads in all regions of Canada, there is no doubt that environmental factors do play a large role in pavement deterioration. On the strongest pavements with the highest levels of truck traffic, the split between load-related and environmental-related deterioration may be in the order of 50:50. On low-volume roads in regions of Canada where the climate is harsh — for example, most of the roads in the Prairies — environmental factors may account for 80 percent or more of the deterioration.

Glossary

AADTs	**Average Annual Daily Traffic** (or, sometimes, just **ADT** for average daily traffic, or **AADTT** for truck traffic). These are measures of traffic volumes. In this report, they are generally expressed on a **two-lane equivalent basis** (the exceptions being where AADTs from source material are being discussed).
AASHO	The former name of AASHTO (American Association of State Highway and Transportation Officials). In the text, important empirical tests of the relationship between axle loadings and pavement performance are referred to as the "AASHO Road Tests."
ESAL	**Equivalent-Single-Axle Load**, or **Equivalent-Standard-Axle Load.** There are a number of similar terms in use (for example, **LEF** or **load-equivalency factor**). They all have the same purpose: to reduce different axle configurations and different masses to one standard measure in terms of the effect of axles on pavements. In the text, ESAL and LEF are used interchangeably, although there is a tendency to use the ESAL more often when discussing the equivalency factors developed in the AASHO Road Tests and LEF when discussing other equivalency factors.
FHWA	**Federal Highway Administration** of the U.S. Department of Transportation.
GVW	**Gross Vehicle Weight.** A number of other terms are in widespread use (gross vehicle mass, gross combination weight, etc.), but in this report GVW is used throughout. It differs from RGVW in that it is a measure of the actual weight of a truck.
LEF	**Load-Equivalency Factor**. See ESAL.
NHS	**National Highway System.** This 33,169-kilometre (two-lane equivalent) network of highways has been labelled "National" by the Transportation Association of Canada.

Maintenance	In this report, **maintenance** means expenditures which are not considered in the provincial accounts as capital expenditures. This differs from usage in other studies where maintenance includes such activities as resurfacing. In other studies **routine maintenance** might be used to describe activities referred to here as maintenance.
OPAC	**Ontario Pavement Analysis of Costs**. This is a model of pavement deterioration which can separate the effects of load and environment. In this report, it is the primary model used to reach conclusions in respect to pavement behaviour and costs.
PCE	**Passenger-Car-Equivalent**. There are a number of other similar terms (for example, **PCUs**). These attempt to measure capacity use in a consistent fashion. One truck might equal two PCEs whereas a car equals one PCE. For this reason, PCE-km are sometimes used to allocate certain road costs.
RCI	**Riding Comfort Index**. This is a common measure of pavement serviceability in Canada, equivalent to twice the PSI index in the U.S.
RGVW	**Registered Gross Vehicle Weight**. The weight at which a truck is licensed to operate.
SN	**Structural Number** is a measure of pavement strength.
TAC	The **Transportation Association of Canada**, formerly **RTAC** or the **Roads and Transportation Association of Canada**. The data base developed in this study is based on TAC data.
Tandem Axle	A group of two axles on a truck with a suspension system which shares the load between the axles.
Tridem Axle	A group of three axles on a truck with a suspension system which shares the load among the axles.
VKT	**Vehicle Kilometres of Travel**
VMT	**Vehicle Miles of Travel**

1. INTRODUCTION

1.1 PURPOSE OF RESEARCH

The purpose of this research is to identify road costs which may be attributed to various classes of vehicles using federal, provincial and territorial roads. The Terms of Reference define the mandate as follows:

> Identification of the contributions of different classes of motor vehicles to the total costs of rural highway infrastructure and operations. Estimation of the roadway costs per vehicle-kilometre for passenger cars, light trucks/vans, buses, and heavy trucks in major weight classes.

In this work, the following questions are addressed:

- Has the "under built" thesis any validity in Canada ("Were pavements designed with less than optimal strength?") and, if so, has this any bearing on road costing?
- Has the "under maintained" thesis any validity ("We are not spending enough on our roads to maintain them.") and, if so, what implications are there for road costing?
- What are the relative contributions of traffic loads and of time (aging or the environment) to pavement deterioration?
- What is the impact of procedures used in other allocation studies? In other words, "What would be the level of allocated costs in Canada if the methodologies of earlier, generally non-Canadian, studies were used?"

1.2 SCOPE

While the objectives sound ambitious, there are qualifications pertaining to the scope of the research. Of most importance, no new data have been collected. In fact, it was not possible even to undertake a comprehensive survey of all the data which already exist in a variety of bewildering formats in each province. The research was conducted within the following constraints:

- The starting point for all information on roads, in terms of system length by road class, and in terms of unit road costs (maintenance, resurfacing and reconstruction costs per kilometre) was the Transportation Association of Canada's (TAC's) data on infrastructure.
- TAC's information on unit road costs and frequencies (that is, how often are roads of a particular class resurfaced?) was analyzed to determine how well it measures road costs. Adjustments were made both to correct obvious errors and to recalculate what are called "optimum" costs — "optimum" because they are developed after considering optimum pavement durability. These adjustments were based on illustrative road sections in a model of pavement deterioration, using typical construction costs from one province. This *is not* the same as conducting an actual investigation of all (or a sample of all) roads in Canada.
- Other aspects of TAC's data have been adjusted on the basis of partial or incomplete information regarding expenditures by provincial highway agencies. For example, only a small amount of information from four provinces has been reviewed to answer the question, "What portion of annual maintenance is related to pavement and, hence, susceptible to wear from axle loadings?" A more thorough analysis might find a different answer for every jurisdiction and every class of road under a range of traffic conditions.
- The traffic and vehicle data used — for example, the proportion of large trucks in the traffic stream and the loads on these trucks — are not based on extensive surveys *or* comprehensive sources. Readily accessible information has been analyzed and extrapolated over the entire network.
- The costing done in this research uses "national averages" or "typical construction costs" for many calculations. Given the known variability in conditions from one province to another — traffic volumes, the type of trucks, and the nature of road costs — these figures may be misleading. However, the alternative of developing information on each class of road in each of 16 jurisdictions was not possible within the scope of this project.

Finally, since the subject of road costs is controversial, it must also be noted that this report makes no attempt to relate costs either to road prices or to any of the various measures of total road revenues such as fuel taxes. The intention was only to allocate or compute costs. The research considered the existing roads *as if* they were the product of efficient investment decisions in the past. No attempt was made to examine the non-road components of the total road costs (policing, vehicle licensing, private user-costs, etc). Nor did the study consider the cost of new roads or capacity additions to existing roads. Finally, no consideration was given to externalities (air pollution, etc.).

2. The Physical Characteristics of Roads

2.1 INTRODUCTION

A prerequisite to the development of a costing methodology is an understanding of the physical properties of roads. (What do heavy axle loads do to pavements?) Further, since this research uses a variety of costing methodologies within the context of a Canadian data base, it is important to sort out the assumptions made about roads. Otherwise, there is a danger that existing methodologies will be used inappropriately. Finally, the mandate for this research poses three questions, all of which require an understanding of the physical nature of roads. This section provides an overview of road engineering which focusses on pavements and pavement deterioration as this component of a road represents the largest cost item, at least for the road agency.[1]

2.2 ROAD DESIGN

Aspects of road design which play a role in cost allocation are:

Capacity: The primary determinant of capacity is the number of lanes on a road, including passing and climbing lanes as well as the more common four (or more) lane approach used on freeways. These capacity considerations are important in some cost-allocation studies. Often, the method of calculating a vehicle's use of capacity is to reduce it to a measure such as the passenger-car-equivalent (PCE).

Bridges: Bridges are built to carry loads. A consequence is that cost-allocation studies tend to use vehicle weight as a means of allocating bridge costs. For example, the costs of a given base bridge may be calculated and treated as a common cost while any costs for a bridge stronger than this are treated as a function of vehicle weight (GVW) or registered gross vehicle weight (RGVW).

Horizontal and vertical geometry: Roads have geometric features — widths, grades, clearances, curvatures — which can be related to vehicle characteristics. For example, grading costs, which determine the vertical geometry, may be assigned on the basis of weight-to-power ratios. Pavement widths may be assigned on the basis of vehicle widths.

Pavements: Pavements are designed with a certain strength, partly determined by the number of expected axle loads. These are measured with a load equivalency factor (LEF), the most common one being the 18,000-pound equivalent-single-axle-load (ESAL) developed in the U.S. Most recent costing studies critically depend on this concept. For example, new pavement costs may be allocated on the basis of treating a minimum pavement thickness as a common cost; any costs over and above this minimum are a function of ESALs.

These design characteristics are used in allocation studies for the purpose of assigning the costs of new roads. The data used in this study, however, are for the cost of the existing roads. This being the case, many of the design-vehicle-characteristic linkages are not made.

2.3 PAVEMENTS

2.3.1 Introduction

The principal pavement used in Canada is a flexible pavement consisting of granular base and sub-base courses and a surface course of asphaltic concrete. This section focusses exclusively on these flexible pavements — an important point since much of the controversy surrounding road costing emanates from recent work in the United States where rigid pavements are more common.

The initial design choice for a flexible pavement is the number of years it will last before a resurfacing is required. This pavement life may be lengthened by increasing the thickness (described later in Figure 2.5) and/or by using better quality materials. Table 2.1 shows typical structures for flexible pavements in three provinces.

Table 2.1
TYPICAL PAVEMENT STRUCTURES

	New Brunswick	Ontario	Alberta
Asphaltic concrete	140–201 mm	50–130 mm	80–100 mm
Granular base course or asphalt stabilized base	150 mm	150 mm	50 mm
Granular sub-base	455–760 mm	150–450 mm	180–330 mm

The thickness of the components may be converted into equivalent granular thicknesses using the following layer equivalencies: surface = 2; granular base = 1; sub-base = 0.67. Using these, the following numbers illustrate the range of equivalent granular thicknesses in different provinces with a variety of sub-grade and traffic conditions:

	Weak sub-grade Heavy traffic	Strong sub-grade Light traffic
New Brunswick	1,090 mm	750 mm
Ontario	700 mm	350 mm
Alberta	615 mm	420 mm

The thicker pavements required in New Brunswick reflect the poor quality sub-grades in that province. Alberta has the smallest range of thicknesses because most of the pavement deterioration there is due to the harsh climate. These environmental aspects of deterioration are discussed more fully in a later section. Alberta also uses an asphaltic stabilized base course because of the unavailability of good granular material in much of the province.

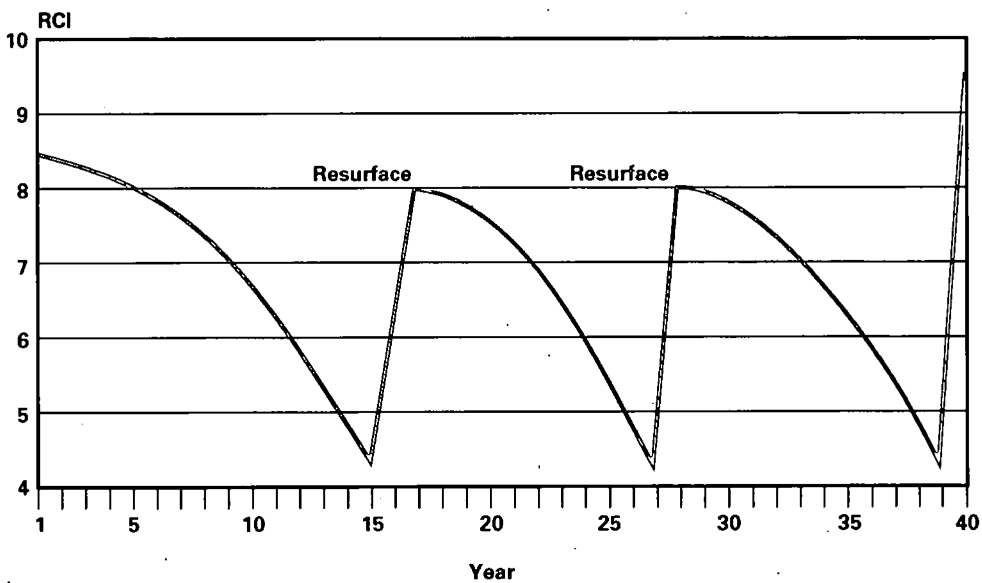
Flexible pavements wear out or deteriorate over time. The FHWA in the United States identified three major types of deterioration (Rilett et al., 1989):

- *Surface distress:* fatigue cracking, low-temperature cracking, rutting, ravelling, bleeding or flushing, roughness due to differential sub-grade volume change.
- *Reduction in surface friction:* reduced skid resistance.
- *Reduction in serviceability:* increased roughness. Reduction in serviceability is also caused by surface distress since the distress normally creates roughness.

For this discussion, it is the third type of deterioration which is of interest as this is the primary operating function of a pavement. In many allocation procedures, this is the measure which can be related to vehicle operating costs (that is, increased roughness means increased vehicle operating costs). In Canada, roughness, or the riding quality of a pavement, is usually measured with the Riding Comfort Index (RCI), a subjective estimate rated on a scale of 0 to 10. The change in RCI over time is usually monitored through objective measures of pavement distortion which have been correlated with the subjective ratings.

New pavements typically have an initial RCI of 8.5. This decreases as the surface distorts under the action of traffic load and climate. On first-class highways, pavements are normally considered to have deteriorated to an unacceptable condition when the RCI has declined to a level of 4.5 (see Figure 2.1). At year 15 and again at year 27, the pavement is resurfaced with an overlay which would vary from about 50 mm on lightly travelled highways to about 90 mm on heavily travelled highways. Generally, flexible pavements in Canada will be resurfaced twice in 40 to 50 years before a decision is made to reconstruct the pavement.

Figure 2.1
Pavement Deterioration Over Time



2.3.2 Pavement Deterioration

The principal mechanisms contributing to the surface distortion of flexible pavements are permanent deformations of the surface created by traffic loads and deformations of the sub-grade which are transmitted through the pavement structure to the surface. Deformation of the sub-grade occurs under the stresses imposed by heavy axle loads, and by freeze-thaw cycles and sub-grade moisture changes. The distortion of pavement surfaces induced by climatic factors is a significant component of pavement deterioration, and flexible pavements deteriorate to an unacceptable RCI magnitude in 25 to 35 years even under very light traffic loads.

The AASHO Road Test conducted in Illinois during the early 1960s provides most of the information known about the impact of traffic loads on pavement deterioration. In this test, the behaviour of pavements of different thicknesses subjected to different truck axle configurations (single and tandem) and axle group loads was observed over a two-year period. Many of the flexible pavement test sections failed very quickly at the beginning of the second spring thaw due to a combination of poor sub-base quality and a sub-grade which was quite sensitive to freeze-thaw cycles. This compromised the development of statistically valid axle coverage damage functions because of the narrow range of axle coverage within which pavements failed. In contrast, many of the thicker reinforced concrete pavement sections (rigid pavements) had not deteriorated to an unacceptable condition by the end of the test, which also created difficulties in the development of statistically valid deterioration models, particularly for the thick, rigid pavement sections. As well, the test sections at the road test were subjected to about one million axle loads over the two-year period: This creates difficulties when pavement deterioration models based on this try to predict behaviour beyond this loading range.

In Canada, the Brampton Test Road has provided information for extending the knowledge developed at the AASHO Road Test to typical operating conditions where traffic loads are imposed at a slower rate. The Brampton Road Test also allowed the contribution of climatic factors to pavement deterioration to be tracked in an objective manner.

In subsections 2.3.4 to 2.3.6, deterioration models are examined in more detail. First, though, the concept of load equivalency is considered.

2.3.3 Load Equivalency

A concept central to deterioration models is the relative pavement damage of different axle loads. In the AASHO Road Test, a standard load was defined as 18,000 lb (8,163 kg) on a single axle supported by dual tires (that is, four tires per axle). This was the common limit for single axles in much of the United States and Canada in the early 1960s. The equivalent single-axle load rating of any other axle load or configuration, ESAL or LEF, is defined as the number of passes of the standard axle load required to create the same amount of damage as one pass of a candidate axle load. For example, a single axle load of 10,000 kilograms (22,050 lb) has an ESAL rating or LEF of 2.25. This is calculated from what is commonly referred to as the "fourth-power law" of pavement damage:

$$\text{LEF} = \left(\frac{L(x)}{L(s)}\right)^4$$

where $L(x)$ is the candidate axle load and $L(s)$ is the standard axle load.[2]

To put the issue in dramatic terms, this 10,000-kilogram truck axle (the maximum load limit in three Canadian jurisdictions) does 160,000 times as much damage to a flexible pavement as does a car axle load of 500 kilograms. That is, the truck's ESAL of 2.25 is 160,000 times as large as the car's 0.000014 ESALs. This concept of load equivalency, and the manner in which these equivalencies increase sharply with load, is of crucial importance in all modern costing studies.

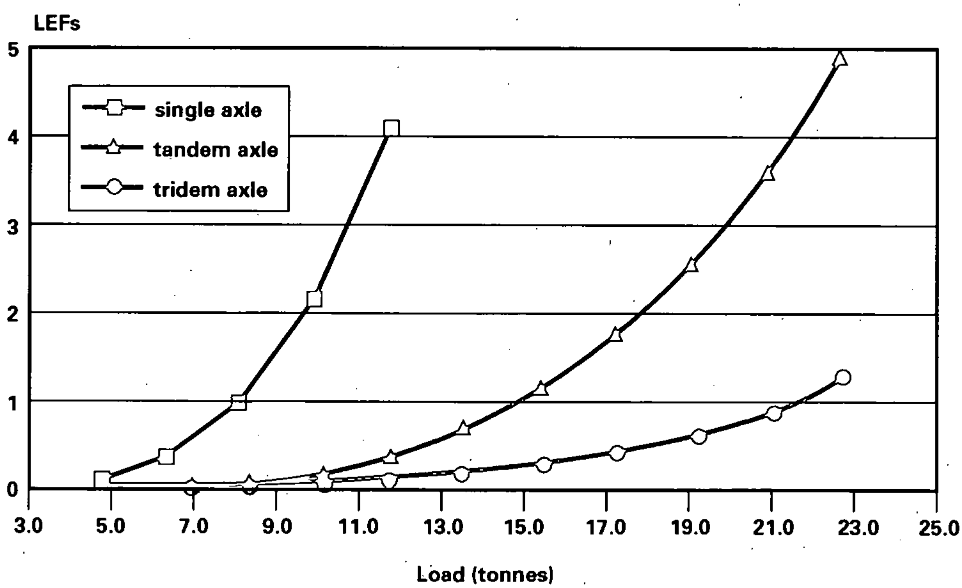
Whatever other controversies exist, most people agree on this point: heavy axle loads (hence, trucks) are a major factor in deterioration (hence, costs).

The current AASHTO ESALs, dating from 1986, were developed from the AASHO Road Tests and additional experimental and theoretical information (see Figure 2.2). The actual calculation depends on a number of factors (pavement strength and the terminal serviceability), but for this study's purpose these complications can be ignored.

More than just load is involved in the impact axles have on pavements. Such factors as the number of tires, tire pressure, vehicle speed, axle suspensions and ambient air temperature all play a part. However, none of these has been incorporated in any of the costing performed in this research nor, as far as is known, in any other work.

Recent Canadian research has developed its own method of calculating LEFs, referred to here as Canroad or Waterloo LEFS, depending on how they are calculated (Appendix B). While it is not possible to describe all the recent research on the relationship between axles and pavements, these Canadian LEFs should be mentioned. First, they are based on actual empirical data from a series of pavement test sites across Canada. Unlike other LEFs, then, they represent Canadian climates, pavements, axle configurations and loads. Second, there is an important implication which flows from the development of these LEFs: they suggest that the damage of a heavy axle is greater than those calculated from AASHTO's LEFs. To illustrate, a typical large truck which might be rated at three ESALs as calculated from AASHTO's numbers, could be rated at six or seven as calculated from these Canadian LEFs. The important point is that use of the Canadian LEFs affects the *relative* distribution of pavement damage (hence, costs) among truck types.

Figure 2.2
AASHTO Load Equivalencies



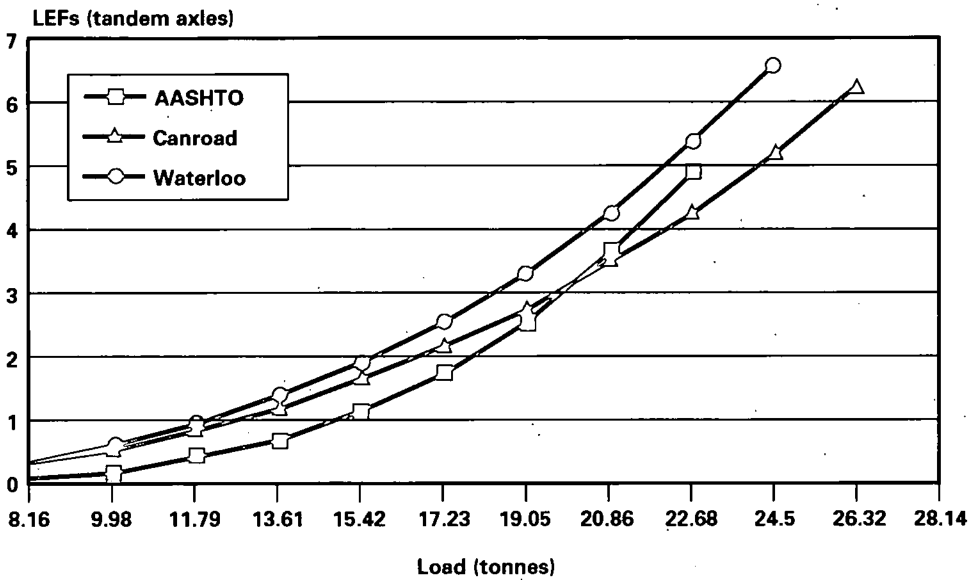
A comparison of the AASHTO, Canroad and Waterloo LEFs for tandem axles is shown in Figure 2.3. For example, at 15.4 tonnes, the AASHTO LEF of 1.09 is considerably lower than the Canroad 1.59 or the Waterloo 1.86. There is a 70 percent difference in what these equivalency factors reveal about the impact of axles on pavements. For most of this research, however, AASHTO's ESALs are used as this is the way pavement deterioration models are calibrated.

To this point, the discussion has focussed on the importance of LEFs in pavement deterioration. Obviously, to the extent deterioration is synonymous with costs, LEFs also play a key role in costing. In fact, one of the studies reviewed in Section 6 simply takes total pavement costs, divides by the number of ESALs, and attributes the resulting cost per ESAL to trucks in proportion to the number of ESALs each truck creates. While this approach may be necessary because of data constraints, it is naïve in the sense that it attributes all aspects of pavement costs to ESALs. There are environmental impacts on pavements (discussed in the next subsection). Second, even if the impact of the environment can be accounted for separately, there is the problem that the simple notion of LEFs as outlined here — the so-called "fourth-power law" — is not responsible for all aspects of pavement performance. As outlined in subsection 2.3.1, there are a number of dimensions to pavement deterioration such as surface distress, skid resistance and roughness. Some are related to axle loads in a manner captured in the pavement deterioration models as indicated by the AASHTO ESALs; some, such as skid resistance, are not; and still others, such as the various forms of distress, are related to axle loads in a manner which differs from the "fourth-power" ESAL.

> . . . the Road Test only measured serviceability loss rather than the individual pavement distress contributing to that loss. Since different distresses occur as different functions of axle loadings, there may be substantial error in attributing the relative causes of deterioration for any given combination of distresses. (U.S. FHWA, 1982, p. IV-45)

In this FHWA study, a series of distress models was constructed to allocate existing pavement costs. This cannot be done here, but it can be recognized that the naïve use of LEFs in determining pavement costs may introduce errors to the analysis.

Figure 2.3
COMPARISON OF LEFS



2.3.4 Models of Pavement Deterioration (1)

One of the reasons for the controversy surrounding the subject of costing is the wide choice of pavement-deterioration models. For this research, three are relevant:

- The OPAC model, the most relevant for Canadian conditions (Jung et al., 1975).
- The Alberta model which has particular relevance for low-volume roads in harsh climates (Cheetham and Christison, 1981).
- The model developed by Small, Winston and Evans (1989) in the United States which has generated some of the recent controversy.

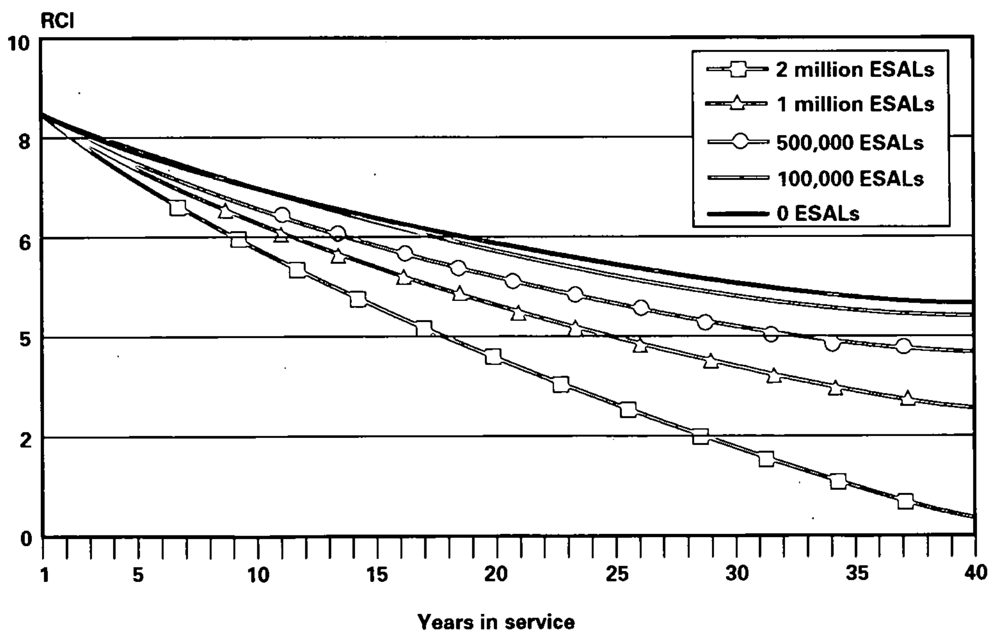
Other models, such as those developed by the World Bank (Paterson, 1987), are also important but, as they consider roads in developing countries with traffic and climatic conditions far different from those in Canada, they are not considered here.

The Ontario flexible pavement deterioration model, OPAC, provides one of the few models which separates load from climate-associated deterioration.

It was developed from the behaviour observed at the AASHO Road Test, the theoretical behaviour of layered elastic systems, and the longer-run Brampton Road Test. Briefly, this is how it works. A proposed pavement structure (see Table 2.1 for an example) is converted to an equivalent thickness of granular material covering a sub-grade. The deflection of the sub-grade likely to occur under a standard wheel load is then estimated using a theoretical procedure. The expected traffic loading (ESAL coverage) is then used along with this sub-grade deflection to estimate the loss in RCI over time due to traffic. The loss in RCI due to the environment is estimated in terms of the sub-grade deflection and the number of years in service. The OPAC model also contains a procedure for estimating the probable life span of overlays, although there are concerns about the validity of this component of the model.

Typical results from the OPAC model are depicted in Figure 2.4; the family of curves shown are for total annual ESAL loadings of zero, 100,000, 500,000, one million and two million. "SN" is the structural number, that is, the strength of the pavement.

Figure 2.4
RCI Profile, Using OPAC Model
(SN = 4.9)



As illustrated, pavements deteriorate to an unacceptable level of roughness (an RCI below 4.5) in about 40 years in the absence of any axle loads. (The OPAC model may actually overestimate pavement lives in the absence of axle loads.) With one million axle loads, an RCI of 4.5 is reached in about 20 years; with two million ESALs, an RCI of 4.5 is reached in about 14 years. Only a few sections of the busiest freeways in Canada experience more than two million ESALs a year.

The curves also indicate that both axle loads and the environment play a role in pavement deterioration. Further, the relative importance of environmental factors *decreases* with heavier loadings (Rilett et al., 1989). For example, for a typical flexible pavement in Southern Ontario, the environment may account for as much as 80 percent of the deterioration on a low-volume road (less than 250,000 ESALs per year). On a high-volume road, say over two million ESALs per year, environmental factors may only account for half the pavement deterioration. The same is true for overlays: the higher the traffic volumes (axle loads), the lower the portion attributable to the environment.

Another point which emerges from this model is that the role of the environment *increases* with longer initial pavement lives (Rilett et al., 1989). Again, the same is true for overlays.

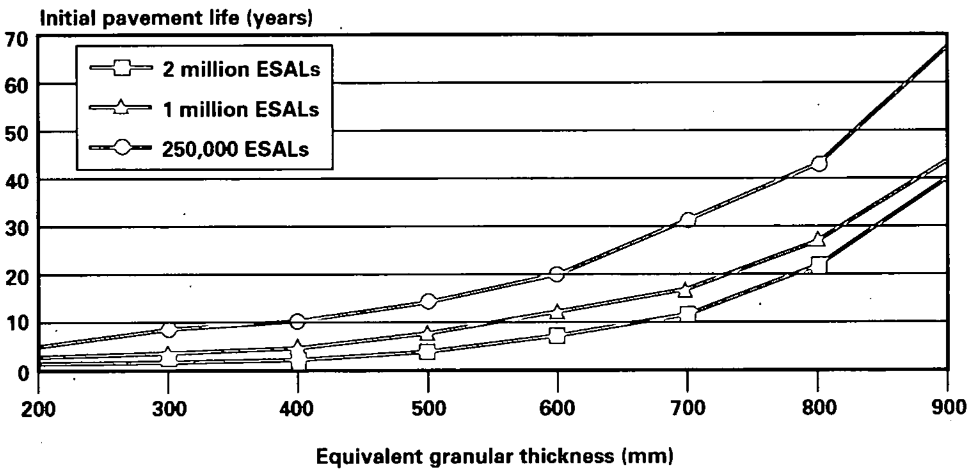
To oversimplify, the environment grows in importance as stronger and thicker pavements are built (for a given demand loading), and it grows in importance as traffic volumes (axle loads) decline. To turn this around, axle loads play a larger role in deterioration where pavements are built for short initial lives, and where traffic volumes are high. Although this sounds relatively straightforward, there is a qualification:

> While pavements in more severe climates may well have to be designed primarily for environmental factors (. . . i.e., they are "over-designed" for traffic loading, per se), it would be dangerous to extrapolate this too far. For example, if a pavement were designed only for environmental factors, and an unexpected increase in traffic loads occurred, then very rapid deterioration would likely occur. . . . Moreover, existing models such as OPAC assume that environmental and load-associated deterioration is separable right to the end of the

service life. In reality, the interaction between traffic and environment may be the dominant factor in deterioration as the pavement becomes older. (Rilett et al., 1989, p. 39)

A final characteristic of pavements, as revealed by the OPAC model, is shown in Figure 2.5. Pavements exhibit increasing returns to scale, as shown by the fact that pavement life increases with pavement thickness ("equivalent granular thickness") *at an increasing rate.*

Figure 2.5
PAVEMENT STRENGTH AND INITIAL YEARS TO FAILURE

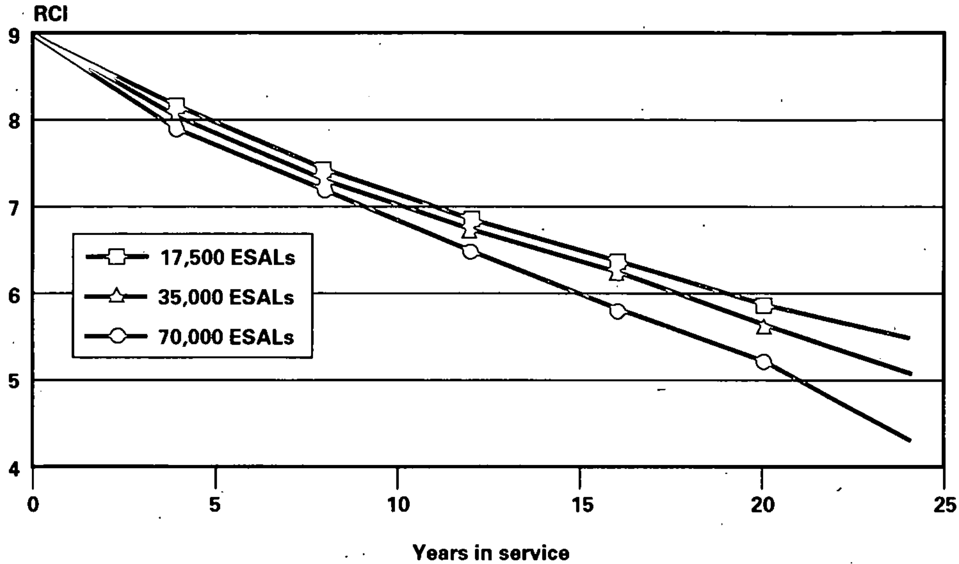


2.3.5 Models of Pavement Deterioration (2)

The Alberta model is based on data from a large number of pavement sections, some as old as 25 years. Recursive regression equations were developed, and the truck loading variable was found to be weakly significant. Pavement deterioration as a function of pavement life, for three levels of annual axle loads, is shown in Figure 2.6.

The model indicates that, for the light traffic loads and harsh climates in Western Canada, the environment causes most deterioration. For example, with annual ESALs of 17,500, an RCI below 4.5 is reached in about 26 years. With four times this loading, the model predicts an RCI below 4.5 in about 22 years. This observation reinforces the argument that where traffic is light, environmental factors play the largest role in pavement deterioration.

Figure 2.6
RCI PROFILE, USING ALBERTA MODEL



2.3.6 Models of Pavement Deterioration (3)

The final deterioration model to be considered is the one developed by Small, Winston and Evans which supports the claim that pavements have been built without sufficient durability and that, accordingly, pavement costs for trucks are higher than they would be with optimally-designed pavements. (In summarizing Small, Winston and Evans, it should be pointed out that most of their argument is concerned with rigid pavements. While they extend the discussion to flexible pavements, they point out that they are not as confident of the results.)

The following is the model they propose, based on their re-analysis of the AASHO Road Test data:

$$\mathrm{RCI}(t) = \mathrm{RCI}(0) - [\mathrm{RCI}(0) - \mathrm{RCI}(f)] \left(\frac{Qt}{N}\right) e^{mt}$$

The Canadian RCI (a 0-to-10 scale) has been used in the above rather than the American PSI (a 0-to-5 scale), but this does not affect the results. RCI(t) is the serviceability index at time t, RCI(0) is the initial serviceability and

RCI(f) is the terminal serviceability (that is, the point at which the pavement is resurfaced). Q is the number of ESAL loadings experienced, N is the total ESALs-life of the pavement, and m is a factor to account for the annual percentage increase in roughness due to climatic factors.

Small, Winston and Evans' re-analysis of the AASHO Road Test data for flexible pavements results in the following prediction for N, pavement life:

$$N = e^{12.062} (D + 1)^{7.761} (L_1 + L_2)^{-3.652} (L_2)^{3.238}$$

where D is the structural number of the pavement, L_1 is the axle load in thousands of pounds, and L_2 equals 1 for single axles and 2 for tandem axles. Setting $L_1 = 18$ (that is, the 18,000-lb standard axle load) and $L_2 = 1$, the pavement performance model may be re-written as:

$$\mathrm{RCI}(t) = 8.5 - \left[\frac{4Qt}{3.7021(D + 1)^{7.761}}\right] e^{mt}$$

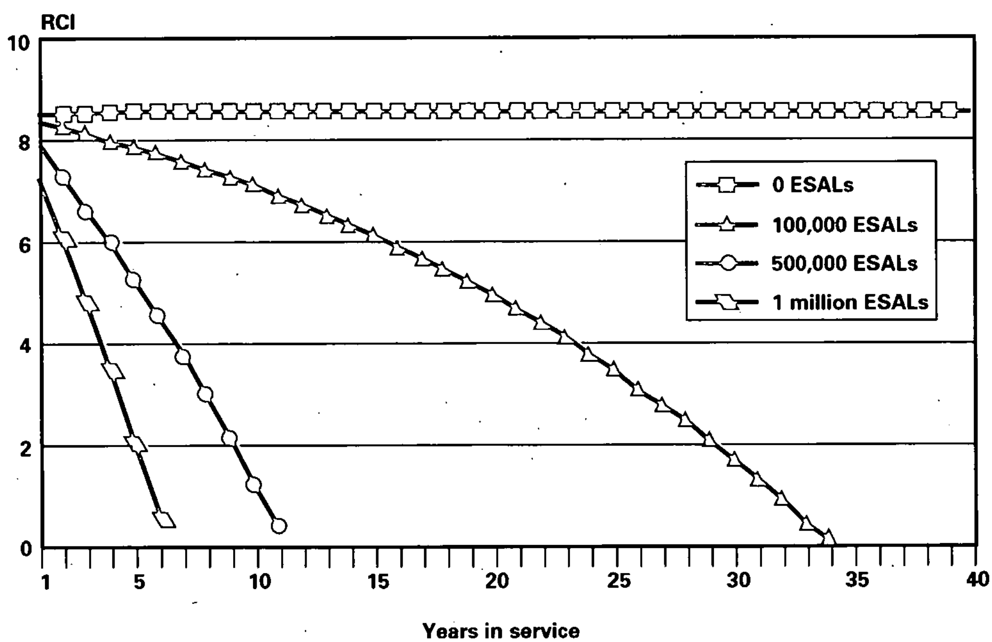
Again, RCI values have been used instead of PSI. The value "4" in the equation is simply the difference between the RCI of a new pavement and the value of RCI when resurfacing is ordinarily done.

This equation may be used to develop the RCI profile of a flexible pavement with a thickness the same as that used in Figure 2.4 (SN of 4.9). The results are shown in Figure 2.7. For this illustration, an annual increase in roughness due to climatic factors has been set at 2.3 percent. Small, Winston and Evans actually use a value of 4.0 percent for most of their calculations and the World Bank, from which these estimates were derived, suggests a figure more in the order of 5.0 to 10.0 percent for severe climates (Paterson, 1987, p. 393). There is considerable uncertainty about the value of m in the above equation.

As indicated in Figure 2.7, this model allows for no deterioration in the absence of axle loads, unlike the OPAC model. The authors, while unsure about this, offer anecdotal evidence to suggest that this may actually be the case, at least for rigid pavements. A second point to note about the curves in Figure 2.7 is their relative steepness in comparison to those generated from the OPAC model (Figure 2.4). For example, with 100,000 ESALs annually, the Small, Winston and Evans pavement shown in Figure 2.7 reaches an RCI below 4.5 in about 21 years. In comparison, the OPAC model predicts that this point is reached in 37 years. With one million ESALs, an RCI of less than 4.5 is reached in about 12 years with Small, Winston and Evans. The OPAC model, with the same pavement strength, suggests this point is reached in 20 years.

A third observation about the Small, Winston and Evans model, which is not evident from Figure 2.7, is that the steepness of the curves increases for higher values of *m* — the climatic factor. For example, with 100,000 annual ESALs, a pavement will reach an RCI of 4.5 in about 13 years when the climatic factor is 7 percent as compared to the 21 years shown in Figure 2.7.

Figure 2.7
RCI Profiles, Using Small, Winston and Evans Model (Environmental degradation = 2.3%; RCI = 2*PSI)



To demonstrate the differences in pavement performance predicted by the OPAC model and the one proposed by Small, Winston and Evans, the numbers in Table 2.2 show the initial years in service of a flexible pavement under a number of annual ESAL loads. As shown, the Small, Winston and Evans model is considerably more sensitive to axle loadings than the OPAC model. This probably reflects the behaviour at the AASHO Road Test where many of the flexible pavement sections failed prematurely.

Table 2.2
Years in Service, OPAC Model versus Small, Winston and Evans Model

Annual ESALs	OPAC model	Small, Winston and Evans model		
		$m = 0.0$	$m = 0.023$	$m = 0.07$
100,000	37	34	21	13
500,000	26	7	6	5
1,000,000	20	3	3	3
2,000,000	14	2	2	1
4,000,000	10	1	1	1

The implications of the model proposed by Small, Winston and Evans are that, for a given traffic load, thicker pavements are required than those suggested by the OPAC model. Additionally, given the sensitivity to ESAL loadings in the Small, Winston and Evans model, the optimum pavement strategy would be more sensitive to the key design variable — initial pavement life — than that suggested by the OPAC model.

2.3.7 Roads with Other Than Flexible Pavements

Over half the roads in Canada (federal, provincial, territorial measured on a two-lane equivalent basis) do not have the flexible pavements discussed in the preceding sections. Instead, they are surface-treated, gravel or earth. To put this in perspective, however, this half of the network only accounts for about 20 percent of the total costs and a very small proportion of total travel. Whatever their cost or importance, none of the models described thus far consider these road surfaces. Although there are models available as, for example, in the work by the World Bank (Paterson, 1987), it is unlikely that these are relevant given the climates for which they have been calibrated.

For this reason, there is an important cautionary note to introduce here about the cost allocations attempted later in this report: these are done on the basis of the AASHTO ESALs and/or Canadian LEFs described previously, *even though* there is no evidence to suggest that these are appropriate.

2.3.8 Summary

Pavements and pavement performance are important in any road costing exercise.

The *key design variable* for pavements is the initial pavement life. The decision to build for a longer initial life has two implications: stronger pavements initially (which cost more), and a deferral of the time at which resurfacing has to occur (which reduces costs). The economic consequences of this decision are examined in Section 5.

Heavy axle loads play a key role in pavement deterioration, suggesting, therefore, that heavy axles bear a large portion of pavement costs.

The *environment* plays a large role in pavement deterioration (at least from the best evidence on Canadian pavements). It may be overly simplistic to attach any single number to this statement as soil, pavement and traffic conditions vary considerably. Nevertheless, environmental factors may account for half of the deterioration of the strong pavements found on the busiest freeways with a high proportion of trucks, and they may account for almost all of the deterioration of the weaker pavements found on low-volume roads with very little traffic (particularly where the climate is severe).

For the purpose of costing, the concept of *load equivalencies* for axles is indispensable. However, the naïve use of LEFs — that is, linking of all aspects of pavement performance to one LEF concept — may introduce an element of error into any such exercise. Further, the choice of LEF has, as will be shown in Section 7, a pronounced impact on the results.

This section would be incomplete if mention were not made of a large-scale current pavement research project (SHRP). This is an American effort, although other countries including Canada are involved. It may well be that the knowledge about pavements, and hence costing methods, will change substantially as a result of this work. One point that emerges from the results to date is the difficulty in collecting data on pavements for the purpose of gauging performance. Long periods are involved (20 to 40 years). During this time, truck weight limits may change. Further, material properties used in construction may vary from one section to another. Of most importance, it has been found that it is extremely difficult to record accurately the history of actual axle loadings and environmental factors on any particular pavement over an extended period of time.

2.4 BRIDGES

Bridge costs, as will be described in Section 3, account for only 6 percent of TAC's calculation of total road costs. This is one of the reasons little attention is given to the physical characteristics of bridges here. Another is that the relationships between bridge wear and traffic are less well understood than in the case of pavements. This, at least, is the conclusion of the 1988 FHWA study which looked specifically at the question of the costs heavy trucks impose on roads:

> Design for bridges is fundamentally different from that for pavements. Bridges are built for ultimate strength and behave differently under loading than do pavements. While there is general consensus that pavement deterioration is related to the number of axle load repetitions, the state-of-the-art in bridge fatigue analysis has not advanced to the point where bridge costs can be directly related to travel by different vehicles. (U.S. DoT, 1988, p. III-8)

2.5 MAINTENANCE

Later sections consider maintenance, or what are sometimes referred to as "routine maintenance" costs. The unknown factors are these:

- Are maintenance activities (costs) a function of the "initial pavement life" variable in the design of pavements?
- Are maintenance activities a function of traffic (either axle loads or the number of vehicles or other measures of traffic)?
- What portion of maintenance activities are related to pavements and, hence, possibly load-related?

Unfortunately, no good answers to these questions have been found. One recent study from California does suggest a strong relationship between truck traffic and maintenance costs (Kitamura et al., 1990). The authors say that, in California, average annual maintenance costs per heavy-truck mile amount to $7.60 while for cars the cost is only $0.08. However, without knowing more about what they consider to be maintenance as compared to what the provinces include in their accounts as maintenance, it is difficult to make much of this. It is possible that the American authors include factors which in Canada are classified as resurfacing or even reconstruction.

The Trucking Research Institute report discussed maintenance costs as follows, although it appears to refer *only* to pavement-related maintenance:

> Pavement maintenance is one of the most important elements of cost allocation. . . . Unfortunately, however, no single source can be relied on as to the most appropriate methodology to use. The Federal studies have not focused on maintenance because of the lack of Federal funding for maintenance. State studies have mostly relied on expert opinion to determine the proportion of costs that is load-related, as well as to determine what the appropriate relationship is between traffic loads and pavement maintenance requirements. (The Urban Institute, Sydec, Inc., 1990, p. 80)

3. TAC Data Base on Road Costs

3.1 SOURCE DATA

For a number of years TAC has compiled data on roads, including information on lengths in two-lane equivalent kilometres and on costs. Although information on the entire 879,530-kilometre network is available, only the 292,003 kilometres of federal, provincial and territorial roads are of interest here. A summary is shown in Table 3.1. Only 5 percent of this network, including all the paved urban roads, is federal.

Table 3.1
THE ROAD NETWORK
(TAC'S DATA ON FEDERAL, PROVINCIAL AND TERRITORIAL ROADS, TWO-LANE EQUIVALENT BASIS)

Road class	Length (km)
Freeway	13,441
Paved (urban)	1,209
Paved (rural)	129,855
Surface-treated	32,968
Gravel	109,622
Earth	4,908
	292,003

Source: RTAC, 1990.

From each of 16 jurisdictions — four federal departments, 12 provinces and territories — TAC collects information on the costs of maintaining roads and bridges. "Maintaining," in this instance, includes five activities:

- annual maintenance of the road surface and roadside (everything from snow ploughing and grass cutting to crack filling);
- periodic resurfacing;
- reconstruction of road surfaces after a certain number of resurfacing cycles;
- bridge maintenance, restoration and reconstruction; and
- administration.

A description of the methodology is provided by TAC (RTAC, 1990); an even more complete description is available in what is referred to as the "HITRIS" study (RTAC, 1987a).

The data are collected and compiled in a consistent manner which helps with one critical problem with road costing in Canada — obtaining appropriate data. Every jurisdiction has numbers; the difficulty has been in collecting and massaging them so that their meaning is consistent. Another point is that in TAC's data, "cost" is *not* what each jurisdiction actually spends on its roads. Rather, it is what TAC refers to as "needs." "This model [of needs is used] to relate typical highway expenditures to estimates of funding required to achieve an acceptable minimum standard. As such, these 'needs' are estimated theoretical levels of funding only." (RTAC, 1990, p. 17).

The advantage of using the TAC data is that it represents the "costs" of maintaining the road system indefinitely. Unlike information on expenditures, there are no fluctuations based on everything from political motives (expenditures increasing before an election) to a bad winter (and increased snow ploughing expenses). Further, there is no confusion between maintaining existing roads and adding new capacity.

If the object of a costing exercise, however, is the design of road prices, there are also disadvantages in the use of TAC's data since they do not include land costs, policing costs, or private user-costs. Further, the amounts assume past investment decisions were optimal, that is, that the size and capacity of the network are the same as would be with a network built had the road agencies received their funding from a system of efficient prices.

In TAC's latest publication, expenditure needs for the fiscal year ending in March 31, 1989 were $11.4 billion, with the federal/provincial/territorial component shown at $6.1 billion. The balance of $5.3 billion is municipal (RTAC, 1990, p. 18). However, it appears there were errors made in printing these figures as the spreadsheet from which they were derived only shows a total of $5.1 billion for federal/provincial/territorial roads.[3]

Costs used in this study, at least as a starting point, are as shown in Table 3.2. The maintenance and pavement component is described in more detail in Tables 3.2 to 3.4 as totals or averages for the whole network even though the analysis was done at the level of the individual jurisdiction. Use of the TAC data for this research, however, was conditional on the figures from individual jurisdictions being treated as confidential.

Table 3.2
TAC's Road Costs (Expenditure Needs)
(TAC's data on federal, provincial and territorial roads, millions of 1989 $)

Annual maintenance		$1,824.0
Pavement		
– resurfacing	$1,477.8	
– reconstruction	1,294.9	
– total		2,772.7
Bridges		296.3
Administration		201.5
Total		**$5,094.5**

Source: RTAC Lotus files.

In Table 3.3, the total $4.6 billion in maintenance and pavement costs is shown according to class of road. Paved rural roads dominate the costs of the network, comprising as they do 68 percent of the total. Paved roads in total — that is, the first three classes on Table 3.3 — account for 78 percent of total costs. The remaining 22 percent of maintenance and pavement costs — which amount to over $1 billion — are for surface-treated, gravel and earth roads. The cost for these last three classes are allocated to road users in a later part of this study. However, as previously pointed out, the allocation is not made on the basis of any information about the performance of these surface-treated, gravel or earth surfaces.

Table 3.3
Total Maintenance and Pavement Costs
(TAC's data on federal, provincial and territorial roads, total annual expenditure needs, millions of 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	139.2	100.7	142.3	382.2
Paved (urban)	5.5	28.5	12.4	46.4
Paved (rural)	1,005.5	1,269.1	862.7	3,137.3
Surface-treated	161.6	44.4	165.0	371.0
Gravel	494.3	35.2	110.7	640.2
Earth	18.0	0.0	1.8	19.8
	1,824.0	**1,477.8**	**1,294.9**	**4,596.7**

Source: RTAC Lotus files.

In Table 3.4, average maintenance and pavement costs are shown. These have been calculated by dividing the numbers in Table 3.3 by the lengths in Table 3.1. They indicate possible incongruities in the data base: for example, paved urban roads have an annual resurfacing cost of $23,542 per two-lane kilometre which is considerably higher than for other roads.

Table 3.4

AVERAGE MAINTENANCE AND PAVEMENT COSTS

(TAC'S DATA ON FEDERAL, PROVINCIAL AND TERRITORIAL ROADS, ANNUAL EXPENDITURE NEEDS PER TWO-LANE KILOMETRE, 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	10,355	7,492	10,589	28,435
Paved (urban)	4,554	23,542	10,290	38,386
Paved (rural)	7,743	9,773	6,644	24,160
Surface-treated	4,901	1,345	5,003	11,250
Gravel	4,509	321	1,010	5,840
Earth	3,660	0	374	4,034

Source: RTAC Lotus files.

In Table 3.5, average unit costs for resurfacing and reconstruction are shown, as well as the average duration (that is, number of years between resurfacing or reconstruction). These have been calculated as weighted values; that is, the figures from individual jurisdictions have been weighted by the length of the road section there. Again they indicate that there may be some "noise" in the data base. Paved urban roads resurfaced every 3.1 years?

Table 3.5

UNIT COSTS AND FREQUENCIES

(TAC'S DATA ON FEDERAL, PROVINCIAL AND TERRITORIAL ROADS, EXPENDITURE NEEDS PER TWO-LANE KILOMETRE, 1989 $)

Road class	Resurfacing costs/km	Resurfacing frequency (years)	Reconstruction costs/km	Reconstruction frequency (years)
Freeway	90,385	14.5	522,482	49.3
Paved (urban)	71,435	3.1	401,152	39.2
Paved (rural)	72,852	16.7	303,325	47.3
Surface-treated	9,840	5.5	167,280	34.6
Gravel	4,437	4.9	22,504	11.0
Earth	0	0.0	7,478	8.8

Source: RTAC Lotus files.

3.2 ADJUSTMENTS

A closer examination of TAC's data, at the level of the individual jurisdiction and individual class of road, reveals anomalies or, at least, many numbers difficult to understand. For example, in one province paved rural roads are reconstructed every 50 years and resurfaced every 45 years. This is, presumably, a coding error. As another example, in two provinces paved rural roads are resurfaced every 2.25 and 3 years respectively. This is at odds with existing practices, according to informal discussions with highway people in the two provinces. Since these two provinces account for a large portion of the total length of rural paved roads, these short resurfacing lives have a significant impact on the total road costs computed by TAC.

In light of these and other suspected errors, adjustments have been made to the original TAC data before using them. A conservative approach has been taken, with only the most extreme values in the TAC data being changed. For example, rather than trying to second guess the road agencies as to when paved roads really do require resurfacing, any value between 5 and 25 years has been accepted, and only values outside this range have been changed (to 15 years). None of the wildly different estimates of reconstruction costs have been adjusted: for freeways, these estimates varied from a low of $200,000 per two-lane kilometre to a high of $1 million.

The following is a summary of the adjustments made:

Maintenance costs: In three cases, jurisdictions are included in TAC's data with zero maintenance costs for a particular class of road. To adjust these, the average cost per kilometre has been used. The "average" is different than that shown on Table 3.4 as it is calculated without the road length of the candidate jurisdictions included in the denominator.

Resurfacing costs: The 16 road agencies are divided in their opinion (or practices) as to whether or not surface-treated, gravel and earth roads require resurfacing. Half the individual cells in the TAC matrix show a cost while the other half do not. However, *no* adjustments have been made here (no information has been found upon which to make such adjustments).

In the case of freeways and paved rural roads, there are three instances where roads are shown with a zero resurfacing cost. Again, as with maintenance, the procedure followed was to substitute a value calculated from the average of all those jurisdictions showing a cost.

Resurfacing frequency: By far the most significant adjustment made to TAC's data concerns the estimates provided for the average life of an overlay. In total, there are 17 instances in the data where a province is shown to resurface every four years or less, or to resurface every 26 years or more. All values lying outside the range of 5 to 25 have been changed to 15 years.

Reconstruction: Although reconstruction costs vary significantly from jurisdiction to jurisdiction, these have not been adjusted. Rather, they are the subject for discussion under "Pavement Economics" in Section 5.[4]

The result of these adjustments on maintenance and pavement costs is shown in Tables 3.6 to 3.8. No changes have been made to TAC's estimate of costs for bridges. Finally, a new figure has been computed for administration based on the average "add-on percentage" of 4.1 percent used in the original. The result is an estimated cost of $171.5 million. A summary of the final adjusted TAC data is shown in Table 3.9. Total costs ("needs") of $4.3 billion are considerably lower than the original TAC Lotus files ($5.1 billion) and even more significantly lower than TAC's published figures ($6.1 billion).

Table 3.6
Adjusted Total Maintenance and Pavement Costs
(Total annual expenditure needs, millions of 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	139.2	96.1	142.3	377.6
Paved (urban)	5.5	5.8	12.4	23.7
Paved (rural)	1,005.5	567.5	861.3	2,434.3
Surface-treated	167.7	38.0	165.0	370.6
Gravel	494.3	35.2	110.7	640.2
Earth	18.0	0.0	1.8	19.8
	1,830.1	**742.6**	**1,293.5**	**3,866.2**

Table 3.7
Adjusted Average Maintenance and Pavement Costs (Annual Expenditure Needs per Two-Lane Kilometre, 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	10,355	7,151	10,589	28,094
Paved (urban)	4,554	4,762	10,290	19,607
Paved (rural)	7,743	4,370	6,633	18,746
Surface-treated	5,086	1,153	5,003	11,242
Gravel	4,509	321	1,010	5,840
Earth	3,663	0	374	4,037

Table 3.8
Adjusted Unit Costs and Frequencies (Expenditure Needs per Two-Lane Kilometre, 1989 $)

Road class	Resurfacing costs/km	Resurfacing frequency (years)	Reconstruction costs/km	Reconstruction frequency (years)
Freeway	90,385	14.5	522,482	49.3
Paved (urban)	71,435	15.0	401,152	39.2
Paved (rural)	72,852	17.8	303,325	47.3
Surface-treated	9,840	5.6	167,280	34.6
Gravel	4,437	4.9	22,504	11.0
Earth	0	0.0	7,478	8.8

Table 3.9
Adjusted TAC Road Costs (Expenditure Needs): Summary (Millions of 1989 $)

Annual maintenance		$1,830.1
Pavement		
– Resurfacing	$742.6	
– Reconstruction	1,293.5	
– Total		2,036.1
Bridges		296.3
Administration		171.5
Total		**$4,334.0**

4. Vehicle and Traffic Data

A critical aspect of a costing study is data on, or assumptions about, vehicles and traffic. Without this, it is impossible to assess TAC's costs and to allocate the results to users. The scope of this research, however, did not include the collection of new data. Therefore, the procedure followed has been to take known information from several sources (Appendix A) and extrapolate this over the entire 292,003-kilometre network. This should not be confused with characteristics developed on the basis of an actual survey: the information shown in Tables 5.1 through 5.3 is little more than an educated guess about fleet and traffic characteristics in Canada and, because of the nature of the information used, it has an Ontario bias to it.

Six aspects of vehicles and traffic are required for most cost-allocation exercises:

- Total vehicles;
- Vehicle kilometres of travel;
- Average weight measured in two ways: average actual weight or GVW and average registered weight or RGVW;
- Traffic volumes measured as AADT;
- Proportion of trucks in the AADT; and
- Average LEFs per vehicle.

Most cost-allocation studies separate vehicles into categories, sometimes by class of road. Attempts were made to do this in this study but the results, particularly when applied to provincial data on road costs, were not credible. It was found that road information (road classes by length and associated costs) could be "built up" from the level of the individual jurisdiction to the level of a national average with confidence, but that the same was not true for vehicle and traffic characteristics. Traffic volumes are considerably lower in Western Canada, for example, than in Southern Ontario. More serious was that the nature of trucks changes from one province to another. In Western Canada trucks have neither the liftable axles (which often have high LEFs) nor the high axle weights found in Eastern Canada.

The procedure adopted, therefore, was as follows. Available information from some provinces was used to develop a very aggregate national profile for vehicle and traffic characteristics. Only two truck types were recognized: large and small. Given the available data, it was not even possible to provide a precise definition of the demarcation line between "large" and "small" although for convenience it is considered here to be an RGVW of 4.5 tonnes. These aggregate data on vehicles and traffic were then used in conjunction with the TAC data to perform various cost allocations (Section 7). Once certain unit costs were developed on this basis — such as pavement costs per LEF-km — the results could then be used to develop the costs of an individual vehicle operating on a particular road — for example, a six-axle tractor-semitrailer on a paved rural road. However, because of the confidentially of the TAC data, this could not be done on a provincial basis.

The fleet and the characteristics of the vehicle classes are shown in Table 4.1. Traffic and the proportion of large trucks in this traffic are shown in Table 4.2.

Table 4.1
The Fleet and Fleet Characteristics
(Canada, [illegible])

Vehicles	Population	Average annual km	Annual VKT (billion)	Average GVW (tonnes)	Average RGVW (tonnes)	Average ESALs
Passenger cars	10,249,054	17,380	178.1	1.0	1.0	0.00001
Trucks						
– small	2,309,194	18,000	41.6	1.5	1.5	0.00007
– large	509,381	44,448	22.6	23.3	37.2	1.5
Buses	62,494	19,000	1.2	7.0	8.0	0.02
Motorcycles, etc.	377,997	3,700	1.4	0.2	0.2	0.0
Other	71,846	10,000	0.7	8.0	8.0	0.03
	13,579,966		**245.6**			

Source: Table A.1.

Table 4.2
TRAFFIC VOLUMES
(CIRCA 1987–1990)

Road class	AADT	% Trucks
Freeway	12,000	15
Paved (urban)	4,000	7
Paved (rural)		
– busiest 10%	6,000	13
– medium-volume 30%	3,000	7
– low-volume 60%	700	7
Surface-treated	350	7
Gravel	50	7
Earth	10	7

5. PAVEMENT ECONOMICS

5.1 INTRODUCTION

This section extends the discussion in Section 2 by considering pavement costs. Illustrative examples are developed using Ontario costs for construction and resurfacing and the OPAC model described previously. Since conditions in other parts of the country are different, the results may not be fully applicable to the whole country.

The following questions were examined:

- Given the choices made when designing a pavement — the most important one being the decision on the initial pavement life — how do pavement costs behave?
- What portion of pavement costs vary with the number of LEFs?
- Are TAC's unit costs for maintenance, resurfacing and reconstruction reasonable?
- Can the adjusted TAC costs be further adjusted so as to produce a more "optimal" road cost (that is, optimal with respect to initial pavement life or durability)?

5.2 MAINTENANCE COSTS

"Maintenance" means routine maintenance or expenditures not considered as capital expenditures. This differs from usage in other studies where maintenance includes such activity as resurfacing.

TAC's information indicates that, in total, maintenance accounts for $1.8 billion in annual expenditures and that the national average amounts to anywhere from $3,663 to $10,355 per two-lane equivalent kilometre, depending on the class of road. More information is given in Table 5.1. The point to note is how much these costs vary from one jurisdiction to another.

Maintenance costs, apparently, do vary enormously from one jurisdiction to another.[5] For example, in four provinces where detailed information has been obtained, snow and ice control varies from a low of $613 per two-lane kilometre per year to a high of $5,097. (Snow and ice are easy items to deal with as there is little confusion about how these factors are recorded in different accounts.) In view of this variability, TAC's costs for maintenance are not adjusted (other than the minor corrections discussed in Section 3).

There are, though, the issues discussed in Section 2 to resolve: Are maintenance activities a function of initial pavement life? Are maintenance activities a function of traffic? What portion of maintenance is related to pavements? No answers to these questions have been found. The best that can be offered is a preliminary analysis (Appendix C) which suggests that the pavement-related portion of maintenance might be in the range of 6 to 20 percent. A figure of 15 percent is used in this study as a guess at the national average.

Table 5.1
TAC's Data on Maintenance Costs Per Kilometre
(1988 $)

Road class	Average	Highest value	Lowest value
Freeway	10,355	14,050	3,270
Paved (urban)	4,554	10,600	2,663
Paved (rural)	7,743	12,350	2,900
Surface-treated	5,086	7,000	0
Gravel	4,509	12,000	0
Earth	3,663	5,300	1,580

Source: RTAC Lotus files, as adjusted.

5.3 RESURFACING COSTS

TAC's information suggests that resurfacing costs amount to $1.5 billion a year, this being a function of unit costs — which vary from zero in the case of earth roads to $90,385 per two-lane kilometre in the case of freeways — and the duration of the overlay. In TAC's data, this second item is unrealistically variable. Hence, in Section 3 these costs were adjusted downwards to a level of $0.7 billion, but even this amount is based on leaving any of TAC's duration figures of between 5 and 25 years in place. More information on the original TAC data is shown in Table 5.2. (These are the unit costs of resurfacing, not the average annual costs.)

Table 5.2
TAC's Data on Resurfacing Costs Per Kilometre (1989 $)

Road class	Average	Highest value	Lowest value
Freeway	90,385	170,000	0
Paved (urban)	71,435	80,000	60,000
Paved (rural)	72,852	120,000	0
Surface-treated	9,840	63,900	0
Gravel	4,437	18,000	0
Earth	0	0	0

To calculate pavement costs in the illustrations which follow, typical Ontario overlay costs are used based on a thickness of between 50 mm for light traffic to 90 mm for heavy traffic. The life of the overlay is assumed to be 12 years. (Overlay costs shown apply only to roads with flexible asphalt pavements. The costs of resurfacing other roads in TAC's data are not known. Further, as has been described in Section 3, it is not clear how many provinces actually resurface surface-treated or gravel roads.) The typical Ontario overlay costs, then, are as follows:

Annual ESALs	Overlay costs (two-lane km)
250,000	$55,000
1,000,000	$65,000
2,000,000	$75,000

While conditions and costs vary from province to province, it is difficult to accept the highest numbers in TAC's data. Part of the reason, both for the variability among provinces and the general level of TAC's costs, is explained in the following passage:

> The roadway manager generally will attempt to hold other restoration activities until the resurfacing must be done. This includes such activities as curb renewal, widening of shoulders, intersection improvements and so on. Several contracts were analyzed to determine the percentage these items represented of the basic cost of resurfacing. The average was found to be 15%. Unit costs for resurfacing include these percentages. (RTAC, 1987b, pp. 15-16)

In other words, TAC's information is not *just* for the costs of keeping existing roads in place in perpetuity. It also includes improvements to the quality of the roads. To construct an optimal cost for this study, any of TAC's figures lying within plus or minus 20 percent of the Ontario figures given above are used. No adjustments are made to TAC's figures for surface-treated, gravel and earth roads.

	Optimal resurfacing costs and duration (per two-lane km)		Accepted TAC values (per two-lane km)	
	$	years	$	years
Freeways	65,000	12	52,000–78,000	9–14
Paved (rural)	55,000	12	44,000–66,000	9–14

5.4 CONSTRUCTION OR RECONSTRUCTION COSTS

TAC's information on reconstruction suggests a total annual amount of $1.3 billion. National average unit costs vary from a low of $7,483 for earth roads to a high of $522,482 for freeways on a two-lane equivalent basis. The variability among the provinces is much greater than this as shown, in part, in Table 5.3. No significant adjustments were made to these costs in Section 3. As with TAC's figures on resurfacing though, there is a suspicion that "reconstruction" involves more than just reconstructing pavements. Although none of TAC's background documents provide any explanation, conversations with a member of the RTAC committee which developed the numbers indicate that "reconstruction," in the case of some (perhaps all) provinces, was taken to mean both the reconstruction of the pavement and any required improvements. "Reconstruction," it was explained, "could involve changes to the road alignment and/or the vertical geometry." For this reason, then, the figures in Table 5.3 have to be seen as something more than just the cost of maintaining Canada's road network *in their current state* indefinitely.

Table 5.3
TAC's Data on Reconstruction Costs Per Kilometre (1989 $)

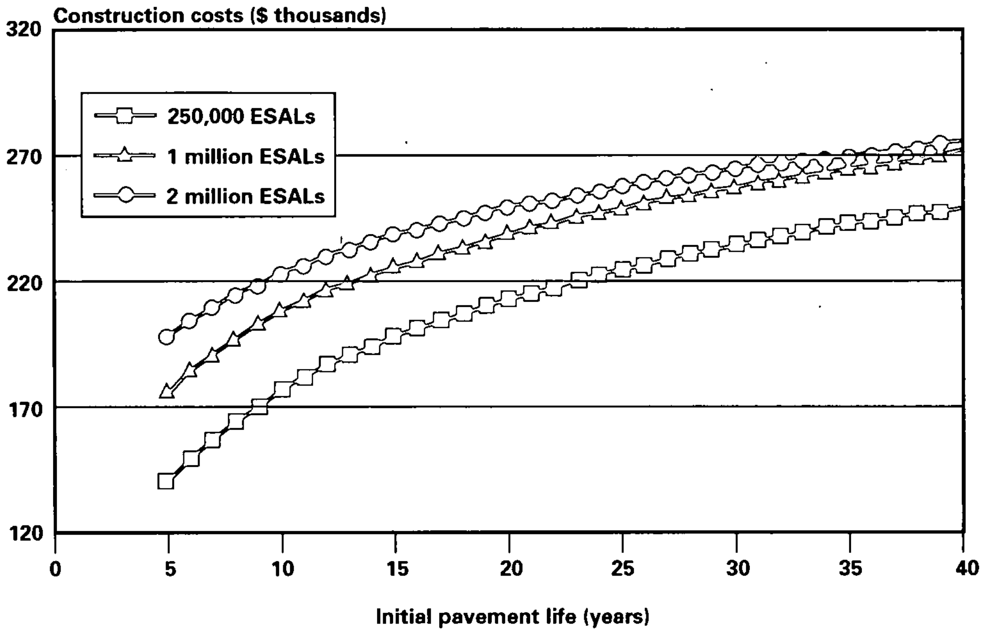
Road class	Average	Highest value	Lowest value
Freeway	522,482	1,000,000	200,000
Paved (urban)	401,152	550,000	234,300
Paved (rural)	303,325	430,000	100,000
Surface-treated	167,280	430,000	0
Gravel	22,504	106,500	0
Earth	7,483	17,483	0

To analyze construction costs, the OPAC model described in Section 2 was used along with the following costs:

Surface course	$950/mm/two-lane-km
Base and sub-base courses	$200/mm/two-lane-km

Figure 5.1 shows construction costs as a function of initial pavement life for three levels of annual axle loads. In looking along any individual curve, it is evident that moderate increases in costs add many years to initial pavement life. Second, in considering the distance between the curves, it is evident that moderate increases in costs add enormously to the number of ESALs a pavement can accommodate. These vertical distances show the economies of scale described previously. For example, with a pavement life of 15 years, costs are $197,079 for 250,000 ESALs and $237,587 for two million ESALs — a 21 percent increase in costs for an eight-fold increase in load-carrying ability.

Figure 5.1
CONSTRUCTION COSTS AS A FUNCTION OF INITIAL PAVEMENT LIFE



Without considering (yet) the portion of deterioration caused by the environment, the average total-cost-per-ESAL curves in Figure 5.2 also demonstrate something about construction costs. Averages have been calculated as the construction costs shown in Figure 5.1 divided by annual ESALs times the number of years of initial pavement life. As shown, average costs — without accounting for environmental deterioration — decrease as the initial pavement life is extended, and as traffic loadings increase. The lowest total average cost per ESAL, then, is found on a road with heavy truck traffic built with a pavement designed to last a long time.

Another point to note about construction costs is shown in Figure 5.3 where costs for two design lives vary with annual ESALs. The data from which this is generated are based on slightly different costs per millimetre than the information used in other graphs. It can be seen that, after a certain point, the curves are relatively flat. This demonstrates the same point as that illustrated by the vertical distance between the curves in Figure 5.1: small additional amounts spent on construction accommodate large increases in loadings. Second, the division between load- and environment-related deterioration can be more or less "read" off this graph. In the absence of any axle loads, a pavement with a 15-year initial life has a cost of $70,000. For a 20-year life, the cost is $94,000 with no traffic loadings. Moving to the right on the graph, all the additional costs are attributable to load. So, for example, at 250,000 ESALs on the 15-year curve, costs are $149,000. At this point about half of the construction costs arise because of load-related factors, and the other half because of environmental factors.

There are qualifications, though. First, the precise values of $70,000 and $94,000 are not fixed. That is, for the illustrations used in this report, a number of values for typical construction costs per millimetre were used and, as a result, the curves in Figure 5.3 move up and down somewhat. Second, the above discussion makes it appear as if the environmental and load-related costs of construction are independent. As discussed in Section 2, while the OPAC model does separate the two, load and environment work together in causing deterioration.

Figure 5.2
Construction Costs Per ESAL

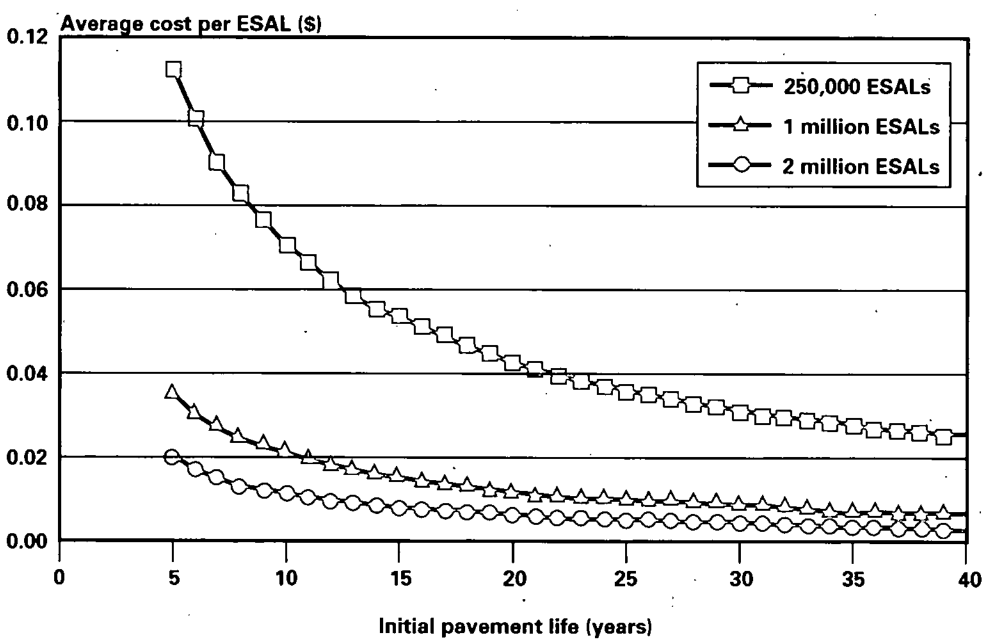
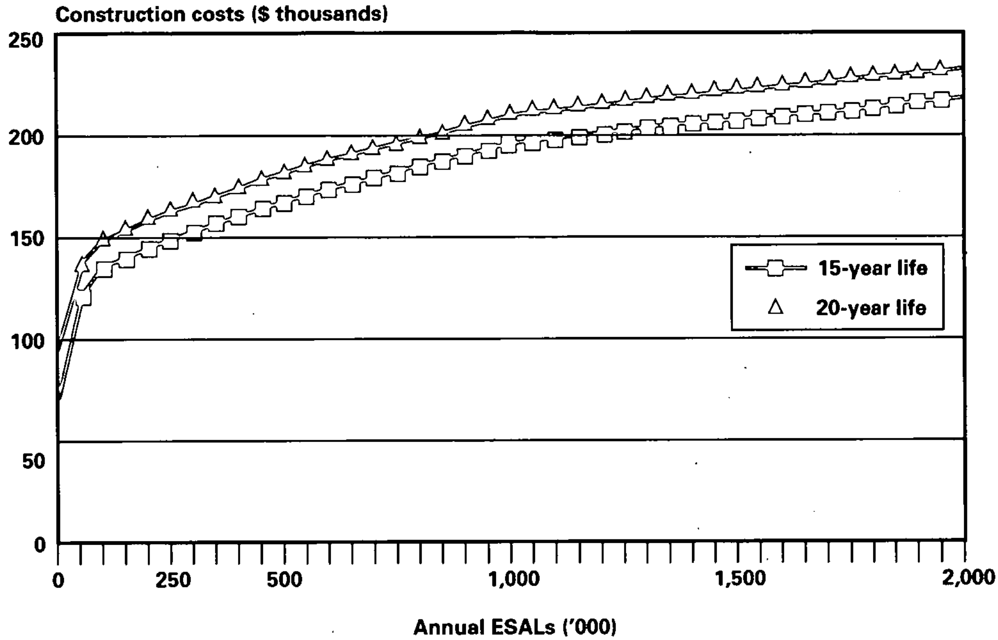


Figure 5.3
CONSTRUCTION COSTS AS A FUNCTION OF ESALS



5.5 MINIMUM LIFE-CYCLE COSTS

In Canada, it is normal in pavement design strategy to minimize initial pavement construction costs, pavement resurfacing costs, and delay costs to traffic created by resurfacing and reconstruction operations. The following discussion of minimum life-cycle costs, however, does not include the third item — delay costs.

The terminology used is:

C = construction costs per two-lane kilometre
R = resurfacing costs per two-lane kilometre
M = annual maintenance costs per two-lane kilometre
N = time horizon
n_1 = initial pavement life (that is, the period during which RCI declines from 8.5 to 4.5)

n_2 = overlay #1 life, assumed to be 12
n_3 = overlay #2 life, assumed to be 12
r = discount rate

The first way of looking at the problem is as follows:

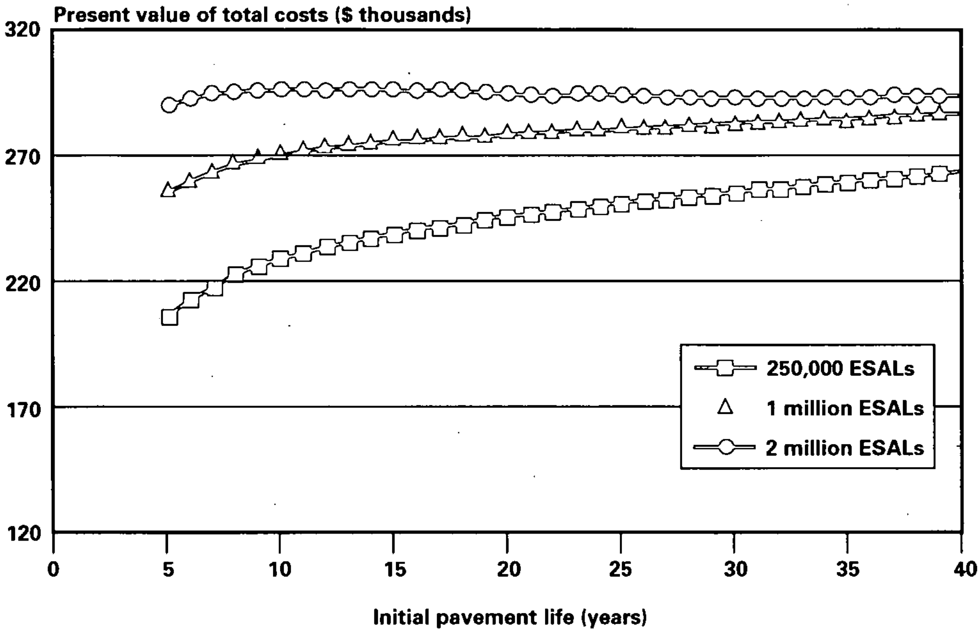
$$\text{Total cost} = C + \frac{R}{(1+r)^{n_1}} + \frac{R}{(1+r)^{(n_1+n_2)}} + M \times \left[\frac{(1+r)^N - 1}{r(1+r)^N}\right]$$

The last term, the present value of annual maintenance costs, does not affect the analysis and, therefore, is ignored. In Figure 5.4, cost curves — that is, the present value of construction and resurfacing costs — for three levels of annual ESALs are shown using a discount rate of 5 percent. The curves for the higher annual axle loadings are quite flat, suggesting that the choice of an initial pavement life is not critical. For example, in the case of two million ESALs, there is only a 2.2 percent difference between the highest and lowest cost. The curve for 250,000 annual ESALs does rise continuously, suggesting that the optimum strategy may be to build pavements with short lives for low-volume roads.

For a high ESAL load, increased construction costs of thicker and thicker pavements are just about offset by the savings in the present value of resurfacing costs. That is, longer initial pavement lives "push" resurfacing time further into the future and the effect is about equal to the increase in initial costs. For low-volume roads (low annual ESALs), construction costs rise more rapidly as initial pavement life is extended, and the offsetting advantage of delaying resurfacing expenditures is less important. (In the previous Figure 5.1, the 250,000 ESAL curve has a steeper slope than the other two.)

The discount rate affects the analysis and, in Figure 5.5, the three curves are recalculated using 10 percent.[6] The slopes are all slightly steeper, although in the case of two million ESALs the difference between the highest and lowest cost is still relatively small (7 percent).

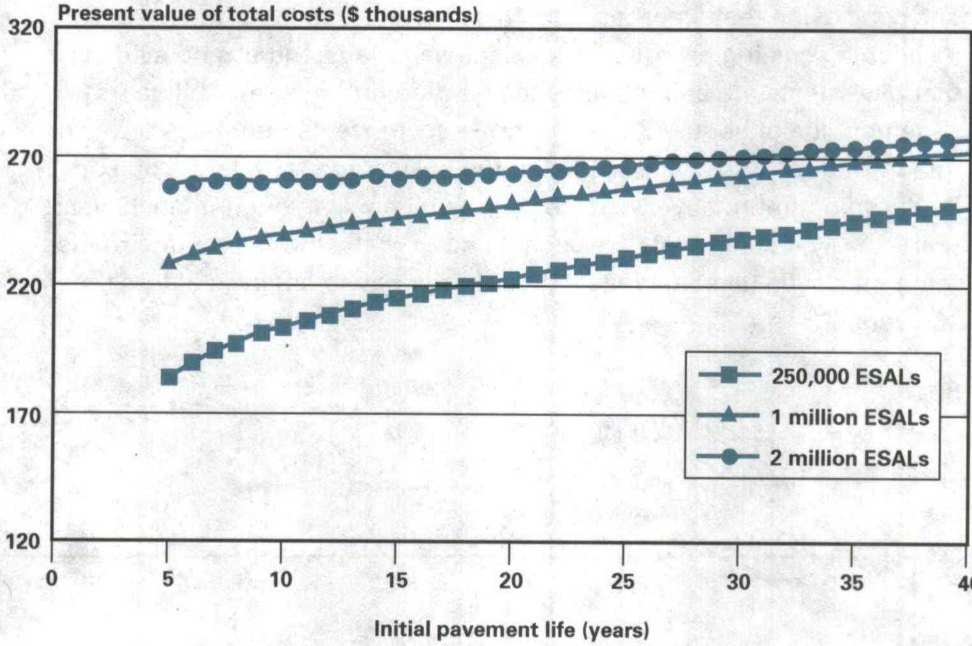
Figure 5.4
PRESENT VALUE OF LIFE-CYCLE COSTS (1)
(R = 5%)



In case one pavement cycle is not a sufficiently long time period in which to analyze optimum pavement lives, the curves in Figures 5.6 and 5.7 show what happens when two cycles are included. In other words, these are based on:

- current construction costs;
- resurfacing costs n_1 years and $n_1 + n_2$ years in the future;
- reconstruction costs $n_1 + n_2 + n_3$ years in the future;
- resurfacing costs $n_1 + n_2 + n_3 + n_1$ and $n_1 + n_2 + n_3 + n_1 + n_2$ years in the future.

Figure 5.5
PRESENT VALUE OF LIFE-CYCLE COSTS (2)
(R = 10%)



As shown in Figures 5.6 and 5.7, the curves are much flatter when two pavement cycles are included in the analysis. With a discount rate of 5 percent, the 250,000 ESAL curve rises initially and, at 17 years, gradually declines. The one million ESAL curve is almost flat with only a 5-percent difference between the highest and lowest point. In the case of two million ESALs, costs fall slowly throughout the entire range: costs at a 40-year initial pavement are 11 percent lower than with a five-year initial pavement life. Again, an increase in the discount rate "tilts" all the curves back up to the right.

A qualification to this analysis concerns delay costs. Their inclusion has the effect of giving all of these curves a more negative slope. In other words, deferred resurfacing costs *along with* deferred delay costs increasingly outweighs the additional construction costs for pavements with longer initial lives. This does not, however, quite resolve the issue of the optimum pavement life. Aspects of pavement performance are poorly understood. A difference of perhaps 10 to 15 percent in total life-cycle costs may not mean much for an asset whose life can vary by 50 percent or more because of a variety of factors — variations in construction quality, short-run changes in traffic, variations in material properties — which are not yet included in performance models.

The conclusion that emerges from this analysis is that, for the purpose of developing costing procedures for Canadian roads, there is no evidence that pavements are being built with less than optimum durability. Any initial pavement life of about 15 years or more seems to be optimal in terms of minimizing total life-cycle costs. For the busiest roads, in terms of axle loads, an optimum pavement life may be somewhat longer than 15 years (particularly if delay costs are considered). For the lowest-volume roads, there may even be some reason to consider pavement lives of less than 15 years.[7]

Figure 5.6
PRESENT VALUE OF LIFE-CYCLE COSTS (3)
(R = 5%)

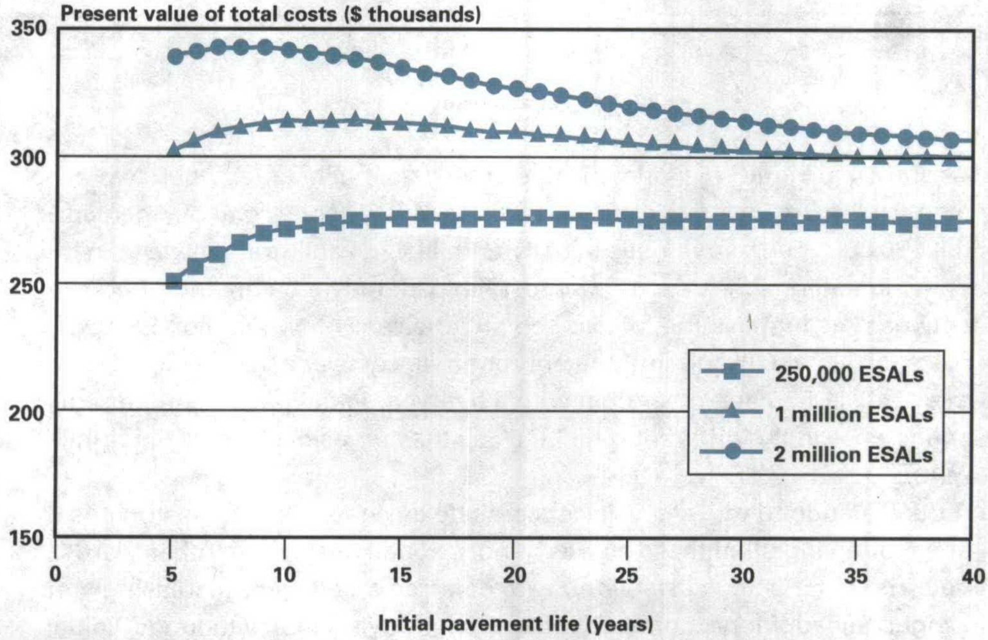
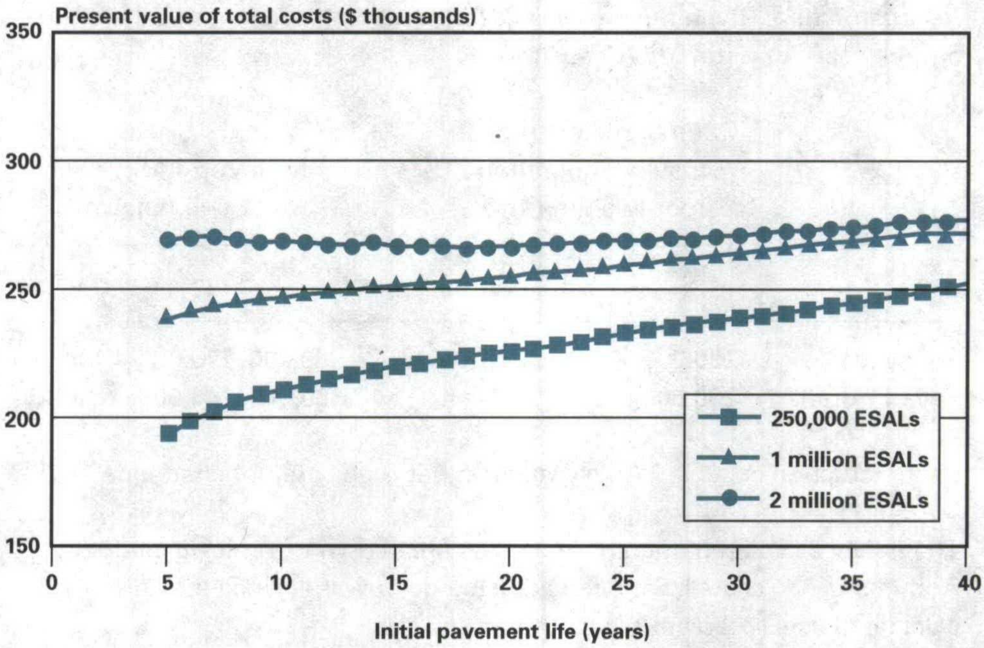


Figure 5.7
PRESENT VALUE OF LIFE-CYCLE COSTS (4)
(R = 10%)



5.6 OPTIMAL ROAD COSTS

For the purpose of costing in Section 7, two sets of TAC costs are used: "adjusted" as described in Section 3, and "optimal" (ignoring any consideration of demand) as developed in this section.

Maintenance: These are the same as the adjusted costs described in Section 3. For the purpose of calculating the costs that vary with usage, it is assumed that 15 percent are pavement related.

Resurfacing: These are as described in subsection 5.3. That is, for freeways, any TAC numbers between $52,000 and $78,000 and a duration of between 9 and 14 years remain unchanged. Other values are set at $65,000 and 12 years. For other paved roads, rural or urban, any TAC numbers between $44,000 and $66,000 with a duration of 9 to 14 years remain unchanged.

Other values are changed to $55,000 and 12 years. TAC's figures for the remaining three classes of roads are not changed (except for the adjustments described in Section 3).

Reconstruction: Given the analysis in the preceding section, these are the figures used for optimal TAC costs:

	Optimal reconstruction costs and duration (per two-lane km)		Accepted TAC values (per two-lane km)	
	$	years	$	years
Freeways	225,000	45	180,000–270,000	40–50
Paved (rural)	200,000	45	160,000–240,000	40–50

Reconstruction costs in TAC's data for other roads are not changed.

The newly calculated optimal TAC costs are shown in Tables 5.4 to 5.6. Administration costs have been adjusted downwards since they are calculated as 4.1 percent of all other costs.

Table 5.4
Optimal Total Maintenance and Pavement Costs (Total Annual Costs, Millions of 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	139.2	73.6	61.0	273.8
Paved (urban)	5.5	5.9	6.4	17.9
Paved (rural)	1,005.5	582.5	551.0	2,139.0
Surface-treated	167.7	42.1	165.0	374.7
Gravel	494.3	35.2	110.7	640.2
Earth	18.0	0.0	1.8	19.8
	1,830.1	**739.3**	**895.9**	**3,465.3**

Table 5.5

OPTIMAL AVERAGE MAINTENANCE AND PAVEMENT COSTS

(ANNUAL COSTS PER TWO-LANE KILOMETRE, 1989 $)

Road class	Maintenance	Resurfacing	Reconstruction	Total
Freeway	10,355	5,475	4,538	20,368
Paved (urban)	4,554	4,916	5,301	14,772
Paved (rural)	7,743	4,486	4,244	16,472
Surface-treated	5,086	1,276	5,003	11,365
Gravel	4,509	321	1,010	5,840
Earth	3,663	0	374	4,037

Table 5.6

OPTIMAL TAC ROAD COSTS: SUMMARY

(MILLIONS OF 1989 $)

Annual maintenance		$1,830.1
Pavement		
– resurfacing	$739.3	
– reconstruction	895.9	
– total		1,635.2
Bridges		296.3
Administration		154.2
Total		**$3,915.8**

6. COSTING METHODOLOGIES

6.1 INTRODUCTION

To an economist, "the cost of an event is the highest-valued opportunity necessarily forsaken." (Alchian, 1977, p. 301). The purpose of the cost concept is to enable choices to be made among available options. This did not raise many difficulties as long as traditional economic analysis concentrated on single-product firms. But, in reality, many production processes yield more than one product. The question then becomes one of knowing how to allocate the costs of a common input among joint outputs.

If, for example, an airplane carries passengers and freight, what portion of the costs of gasoline, labour and facilities should be attributed to each? The airline itself does not have to make this allocation of common costs; its interest is in ensuring that the total cost of the whole set of joint products is less than the total revenue from their sale. To maximize revenues, it has to ensure that the marginal revenue from the sale of each of the joint products equals or exceeds the marginal cost of their production. Market prices will be those instruments which allocate the amount produced among the competing consumers and yield a maximum wealth to the producer. In other words, pricing and output decisions can be made even though common costs cannot be assigned.

This normative argument which is based on the role of rationing by market prices explains why economists have long considered certain cost allocations unnecessary and possibly misleading. For instance, Stigler warns that "any allocation of common costs to the product is irrational if it affects the amount of the product produced, for the firm should produce the product if its price is at least equal to its minimum marginal costs." (Stigler, 1966, p. 165).

But many situations, internal as well as external to the activities of the firm, generate needs to allocate common costs and, therefore, to develop practices which are consistent with the required use. Consider, for example, accounting rules and/or tax regulations. These may require firms to allocate joint costs. Or, consider a firm's efforts for internal efficiency. In effect, in large firms it may be necessary to allocate costs to set internal prices. The computer division of a company, for example, may "charge" other divisions for computer time. The objective of allocating costs is to ensure the cooperation of different managers in maximizing joint profits. Large firms, therefore, need cost allocations to define and design managerial incentive and reward structures when decentralized decision making prevails.

Regulation is an example of where actions external to a firm give rise to the need for cost allocation. The regulator, acting as an alternative to the market pricing mechanism, needs information on how common costs should be allocated among different products if the actual economic forces at work are to be changed or modified.

The case of a public road, however, is different from a private firm which may allocate costs for internal or external reasons. Here there is a complete dissociation between the way the product is offered (the service of the road according to the principle of first come, first served) and the manner in which fees are collected (registration fees and fuel taxes prepaid before consuming the output of the road). To understand the role of cost allocation in this context, consider the characteristics of the industry:

- Revenues from users (that is, those levies in Canada which have traditionally been considered "road-user taxes") are not tied to road expenditures. (With one or two minor exceptions, this is generally true in Canada.) This raises the issue, then, of the role of cost allocation under a system which does not use explicit road prices and which does not link any tax with road expenditures.
- There are economic indivisibilities in building roads (that is, investment is "lumpy") which means — in considering an individual road — there are economies of scale. This has traditionally been used to identify a natural monopoly. The issue becomes one of setting prices and of relating these prices to various notions of cost in a situation where there are increasing returns to scale.
- An individual road has a given capacity. In places where traffic volumes approach this limit, cost-allocation studies attempt to measure a capacity cost. But, in places where traffic volumes are less than the capacity of the road — a situation which characterizes most Canadian roads — roads are a pure public good. "As long as there is neither wear nor congestion, the services of the road should be free since they are pure social goods." (Walters, 1968, p. 20).

A road, however, is only one part of a network. This further complicates the allocation of costs and the relationship of these costs to user-charges. Some have envisaged the network as an industry producing two services: car travel or traffic capabilities and truck travel or load-bearing capabilities. The question is whether each production occurs under constant returns to scale or not. There is agreement with respect to the load-bearing capability of pavements: there are sharply increasing returns to scale (see Sections 2 and 5). But, in the case of traffic output, there is no consensus. Some suggest that capacity increases faster than the number of lanes. Others argue that the need for, and cost of, intersections grows faster than road width and, further, that the cost of the land in dense urban areas favour the decreasing returns to scale argument.

A second question, following from the first, is whether or not there are economies of scope. Diseconomies of scope exist if the cost of producing traffic volume and traffic axle-loadings jointly is more than the cost of separate production. The essential idea here is captured in the following: "the wider the road is made in order to accommodate more cars, the greater the cost of any additional thickness required to handle a heavy vehicle, because all the lanes must be built to the same thickness." (Small, Winston and Evans, 1989, p. 102).

Many of these arguments (and questions), however, are unnecessary in the context of Canadian roads, the vast majority of which operate at less than capacity volumes. This point is not obvious to those who spend their time on the few sections of the network around major urban areas which are congested, or those who travel on some interurban highways on a July weekend. Nevertheless, it remains true — see the rough estimates of AADTs[8] in Section 4 — and the implication is that an optimal road user-charge will not recover the full cost of the road network. The underlying assumption of any Canadian costing study, therefore, should be that there are increasing returns to scale and, further, that a marginal cost pricing scheme will not produce revenues equal to road expenditures.

6.2 APPLICATIONS

Theoretical foundations aside, there are four commonly recognized costing methods in use. These follow the terminology of the Trucking Research Institute in the United States. (The Urban Institute, Sydec, Inc., 1990)

The incremental method: Used in the 1956 federal study in the United States, this is based on the concept of avoidable costs: if a cost can be avoided because a particular vehicle class is excluded, then this cost is properly attributable to that class. In effect, the methodology recognizes a base road and associated cost which is assigned to all vehicles. Pavement costs are assigned to all vehicles in proportion to axle-miles and other costs (bridges, grading) in proportion to vehicle-miles. Costs for features of the road not included in the base system are assigned to larger and heavier vehicles.

The federal method: Also developed in the United States in the 1982 FHWA study, this method has been further generalized in Australia and the United Kingdom. Although similar in its basic philosophy to the incremental approach, the two methods differ in the way they allocate pavement costs and bridge replacement and repair costs. The first major difference lies in the definition of a minimum pavement and the use of ESALs for allocating pavement costs over and above this minimum. The incremental method benefits users with heavy axles as, in effect, they capture all of the benefits of the economies of scale inherent to pavement strength production. The use of ESALs in the federal method assigns these costs equally to all vehicles in proportion to their responsibility for ESALs. Secondly, under the federal method, expenditures for rehabilitation and replacement which were not taken into consideration under the incremental method, are based on distress models which simulate the consumption of pavements. Finally, rather than allocating bridge replacement and repair costs in proportion to the allocation for new bridges as the incremental method does, the federal method uses a bridge replacement function.

The benefits-based method: This assigns cost responsibility across road user classes in proportion to some measure of differential benefits derived from highway expenditures. It is a variant of the benefit theory of taxation holding that people should be taxed according to benefits received from government expenditures. The underlying principle is to reproduce, in the public sector, the one-to-one relationship which exists in a market economy between benefits received and opportunity costs incurred. To allocate benefits, however, consistent information on operating costs, travel time costs and accident costs of road users is required. This is difficult to find. In any case, most have rejected the benefits method as it is at odds with the efficiency goals of public policy.

The marginal cost method: Often advocated by economists but rarely used in practice, this method holds that users should pay the marginal social cost of using the road network. Until recently the required procedures for allocating costs in this manner were not well developed. The 1982 FHWA study made an attempt at such an approach in one of its appendices (U.S. FHWA, 1982, Appendix E). More recently, Newbery (1988a, 1988b) and Small, Winston and Evans (1989) have presented theoretical frameworks and applied the results, respectively, to the United Kingdom and the United States. In general, the marginal cost method considers two categories of cost: the private cost of road use and the social road-use costs. The first category includes the vehicle operating costs and the cost of the operator's time. The second category includes costs borne by third parties: highway agency costs, pollution costs, road damage costs (that is, the passage of a candidate vehicle raises the costs of subsequent vehicles by, for example, making the pavement rougher) and congestion costs. There is disagreement as to whether the correct cost is a short- or a long-run one.

The underlying philosophy of these four approaches is different. The first three are based on equity principles, whereas the last one is essentially efficiency-oriented. More specifically, among the equity methods, the first two put the emphasis on the use of costs as an allocation device and the third puts the emphasis on benefits received. The incremental and federal methods attempt to determine equitable cost allocations among various user classes according to a cost-occasioned standard. Although the benefits-based method shares the same equitable principle, it proceeds by allocating benefits to highway user classes rather than costs. Finally, the marginal cost method, which searches to promote economic efficiency is not constrained by having to consider road expenditures as total costs.[9] The basic principle is that each trip should be priced at its marginal social cost. This marginal cost pricing rule, then, does not involve allocations of costs among users. For this reason, it is similar to the situation encountered by a multi-product firm where the only concern is that marginal revenues equal or exceed marginal costs.

6.3 COSTING STUDIES

6.3.1 1982 FHWA Study

One of the more widely emulated cost-allocation studies was undertaken in the early 1980s in the United States. In it, capital expenditures are separated into three categories: pavement, bridges and other. There are no annual (that is, non-capitalized) costs included. Pavement costs consist of new pavements, either rigid or flexible, and pavement rehabilitation which consists of resurfacing, restoration, rehabilitation and reconstruction ("4-R" costs). The main elements of bridge costs are new bridges, replacement bridges and bridge repairs. The third "other" category consists of right-of-way, grading, and other miscellaneous capital costs such as administration, planning, and preliminary engineering.

New pavement costs are assigned in a two-step procedure: the costs of minimum pavement thickness are treated as common costs and allocated on the basis of vehicle-miles of travel (VMT), and the costs of extra pavement thickness are based on the relative consumption or damage of pavements by vehicle classes and are allocated on the basis of ESALs. Pavement 4-R costs are assigned to each vehicle class according to distress models and the relative importance of each type of distress. The distress models take into account the interaction of the environment and the repetitive passage of ESALs.

New bridge costs are allocated on the basis of the incremental strength method; that is, over and above a certain minimum strength, additional costs are assigned on the basis of GVW. Bridge repair costs are treated as a residual, and the costs of replacement bridges have a special set of relationships to vehicle characteristics.

The third or "other" category consists of grading and drainage costs which are first allocated on the basis of vehicle weight-to-horsepower ratios; and lane-width costs which are first allocated on the basis of width characteristics of vehicle classes. As a second step, all of these costs are translated into costs per VMT.

These three capital costs are allocated to three highway classes: interstate highways, other arterials and collectors, and local roads and streets. Further, these three highway classes are costed in either rural or urban settings. In Table 6.1, a summary is shown of the distribution of costs among two vehicle classes by allocation factor. In total, the FHWA approach assigns 59.9 percent of costs to passenger vehicles and the remaining 41.1 percent to trucks. Most of the passenger vehicles share of costs can be explained by its responsibility for the residual factor (VMT) whereas most of the trucks share of costs can be explained by its responsibility for ESALs.

Table 6.1
FHWA Distribution of Highway Costs
(Cars versus Trucks, by Attributable versus Residual Factors)

Vehicle class	Total costs	Allocation Factor	
		Attributable (ESALs)	Residual (VMT)
Passenger vehicles	59.9%	16.7%	42.2%
Trucks	41.1%	36.6%	4.5%

Source: U.S. FHWA, 1982, p. I-9.

6.3.2 U.K. Cost Study

The U.K. allocation of costs is more complete than the 1982 FHWA allocation as it estimates expenditures by both central and local government. It then attributes these among users according to many factors. Expenditures include capital and maintenance road costs, and policing and traffic warden costs. The FHWA study only dealt with the first of these. The U.K. procedure uses five allocation factors: maximum gross vehicle weight (max GVW), passenger car units (PCU), travel distance (VKT), average laden gross vehicle weight (av GVW), and standard axle loads (indicated here as LEFs). Most are multiplied by the total kilometres for each vehicle class (av GVW-km). Four road classes are recognized, including what would be considered "local" or "municipal" roads in Canada.

Capital expenditures are allocated to vehicle classes in a two-step procedure: the first resulting in 15 percent of costs allocated to vehicles over 1.525 tonnes in tare weight, with the allocating factor being max GVW-km; and the second resulting in the remaining 85 percent of costs being allocated to all vehicles according to their PCU-km. The allocation of maintenance costs (which has a broader meaning than in TAC's data) is "based on expert advice from highway engineers and research scientists" (U.K. DoT, 1990-91, p. 1). The allocation factors are VKT, av GVW-km, and ESAL-km. As with all allocations, there are arbitrary aspects to these U.K. procedures.

Table 6.2 shows the result of the U.K. method for fiscal year 1990-91. Overall, 67.7% of the costs are allocated to passenger vehicles (cars and buses), 23.6% to trucks and 8.7% to pedestrians — the main component of the "other" user class. The use of incremental procedures results in most capital costs being assigned to passenger vehicles as they account for most travel (84.7% of the PCU-km), with much of the balance being assigned to trucks as they account for most of the weight (85.7% of the max GVW-km). Current expenditures, on the other hand, are allocated primarily to passenger vehicles as, again, they account for most of the travel (VKT) and a large proportion of the actual weight on the roads (av GVW-km). The major portion of current expenditures allocated to trucks arises because of their responsibility for most of the axle loads.

Table 6.2

U.K. DoT Distribution of Highway Costs

(Vehicle classes, allocation factors, 1990-91)

Vehicle class	Total	Capital			Current			
		PCU-km	max GVW-km	Total	Vehicle-km	av GVW-km	LEF-km	Total
Cars	67.7%	84.7%	12.3%	73.8%	94.2%	69.0%	13.3%	55.6%
Trucks	23.6%	13.7%	85.7%	24.5%	4.3%	29.4%	85.9%	36.4%
Other (incl. pedestrians)	8.7%	1.6%	2.0%	1.7%	1.5%	1.6%	0.8%	8.0%

6.3.3 Australian Study

As in the U.K. research, the Australian study's estimates of road costs "are based on the allocation of all the financial costs incurred by road authorities in the provision of road infrastructure, in road maintenance, and in the supervision of road use." (Australia, Inter-State Commission, 1990, p. 78). The procedure distinguishes two types of expenditures: separable, or those which can be reasonably associated with the use of the road; and non-separable, or those which are common to all users. The allocating factors for separable expenditures are VKT, PCE-km, max GVM-km, and LEF-km. The factor for non-separable costs is VKT. The number of vehicles is also used as an allocation factor for "miscellaneous" expenditures.

All arterial roads — national highways, national and local roads — are considered. Table 6.3 shows the results for two vehicle classes by the allocation factor in 1989-90. As shown, 68.9% of the costs are assigned to passenger vehicles and 31.1% to trucks. Road costs are allocated to passenger vehicles primarily because of their responsibility for total travel (91.4% of VKT and 81.7% of PCE-km). The share of costs allocated to trucks arises because of their responsibility for axle loads (96.1% of total LEF-km) and the total weight on the road (77.4% of total maximum GVW-km).

Table 6.3
Australian Distribution of Road Costs
(by vehicle class, by allocation factor, 1989-90)

Vehicle class	Total costs	Costs allocated by:				
		VKT	PCE-km	LEF-km	Max GVW-km	# Vehicles
Passenger	68.9%	91.4%	81.7%	3.9%	22.6%	95.9%
Truck	31.1%	8.6%	18.3%	96.1%	77.4%	4.1%

The study considers other costs associated with road use, namely, accidents, congestion, noise and atmospheric pollution. However the estimates for these are not included in the global figures. The authors also mention an issue raised by the World Bank: the effect of environmental factors on road deterioration (Paterson, 1987). However, after raising some concerns about the specification and interpretation of Paterson's model, they conclude that their non-separable cost estimates compare well with Paterson's guidelines.

6.3.4 Haritos' Study

The only Canadian research is Haritos' monograph for the Canadian Transport Commission in 1973[10] updated, in part, with the use of RTAC data in 1989 (Nix, 1989). The methodology draws heavily on the incremental method from the first federal study in the U.S. Road expenditures included are: capital (including land), maintenance and policing and justice costs. Capital costs are divided between escapable (those which vary with usage) and inescapable (those which do not vary with usage) according to one of two assumptions: either all capital costs are inescapable or else two thirds of capital costs are inescapable. Similarly, maintenance is classified into escapable and inescapable categories. In this case, though, the separation is made on the basis of a lengthy analysis of specific items contained within a maintenance account and some guesswork as to how these vary with usage. Costs, both capital and maintenance, are then allocated to vehicles on either an annual basis (inescapable) or on a trip basis (escapable) according to a complicated series of what essentially are arbitrary assignments. The most important aspects of these are developed directly from the incremental method. The end result is a comparison of annual road revenues (making assumptions about what constitutes a road tax) and these elaborate assignments of costs. The findings and the methodology are dated by now and there is not much purpose served in describing them here.

6.3.5 Marginal Cost Studies

Economists argue that roads should be viewed as a valuable and scarce resource and, therefore, their use should be rationed by the price mechanism. In the particular context of a road which is characterized not only by the private costs of road use, but also by externalities such as congestion, pollution, road damage and accidents, an efficient price implies that road users should pay the marginal social cost of using the road network, regardless of the particular trip undertaken.

The 1982 FHWA study: an early application of the concept of a short-run marginal cost (SRMC) to roads is found in the 1982 FHWA study. Costs are calculated in a two-step procedure. First, private costs of road use paid by owners are computed: fuel, wear and tear, driver's time and so forth. Second, the social costs arising from vehicles using roads and borne by third parties are calculated.

The first of these social costs is pavement wear which is subdivided into two distinctive parts: pavement repair costs borne by the road agency and road damage costs borne by road users. Both are a function of axle loads. Environment and soil conditions are recognized for their potential effect on pavement deterioration, but are not taken into account for technical considerations. The portion of pavement wear borne by users arises because rougher pavements increase vehicle operating costs.

The second social cost is the cost of congestion which is subdivided into three parts: the decrease in speed below free-flow levels, implying additional travel time; the increase in operating costs resulting from these delays; and the increase in the frequency of accidents. The first two parts are computed by using linear volume-delay functions whereas accident costs, though known to be important, are not incorporated because of an absence of good estimates.

The third social cost is air, water and noise pollution arising from vehicle use. Air and noise pollution costs are computed; however, water pollution costs are not because of insufficient evidence on how to estimate efficient prices.

The final result of these computations gives an idea of what an efficient user-charge system may be (see Table 6.4). They depend on the vehicle used, the location, the congestion (measured as a "volume-to-capacity" or *V/C* ratio) and the road class.

Table 6.4
FHWA Efficient User-Charges
(U.S. 1981 cents per VMT)

Vehicle type	Location	Key parameter	Road-use costs	Congestion costs	Pollution costs	Total
Auto – 3,000 lb (1.4 tonne)	Rural	V/C = .05	0.3	0.3	0	0.6
Auto – 3,000 lb (1.4 tonne)	Urban	V/C = .85	0.7	11.2	1.6	13.5
Truck 3-axle – 40,000 lb (18 tonne)	Small urban	V/C = .35 PCE = 1.2 ESAL = 0.8	33.6	2.2	0.4	36.2
Truck 5-axle – 72,000 lb (33 tonne)	Urban interstate	V/C = .15 PCE = 1.2 ESAL = 1.6	40.6	1.4	7.0	49.0
Truck 3-axle – 60,000 lb (27 tonne)	Urban collector or rural	V/C = .25 PCE = 2.0 ESAL = 4.0	244.5	3.1	12.0	259.6
Truck 4-axle – 100,000 lb (45 tonne)	Rural arterial	V/C = .05 PCE = 3.0 ESAL = 27.2	503.5	0.3	0.2	504.0
Truck 9-axle – 105,000 lb (48 tonne)	Rural interstate	V/C = .15 PCE = 3.0 ESAL = 1.0	9.0	1.2	0.1	10.3

Source: U.S., FHWA, 1982, pp. E-53 and E-54.

Small, Winston & Evans: a second application of a marginal pricing technique was undertaken by Small, Winston and Evans (1989). Their proposal is general in that they integrate two economic principles: the first, an efficient pricing system to regulate demand for highway services, and the second, an efficient investment policy to minimize the total public and private cost of providing them. They compute a congestion cost for an urban expressway and a principal urban arterial respectively as a cost-per-peak-period PCE-mile. It varies from 14.5 to 15.1 cents (U.S.). They also compute the marginal cost of road wear on the basis of their model of pavement deterioration described in Section 2. This varies from 0.2 to 4.0 cents per ESAL-mile. These costs, both congestion and road wear, are only calculated for urban expressways and urban arterial roads.

Newbery: Newbery promotes the idea that road users should pay the true social cost of transport (Newbery, 1990, 1988a and 1988b). His main contribution to the debate lies in his road damage externality theorem which states that: "If the age distribution of roads of a given type is constant, and the traffic flow is constant, and all road damage is attributable to traffic, then the average road damage cost of a vehicle is identically equal to the average maintenance cost allocated in proportion to its number of equivalent standard axles. The road damage externality is zero." (Newbery, 1988b, p. 305). Subsequent users' costs are raised by the transit of a heavy vehicle (the cost raising effect) whereas the resulting road damage also brings forward the date of road repair (the cost reducing effect). Newbery's theorem shows these two effects approximately balance each other. Therefore, when considering road damage costs, only the pavement cost which reflects the increased cost of repairing the roads, and which is borne by the highway authority has to be considered.[11]

Newbery also considers congestion costs. By using statistical results from different British researchers, he computes a short-run marginal congestion cost (MCC) which varies by road classes (motorway, truck, principal and other), by period of time (peak and off-peak) and by vehicle types. This measure is expressed in pence per PCE-km. Table 6.5, taken from Newbery (1990, p. 29), presents some results for the United Kingdom for 1990.

Table 6.5

Marginal Congestion Costs in Great Britain, 1990

	MCC pence/PCE-km	Index of MCC
Motorway	0.26	8
Urban central peak	36.37	1070
Urban central off-peak	29.23	860
Non-central peak	15.86	466
Non-central off-peak	8.74	257
Small town peak	6.89	203
Small town off-peak	4.20	124
Other urban	0.19	6
Other rural	0.05	1
Weighted average	3.40	100

Source: Newbery, 1990, p. 29.

Newbery also looks at accident costs in an aggregate manner, without relating them to road classes and vehicle categories. Pollution costs are only mentioned.

Vitaliano & Held: the most recent contribution on marginal costs is from Vitaliano and Held (1990), but they examine only one of the costs included in an efficient pricing mechanism: road damage. Using a sample of 457 road segments in the State of New York, they estimate the road damage marginal cost generated by the cumulative numbers of ESALs passing over a given road surface. The management of this road network is characterized by a damage-sensitive maintenance strategy. That is, as is also the case in Canada, roads are resurfaced when a measure of serviceability (roughness) reaches a certain point. Moreover, they attribute 50 percent of pavement deterioration to the environment. Their estimate of a user-charge per ESAL-mile varies from 1.15 cents (U.S.) for rural and urban interstates to 28 cents for rural collectors. For a five-axle tractor-trailer weighing 80,000 lb, pavement wear costs per mile vary from 3 cents when driving on rural and urban interstates to 74.2 cents when running on rural collectors.

7. COSTING

7.1 INTRODUCTION

There are numerous ways to develop costs for Canadian roads: Which methodology should be used? What TAC data or what modifications to TAC data should be included? What assumptions should be made about traffic and vehicles? And what adjustments should be made in light of the analysis of pavements in Section 2? This section explores the possibilities. A cautionary note: all calculations could benefit from firmer data on construction costs, vehicles and vehicle characteristics.

In subsection 7.2, the FHWA, the U.K., and the Australian methodologies are used with both the adjusted and the optimal TAC data on costs. In subsection 7.3 an exploratory cost allocation is described which combines the best information from TAC with the information in Sections 2 and 5, along with features of the other allocation studies. In subsection 7.4 an attempt is made to calculate marginal pavement costs for existing roads.

7.2 FHWA, U.K. AND AUSTRALIAN METHODS

A summary of TAC's costs allocated according to the methods of other allocation studies is shown in Tables 7.1 and 7.2, with details in Appendix D. Observations are:

- TAC's maintenance and administrative expenditures are not incorporated into the FHWA method. If administration expenditures had been "loaded" onto other costs, the costs would be 4.1 percent higher than those shown. The main feature of the FHWA method shown in Tables 7.1 and 7.2 is the treatment of existing pavement costs. The only way of replicating this complex part of the FHWA method is to use one of the FHWA tables showing the final distribution of costs to various vehicle classes. This, however, introduces errors as the vehicle classes used do not match those available from Canadian data. Further, it is likely that the distribution of vehicles among these imperfectly matched classes is different in the two countries. For these reasons, the numbers shown in Tables 7.1 and 7.2 under the FHWA method are not particularly meaningful.

- "Maintenance," as used in the U.K. DoT's method encompasses all expenditures found in TAC's data. The result is that none of the U.K. methods for treating what are referred to as "capital costs" is relevant. Capital costs for the U.K. DoT are expenditures for "new construction and improvements."

- The cost allocation in the U.K. method applies to a wider range of roads than those in TAC's data. As a result, some judgement has to be used in knowing how much of the U.K. methodology to borrow. For example, "pedestrians," as an allocation factor, have not been used in the numbers shown in Tables 7.1 and 7.2.

- Under the U.K. method, all resurfacing and reconstruction costs, and a portion of maintenance costs (as defined here) are allocated to vehicles on the basis of ESAL-kilometres. There is no recognition that pavement deterioration is caused by factors other than axle loads. The result, as is evident in the numbers shown in Tables 7.1 and 7.2, is that trucks are assigned a large proportion of total costs.

Table 7.1
Cost Allocations, Adjusted TAC Data (1989 Can $)

	FHWA method pavement & bridge costs only		U.K. method		Australian method	
	Total costs (millions)	Per km (cents)	Total costs (millions)	Per km (cents)	Total costs (millions)	Per km (cents)
Passenger cars	521.4	0.5	1,130.4	1.0	2,175.5	2.0
Small trucks	408.5	1.5	296.7	1.1	548.8	2.0
Large trucks	1,309.8	7.5	2,876.8	16.5	1,567.4	9.0
Buses	47.7	6.0	14.6	1.8	17.8	2.3
Motorcycles, etc.	3.7	0.5	7.4	0.9	15.3	1.9
Other	41.3	10.5	8.1	2.1	9.2	2.3
	2,332.4		4,334.0		4,334.0	

Table 7.2
Cost Allocations, Optimal TAC Data (1989 Can $)

	FHWA method pavement & bridge costs only		U.K. method		Australian method	
	Total costs (millions)	Per km (cents)	Total costs (millions)	Per km (cents)	Total costs (millions)	Per km (cents)
Passenger cars	459.7	0.4	1,118.7	1.0	2,050.6	1.9
Small trucks	338.3	1.2	293.8	1.1	517.5	1.9
Large trucks	1,058.4	6.1	2,474.6	14.2	1,308.6	7.5
Buses	38.6	4.9	14.2	1.8	16.8	2.1
Motorcycles, etc.	3.3	0.4	7.3	0.9	14.4	1.8
Other	33.3	8.4	7.8	2.0	8.7	2.2
	1,931.5		3,916.6		3,916.6	

- The Australian method applies to a wider variety of expenditures than those included in TAC's data. However, once the TAC accounts have been matched with the Australian accounts — a process which requires some judgement — the allocation procedure is relatively straightforward.
- Under the Australian method, at least the portion of the methodology which is applicable to TAC's data, non-separable costs — those which do not vary with usage — account for about two thirds of the total

(Appendix D, Table D.7). As these are allocated on the basis of VKT, the result is that automobiles are assigned a far higher proportion of costs than in the other methods.

7.3 AN EXPLORATORY ATTEMPT TO ALLOCATE TAC'S COSTS

Appendix E describes an exploratory allocation method. It is exploratory in the sense that more work is required on many of the underlying variables before much confidence could be had in the results. Although it is possible to test the sensitivity of the results against assumptions made about the questionable variables — for example, that the average truck in Canada generates 1.5 ESALs — such work has not been done.

The method starts with TAC's costs as described in Section 3. It then modifies these according to the information in Sections 2 and 5. Owing to the gaps in the knowledge about roads other than those with flexible pavements and owing to the insignificance of urban paved roads (in the network under consideration), only two classes of roads are considered: freeways and rural paved roads. In TAC's original numbers these two classes account for 76.6 percent of total maintenance and pavement costs (see Table 3.3). Rural paved roads, for this exploratory method, are separated into three categories according to the AADT estimates in Appendix A.

The results are shown in the accompanying tables, starting with unit costs on Table 7.3. Expenditures are allocated in the following manner:

- Administration costs, set at 4.12 percent of all other costs, are treated as a fixed cost and allocated on the basis of VKT.
- Bridge costs, following the example of the Australian study, are treated in two components: 58 percent are fixed and allocated with VKTs; 42 percent are a function of vehicle weight and allocated on the basis of the average weight of vehicles times the distance driven (GVW-km).
- TAC's maintenance costs for rural paved roads are altered slightly so that the busiest roads have a higher cost per kilometre than the least travelled roads (see Table 7.3). This is done to account for the fact that maintenance costs may be (partly) a function of traffic volumes. (The alterations do not change the average cost for all paved rural roads.)

The 15 percent of maintenance costs that are pavement related are added to other pavement costs.

Table 7.3
UNIT COSTS
(1989 $, TWO-LANE EQUIVALENT BASIS)

Roads	Maintenance costs/km	Resurfacing costs/km	Reconstruction costs/km
Freeway	10,355	65,000	225,000
Paved (rural)			
– busiest 10%	9,292	65,000	200,000
– medium-volume 30%	7,743	55,000	170,000
– low-volume 60%	7,485	55,000	160,000

- Pavement costs, which include resurfacing, reconstruction and a portion of maintenance, are a function of both axle loads and the environment. In this attempt to develop an allocation procedure, the proportion of deterioration attributable to environmental factors (*E*) has been set at:

	E
freeways	40%
busiest rural highways	50%
medium-volume rural highways	70%
low-volume rural highways	80%

  Pavement costs are allocated as follows: cost times *E* is a fixed cost; cost times 1-*E* is a function of ESALs and allocated as an average cost per ESAL.

- Maintenance costs related to traffic, a further 15 percent of the total, are treated as variable and allocated to vehicles on the basis of distance driven (VKT).

- Maintenance costs which are not related to pavements and which are not a function of traffic — the remaining 70 percent — are treated as a fixed cost and allocated on the basis of VKT.

The result of these procedures is shown in Table 7.4. Since bridge and administration costs are treated on a system-wide basis, these amounts are not included.

Table 7.4

VARIABLE VERSUS FIXED COSTS

(ANNUAL PAVEMENT AND MAINTENANCE COSTS PER TWO-LANE KILOMETRE)

Road class	Variable costs		Fixed costs
	VKT	ESAL	
Freeways	1,553	6,393	11,511
Paved (rural)			
– busiest 10%	1,394	4,928	11,432
– medium-volume 30%	1,161	2,502	11,259
– low-volume 60%	1,123	1,609	11,676

From Table 7.4, the proportion of costs which are fixed on each class of road is:

	Proportion of fixed costs
Freeways	59.1%
Paved (rural)	
– busiest 10%	64.4%
– medium-volume 30%	75.4%
– low-volume 60%	81.0%

The costs per unit of output — arbitrarily dividing fixed costs by total kilometres of travel — are as shown in Table 7.5.

Table 7.5

COSTS PER UNIT OF OUTPUT

Road class	Variable costs		Fixed costs $ per VKT
	$ per VKT	$ per ESAL-km	
Freeways	0.0004	0.0065	0.0026
Paved (rural)			
– busiest 10%	0.0005	0.0115	0.0052
– medium-volume 30%	0.0011	0.0217	0.0103
– low-volume 60%	0.0044	0.0599	0.0457

Administration costs for the whole network amount to $0.0009 per kilometre driven by all traffic. Bridge costs, again for the whole network, are $0.0002 per GVW-km plus the fixed cost of $0.0047 per kilometre.

Costs by vehicle and road class are shown in Table 7.6. These include system-wide bridge and administration costs. The multiplication of these costs and the VKT by vehicle class result in the following allocation of total annual costs:

cars	$1,563.1 million	59.3%
small trucks	393.7 "	14.9%
large trucks	651.0 "	24.7%
buses	12.1 "	0.5%
motorcycles, etc.	10.7 "	0.4%
other	6.2 "	0.2%
Total	$2,636.9 million	100.0%

There is a further $1.03 billion representing either roads not dealt with here (gravel, etc.) or bridge and administration costs not assigned to the paved freeways and rural roads.

Table 7.6
Costs by Vehicle and Road Class
(Annual cents per kilometre, 1989 Can $)

Road class	Cars	Small trucks	Large trucks	Buses	Motor-cycles	Other
Variable costs/km						
Freeways	0.06	0.07	1.52	0.20	0.04	0.23
Paved (rural)						
– busiest 10%	0.09	0.10	2.30	0.24	0.07	0.27
– medium-volume 30%	0.13	0.14	3.87	0.30	0.11	0.35
– low-volume 60%	0.46	0.47	9.93	0.71	0.44	0.79
Fixed costs/km						
Freeways	0.46	0.46	0.46	0.46	0.46	0.46
Paved (rural)						
– busiest 10%	0.72	0.72	0.72	0.72	0.72	0.72
– medium-volume 30%	1.23	1.23	1.23	1.23	1.23	1.23
– low-volume 60%	4.77	4.77	4.77	4.77	4.77	4.77
Total costs/km						
Freeways	0.53	0.53	1.98	0.67	0.50	0.69
Paved (rural)						
– busiest 10%	0.81	0.82	3.03	0.96	0.79	1.00
– medium-volume 30%	1.36	1.37	5.10	1.53	1.34	1.58
– low-volume 60%	5.23	5.24	14.70	5.48	5.21	5.57

While this methodology attempts to incorporate the best data from Appendix A, the best information available about pavement performance in the Canadian context, and the best features of other allocation studies, *more work* is required in testing and refining these procedures before they would be suitable for making any conclusions about policy.[12]

7.4 MARGINAL COSTS

In Appendix F, the steps required to estimate marginal costs are described. Again, the results are tentative. They represent *only* the marginal pavement costs of paved roads using the results of the OPAC model and typical Southern Ontario construction costs. Extending these results to all Canadian roads may not be appropriate.

This caveat aside, the process for estimating marginal pavement costs is relatively simple. From the OPAC model described in Section 2 and the construction costs described in Section 5 (Figure 5.3), a series of costs are developed for roads built to withstand a given number of annual ESALs. Initial pavement and overlay lives are assumed to be 15 and 12 years respectively. Further, overlay costs are assumed to increase for roads built for more traffic (axle loads) as described in subsection 5.3 for typical Ontario conditions. Using this information, the following cost curve (total life-cycle costs of pavements) is estimated:

$$C = 89{,}969 + 23{,}214 \times \log(\text{ESALs})$$

Marginal costs are estimated from the cost function as shown in Figure 7.1. For roads built for 250,000, one million and two million ESALs annually, marginal pavement costs are 4.0 cents, 1.0 cent and 0.5 cents respectively. To put these amounts in perspective, total marginal costs per kilometre for three trucks are shown in Table 7.7. The first truck is a heavily loaded three-axle truck typical of those used in the construction industry in Eastern Canada. The second, the five-axle tractor-semitrailer, is the most common large truck configuration in Canada. For the sake of this illustration, it is shown at the practical maximum weight for cross-Canada operations (some provinces allow higher weights). The last configuration shown is an eight-axle B-train, the largest truck in Canada except for those operating under special permit. It is used to haul heavy, bulk commodities. For this illustration, it is shown at the highest practical weight for cross-Canada operations.

Figure 7.1
MARGINAL PAVEMENT COSTS
($ PER ESAL-KM)

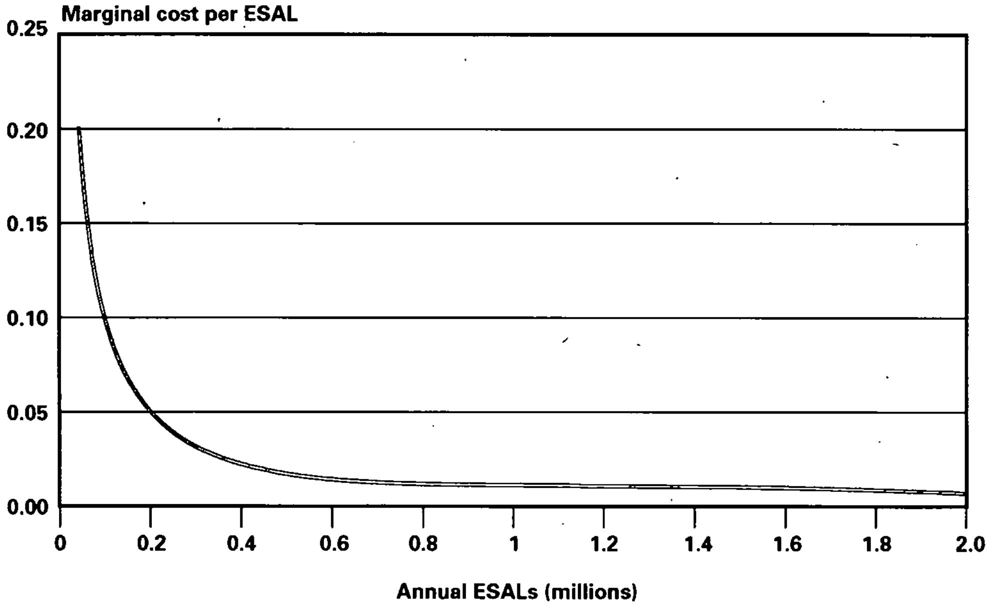


Table 7.7
MARGINAL PAVEMENT COSTS
(CENTS PER KILOMETRE)

	LEFs	Low-volume road	Mid-volume road	High-volume road
3-axle truck 25 tonne	a	10.3	2.6	1.3
	b	15.0	3.8	1.9
	c	19.5	4.9	2.4
5-axle tractor-semi 39 tonne	a	13.5	3.4	1.7
	b	18.4	4.6	2.3
	c	23.4	5.8	2.9
8-axle B-train 62 tonne	a	18.6	4.6	2.3
	b	25.5	6.4	3.2
	c	33.1	8.3	4.1

The calculation of costs in Table 7.7 is based on three different load equivalency factors: (a) ESALs developed from AASHTO; (b) Canadian measurements developed from data collected in the Canroads study; and (c) the reinterpretation of the Canroads data at the University of Waterloo. These different load equivalency factors are used to demonstrate the point that the attempt to develop road costs is highly dependent on a number of engineering measures. They are only illustrations of this point, however, as it is not clear that it is appropriate to use marginal costs developed from a pavement deterioration model calibrated in AASHTO's ESALs to determine the pavement costs of a particular truck where load equivalencies are calculated in a different manner.

A final way of putting these marginal costs into perspective is to consider the traffic data described in Appendix A. These suggest the following annual average ESALs for different segments of Canada's rural highway network:

Rural highways	Annual ESALs	Annual ESALs per lane	Marginal pavement costs per ESAL-km
busiest 10%	427,475	213,737	4.7 cents
medium-volume 30%	115,189	57,594	17.5 cents
low-volume 60%	26,877	13,439	75.0 cents

These have to be viewed in the context of all the qualifications about the traffic data in Appendix A and the assumptions used to estimate the proportion of truck traffic and the average ESALs per truck. Better data are clearly desirable. Even without these, however, the broad observation can be made that marginal pavement costs rise very rapidly for lower-volume roads. Further, for a large number of Canadian roads, these marginal costs may be quite high. *May be*, as there is uncertainty at the low end of the range — that is, annual ESALs as low as 13,439 — as to whether the pavement performance underlying the OPAC model is appropriate. It may well be that the Alberta model is more appropriate for estimating marginal costs for these lower-volume roads. This possibility has not been investigated.

8. Conclusions

The findings of this research can be summarized in the following 15 observations:

1. *Major research objectives:* In terms of the major objective — the calculation of road costs for vehicles in various classes — the work has demonstrated that there are a number of ways of estimating road wear costs. TAC data, substantially modified, along with estimates of vehicles and their characteristics may be combined with any one of several allocation methodologies to produce the required numbers. As an alternative, estimates about the relationship between axle loads and pavement costs can be made and marginal pavement costs calculated. Other aspects of road costs — capacity, users, externalities — have not been investigated.

2. *Qualifications:* This finding that road costs can, and have been estimated, must be qualified. These qualifications are related to four aspects of the procedures described in this report: the appropriateness of the methods used to calculate costs; the quality of the numbers used in the calculations; the extent of the federal, provincial, territorial road network covered; and, finally, the adequacy of the knowledge about roads (primarily pavement performance).

3. *FHWA method:* As to the appropriateness of the various methods, there are practical problems applying FHWA's methodology to TAC's data. First, the FHWA methodology is only appropriate for capital expenditures. Second, the FHWA method of handling existing pavement costs (distress models) is not something that can be done by simply "borrowing" the findings from its work to apply to someone else's road expenditure numbers. For these reasons, the numbers calculated here and shown in Section 7 are not too meaningful.

4. *The U.K. method:* Similarly, it is doubtful that the U.K. method applied to TAC's data results in a credible allocation of costs. For one thing, the U.K. method applies to a larger class of roads and a broader range of expenditures than those considered here. This means that aspects of the methodology have to be applied selectively. The more significant problem with the U.K. method, however, is that it attributes all pavement costs to axle loads. There is no recognition of the deterioration caused by environmental factors.

5. *The Australian method:* The application of the Australian method to TAC's data suffers from some of the same problems encountered with the U.K. method: different classes of roads and broader expenditures considered than those available in TAC's data. However, once a linkage is made between the Australian and TAC expenditure categories, this method is the most appealing of the three considered for Canadian conditions as it treats pavement costs in two components: a portion varying with axle loads, and a fixed portion that does not vary with traffic.

6. *Other allocation methods:* Other allocation methods have been briefly discussed in the report (the "incremental method," Haritos' method which draws on the incremental method, and benefit-based methods). For reasons discussed, however, none is appropriate for use in a modern Canadian cost-allocation study.

7. *Exploratory method:* Drawing on the best features of the various allocation methods described in Section 6, the best features of the adjusted TAC data, and the features of roads described in Section 2, an exploratory allocation method has been presented in Section 7.3. If a cost-allocation study is required in Canada, this method has something to offer. However, the numbers actually calculated are deliberately labelled "exploratory" to indicate that more work is required before the results could be used to influence transportation policy.

8. *Marginal pavement costs:* Allocation studies by their very nature are somewhat arbitrary. The calculation of marginal costs, on the other hand, can be more precise. Further, from the perspective of economics, marginal costs have the advantage of being theoretically sound as they are a prerequisite for efficiency-based policies. In this research, a tentative marginal pavement cost function has been estimated. It suggests that marginal pavement costs range from about 4.0 cents per ESAL-kilometre on low-volume roads to 0.5 cents on high-volume roads. Here, "low" and "high" volume are used as they were in the analysis of pavements using Ontario's OPAC model: 250,000 annual ESALs at the low end and two million ESALs at the high end.

9. *Marginal pavement costs and Canadian roads:* Considering the actual axle loadings on much of Canada's rural highway network, "low volume" may mean considerably less than 250,000 annual ESALs. The data examined in Appendix A suggest that much of the network may

have less than 20,000 annual ESALs. If this is true, marginal pavement costs may be as high as 75 cents per ESAL-kilometre or as high as $3.75 per kilometre for some of the heavier trucks. However, the suitability of extending the OPAC model, used to develop the estimate of marginal pavement costs, and the typical Ontario construction costs to these low-volume roads is not known. Other models of pavement deterioration, such as the one used in Alberta, may be more appropriate. The relative significance of environmental factors in these models may actually mean that marginal pavement costs per ESAL are lower than this figure of 75 cents. None of these possibilities has been tested.

10. *Quality of data:* The second major qualification about the costs estimated concerns the quality of the data used. For the allocation procedures, data had to be developed on the number of vehicles using the roads and the characteristics of these vehicles. The figures assembled here (Appendix A) are adequate for a discussion of allocation studies, *but they do not compare with* the accuracy and level of detail required for a cost-allocation study in the order of those reviewed in Section 6. For the discussion of pavements, pavement economics and marginal pavement costs, the data used here are of an illustrative rather than empirical nature.

11. *Extent of the road network covered:* The third major qualification about the costs estimated concerns the road classes for which costs were computed. Although the allocation procedures described in Section 7 show costs allocated for surface-treated, gravel and earth roads, the procedure of "borrowing" a methodology from somewhere else and extending it to these roads is not sound. In terms of the marginal costs estimated, these are only done for roads with flexible pavements. To this extent, then, this research has not been successful in determining the road costs of vehicles on a large segment (about one half) of the federal, provincial and territorial roads. Admittedly, these roads account for a very small portion of total travel: the figures calculated in Appendix A suggest they account for 2.5 percent of all — urban and interurban — travel in Canada.

12. *Knowledge about roads:* Costing, whether an allocation procedure or the estimation of marginal costs, cannot be undertaken without an understanding of the physical nature of roads. Repeatedly, in this research, questions arose about the underlying causal factors at work when considering one methodology or another. Why and how do

pavements deteriorate? What is the appropriate axle load equivalency factor? Do maintenance activities vary with traffic volumes? And so on. Indeed, at a time when most of the pavement research community is tied up in the largest pavement performance research effort ever undertaken (SHRP), analysts attempting a costing exercise must be prepared to modify their procedures in light of new findings which may emerge. For example, recent work on pavements in Canada even suggests that the number of large trucks has nothing to do with pavement deterioration (Papagiannakis et al.). While this seems unlikely, it does demonstrate the difficulty of finding good empirical measures for pavement performance which, of course, are a prerequisite for good costing procedures. As another example, consider the problems associated with load equivalencies. The three LEFs used in this research can sometimes result in marginal pavement costs for a large truck that differ by a factor of two. Which is the appropriate one to use given that the available pavement performance models are based on one measure, and that the best available Canadian empirical data produce the other measures?

13. *The "Under Built" thesis:* In the United States, an argument has been made that pavement deterioration models are based on a mis-specified relationship between axle loads and pavement lives. The result, the authors of this argument suggest, is that pavements have been built with less than optimal durability. If this also were true in Canada, the implications for a costing study would be that pavement costs should be estimated by using higher initial construction costs than those implicit in TAC's (adjusted) data. However, no evidence can be found that this "under built" thesis is valid in Canada. First, most of the pavements in Canada are flexible pavements and a large part of the argument in the United States concerns rigid pavements. Second, the model of pavement deterioration most applicable to Canadian conditions for areas such as Southern Ontario (the OPAC model), when combined with typical construction costs, suggests that the optimal pavement cost is not particularly sensitive to the choice of initial pavement life. For these reasons, the determination of road-user costs in Canada does not have to be adjusted for any recognition that pavements have been built with less than optimal durability.

14. *The "Under Maintained" thesis:* Another question raised recently, which would also have implications for the calculation of road-user costs, is this: "Are governments spending enough on the roads to

prevent unnecessary and costly deterioration?" An argument has been made in Canada for the past several years that governments are falling behind in the amount they spend on roads. The consequence, the argument goes, is that, in the long run, taxpayers will have to foot the bill for an expensive rehabilitation program. This is a complex argument which this research could not address fully. It may be that a road left to deteriorate will cost more in the long run than a road which is well maintained throughout its lifetime. This research has not investigated such a possibility. What it has investigated, however, is how well the "infrastructure-is-crumbling" thesis is based on facts. After adjusting for problems in TAC's data — the apparent adding mistakes and the failure to distinguish between *preserving* and *preserving and upgrading* roads — the calculations made here suggest that the annual expenditures required to maintain existing roads are in the neighbourhood of $4 billion. This is just about the amount governments are spending. The conclusion, therefore, is that the data do not support the idea that roads are falling apart because of insufficient spending. This conclusion has nothing to do with a related argument heard in Canada recently: governments should spend more on roads to increase capacity.

15. *Axle load versus environmental impacts on pavements:* One of the questions asked in the terms of reference was the relative contribution to pavement deterioration of traffic loads and of time (that is, the environment). The answer has great importance for any costing exercise as it largely determines the share of pavement costs attributed to large trucks. In some studies, most pavement costs are allocated to large trucks as these vehicles account for almost all of the heavy axles. In other studies, the argument is made that, for *rigid pavements*, the existence of environmental deterioration is minimal, if it exists at all. These other cost-allocation studies may be correct (little is known about the pavements for which they allocate costs), and the arguments made in respect of rigid pavements may be correct (they have not been investigated). However, according to the best evidence available in Canada, for flexible pavements and particularly for roads where the total annual axle loadings are relatively modest, *environmental factors account, by far, for the largest portion of pavement deterioration*. This suggests, then, that for most Canadian roads the environment, not axle loads,

is of most consequence in developing any costing procedures. Even on a very high-volume road, say one with two million ESALs per year, environmental factors may account for as much as 50 percent of the pavement deterioration. On low-volume roads, environmental factors may account for 80 percent or more of the deterioration.

ENDNOTES

This report has been written by the authors under contract to the Royal Commission on National Passenger Transportation. Mr. Nix was the project director and in this role took prime responsibility for the development of the data and the writing of the report. Dr. Hutchinson was responsible for all engineering matters and, in particular, developed most of the material in Section 2 and some of the concepts in Section 5. Professor Boucher was responsible for all costing matters and, in particular, developed Section 6, parts of Section 7 and the related appendices.

The authors would like to thank the Transportation Association of Canada for allowing them access to its files for information on the Canadian road network. Thanks are also in order to Royal Commission staff for assembling a large amount of information from the provinces and to John Lawson in particular who reviewed four or five versions of this document and who made helpful suggestions.

The authors are responsible for any errors that may have crept into the analysis and are also responsible for the views expressed.

1. In TAC's estimate, "expenditure needs," the total for all federal and provincial roads is \$5.1 billion. Of this amount, pavements account for \$2.8 billion or 54 percent (see Section 3).

2. With the current AASHTO equivalency factors, the exponent is actually closer to 3.8 than 4.0 and the ESAL of a 10,000 kg single axle on a typical flexible pavement would be more like 2.20 than the 2.25 mentioned in the text.

3. This has been confirmed in discussions with TAC. Something happened between the time the information was taken from the Lotus file and the latest booklet was published. Whatever the problem, the assurance has been given by TAC that "the spreadsheet numbers are the correct ones."

4. The only change made is one minor instance where a province is shown to reconstruct paved rural roads every 10 years. This has been changed to 20 which results in such a minor change to the overall results that the average frequency of 47.3 years remains unaffected.

5. This is on the basis of several conversations with provincial highway people about the nature of TAC's data.

6. It is understood that Treasury Board recommends a discount rate of 10 percent.

7. There is another qualification. Because RCI declines over time at an increasing rate, the "quality" of the road surface may improve with increasing initial pavement life in the sense that there will be more years with high RCI ratings. If this is true, the "output" on any given cost curve in Figures 5.4 to 5.7 is not constant.

8. Road capacity cannot be inferred directly from measures of *average* AADT as the critical variables are the number of vehicles using a particular section of the road during the peak hour. However, if the typical rural highway can handle 1,500 to 2,000 vehicles per hour *per lane*, it seems likely that AADT figures *on a two-lane basis* in the range of 750 to 3,000 are considerably below the capacity of most road sections.

9. In the 1982 FHWA report it is noted that annual user-charge revenues obtained by the marginal social cost method would have resulted in $80 billion when overall spending for highway purposes was about $41 billion. For 1981, total highway user-charge receipts were an estimated $23 billion. For the United Kingdom, Newbery (1988a) computes an overall amount of road taxes equal to £9,760 million whereas the Department of Transport estimates road costs to equal £3,468 million.

10. Other cost-allocation studies have been done. For example, M. Bunting has made some calculations for Ontario; B. Bisson, and others at the University of New Brunswick, have written several relevant papers. Haritos, however, is the only one who attempted a national study.

11. It is not clear that Newbery's theorem is relevant to Canada given that environmental factors are responsible for so much of the pavement deterioration.

12. The question has been raised as to how the opportunity cost of capital is treated in the exploratory methodology. The answer is that, because the method deals with annualized costs, no capital is included. That is, there is no investment, no depreciation, and no (potential) rate of return. It is conceivable that a way of converting TAC's data into information that could generate these amounts might be developed (Haritos used provincial annual expenditures to estimate a capital stock). Such a process has not been attempted.

Appendix A: Vehicle and Traffic Data

A.1 THE FLEET

In 1989 there were 16.7 million vehicles in Canada, 12.8 million of these being passenger cars (Statistics Canada, Catalogue No. 53-219, p. 14). Combining these figures with other information results in the profile of the vehicle fleet shown in Table A.1. The adjustments shown in column 3 are based on the following:

Number of large trucks: In 1987 Statistics Canada shows roughly one million trucks registered in Ontario (No. 53-219). Ontario registration statistics for 1987 show that there were 150,474 registered trucks with a GVW of 4.5 tonnes or greater (Nix, 1990, p. 5). Extrapolating this to the rest of the country, it is estimated that 85 percent of the truck fleet consists of small pickups and vans typically used by tradespersons and often used as a substitute for passenger cars. The remaining 15 percent are classified as "large" trucks.[1]

Number of cars and small trucks: The population of cars and small trucks is thought to be considerably smaller than as indicated by the registration statistics. Reasons for this are unknown and, in any case, are unimportant. The best information available suggests that perhaps 80 percent of the registered vehicles actually exist and are in use at any given time.[2]

Table A.1
The Fleet and Fleet Characteristics (Total Vehicles, by Type)

1 Vehicles	2 Regis-trations 1989	3 Assumed distribution	4 Average annual distance	5 Annual VKT (million)	6 Average GVW (tonnes)	7 Average RGVW (tonnes)
Passenger cars	12,811,318	10,249,054	17,380	178,129	1.0	1.0
Trucks	3,395,874					
– small		2,309,194	18,000	41,565	1.5	1.5
– large		509,381	44,448	22,641	23.3	37.2
Buses	62,494	62,494	19,000	1,187	7.0	8.0
Motorcycles, etc.	377,997	377,997	3,700	1,398	0.2	0.2
Other	71,846	71,846	10,000	718	8.0	8.0
	16,719,529	**13,579,966**		**245,639**		

Source: Statistics Canada, Catalogue No. 53-219 and estimates.

A.2 AVERAGE WEIGHT

Information in Table A.1 on average weights, either GVW or RGVW, is based on a number of sources. None of the numbers is particularly accurate. The primary reason for having information on this characteristic is that some allocation methodologies require such numbers. The only vehicle, however, where this really matters is the large truck. For these, information on weights was taken from a roadside survey conducted in 1983 on all Ontario highways (Perera and Corupe, 1984). In that survey, the average weight of all trucks was 23,300 kg and the average RGVW was 37,200 kg. About 4 percent of the trucks included weighed less than the cut-off point used here (4.5 tonne) to define "large" trucks. However, there is no accurate way of excluding these from the calculation of average weight.[3]

A.3 TOTAL VEHICLE-KILOMETRES OF TRAVEL

It is estimated that all vehicles travel a total of 245.6 billion kilometres a year. The first line in column 5 of Table A.1 is the product of the number of cars times 17,380 km/yr, RTAC's estimate of the average annual passenger car usage (RTAC, 1990, p. 41, developed from Transport Canada's fuel consumption survey).

The remaining figures on Table A.1 for average distance are based roughly on figures used in the 1982 FHWA study (U.S., FHWA, 1982, Appendix C). They are rough as the vehicle categories used do not match those used here. There are some exceptions and/or qualifications to this use of U.S. figures:

- For large freight trucks, estimates of annual kilometres have been developed from Statistics Canada sources (Catalogue No. 53-222, 1988) as follows:

total for-hire and private freight trucks	165,073
total distance travelled (km)	7,337,110,973
average distance travelled (km)	44,448

These figures, which are based on the activity of *surveyed* for-hire and private truckers, exclude the operations of for-hire owner-operators. This probably results in a lower estimate of average distance; however, nothing is done here to correct this possible error. Further, this average of 44,448 kilometres is assumed to apply to the entire fleet of large trucks (that is, the "non-freight" as well as the freight trucks captured in Statistics Canada's survey).

- The average distance shown for buses in Table A.2 is based on the weighted average for three bus categories in the U.S. source: intercity buses, school buses and transit buses.
- The figures shown for "Other" vehicles is simply a guess.

A.4 AVERAGE ANNUAL DAILY TRAFFIC

Six sources have been used to develop AADT estimates for the federal/provincial/territorial roads: TAC's data on volumes on the National Highway System and more detailed data from British Columbia, Saskatchewan, Ontario, Quebec and New Brunswick.

National Highway System: The NHS consists of 24,459 route kilometres or 33,169 kilometres of two-lane equivalent roads (National Highway Policy Steering Committee, 1988, Phase 1 Report) and represents 11.4 percent of federal/provincial/territorial roads. AADT figures for the NHS as given by RTAC are shown in Table A.2.

Table A.2
TRAFFIC VOLUMES ON THE NATIONAL HIGHWAY SYSTEM (FREQUENCY DISTRIBUTION BY AADT)

% of total NHS length (route-km)	AADT
15	>10,001
13	5,001–10,001
21	3,000–5,000
48	< 3,000

Source: RTAC, 1990, p. 30.

The NHS consists of four road classes as shown in Table A.3 (it is unclear whether the total length is 24,459 or 24,359 kilometres). In the third column, lengths have been converted to two-lane equivalents, the total of which is known to be 33,169 kilometres. In column 4, traffic volumes from Table A.2 are roughly mapped into this NHS road-class system. For example, since it is known that 15 percent (3,654 kilometres) of the NHS has traffic volumes above 10,000, it is surmised that the 3,317 kilometres of freeways in the NHS are, in fact, this busiest segment of the NHS. This process was used to continue relating traffic volumes with road classes until all that was left is the least travelled 48 percent of the NHS. The last column of the table shows the traffic volumes on a two-lane equivalent basis.

Table A.3
National Highway System Traffic Volumes by Road Class (estimated)

1 Road class (NHPSC Phase 1 Report)	2 Length (route-km)	3 Two-lane equivalents (estimated)	4 AADT (route-km)	5 AADT (two-lane equiv.)
Freeway	3,317	9,393	>10,001	>5,001
Multi-lane arterial	2,733	5,466	5,001–10,000	2,500–5,000
Two-lane paved	17,722	17,722		
– about 1/3			3,001–5,000	3,001–5,000
– about 2/3			<3,001	<3,001
Gravel	587	587	<3,001	<3,001
	24,359	**33,169**		

The information in Table A.3 can be used to make assumptions about volumes on the 292,003-kilometre network, the basic one being that the busiest 33,169 kilometres are, in fact, the NHS. Freeways have more than 10,000 vehicles per day or, on a two-lane equivalent basis, more than 5,000 assuming a typical four-lane freeway. Those which are classified as "Paved (urban)" in TAC's data are, presumably, comparable to "multi-laned arterials" in the NHS system and, therefore, are assumed to have traffic volumes in the range of 5,000 to 10,000 vehicles per day (2,500 to 5,000 on a two-lane equivalent basis). As for the most important class of road in Canada — the two-lane paved rural highway — the NHS figures suggest that perhaps only about 5,000 kilometres have volumes in the range of 3,000 to 5,000 vehicles. The balance of 129,855 kilometres appears to have volumes of less than 3,000.

British Columbia: Although B.C.'s system of classifying roads does not quite map into the TAC nomenclature, it is close. With a small amount of estimating, the figures in columns 5 to 9 of Table A.4 have been developed. The total lengths are reasonably close to TAC's figures. The figures are thought to be for the summer of 1989. The "special" road class (column 8) has no AADT figures — the largest element of guesswork in Table A.4 is in placing 2,028 kilometres of this class within the "Earth" category.

Table A.4

TRAFFIC VOLUMES ON BRITISH COLUMBIA ROADS

(MAPPING OF INFORMATION INTO COLUMNS 5 TO 9 IS ESTIMATED)

1 Road class	2 AADT	3 Road km	4 Two-lane equiv.	5 Free-ways	6 Rural (paved)	7 Surface treated	8 Gravel	9 Earth
1	> 10,000	1,970	3,160	1,224	1,936			
2	5–10,000	2,273	2,612	43	2,567	2		
3	1–5,000	7,085	7,426		7,258	19	149	
4	500–1,000	4,056	4,073		2,110	282	1,681	
5	100–500	7,188	7,190		2,821	453	3,902	14
6	10–100	14,102	13,915		2,387	560	10,608	360
7	0–10	5,431	4,917		210	33	3,550	1,124
8	special	4,488	2,865		71		1,766	2,028
			46,158	1,267	19,360	1,359	21,656	3,526

Source: British Columbia Ministry of Transportation and Highways.

These are the salient points to note:

- Freeways have volumes of over 10,000 vehicles (that is, over 5,000 when converted to two-lane equivalents, confirming the NHS data).
- Paved rural roads — keeping in mind that the busiest ones shown in Table A.4 are four lanes — have traffic volumes of roughly the following magnitudes:

  23% — 5,000 to 10,000 vehicles per day (this includes those four-lane sections with total volumes over 10,000)

  38% — from 1,000 to 5,000 vehicles per day

  39% — less than 1,000 vehicles per day

- Surface-treated roads have volumes in the range of 10 to 1,000, with 100 to 500 vehicles per day being perhaps the most frequent volumes.

- Gravel roads have volumes of less than 100 vehicles per day.

- Earth roads have — at least those for which numbers are available — less than 10 vehicles per day.

Saskatchewan: Information from Saskatchewan is shown in Table A.5. The first two categories of road correspond roughly to TAC's "Freeway" and "Paved (rural)" roads (see RTAC, 1990, p. 8). The third class, in terms of total length, approximately corresponds to the total "Surface-Treated" roads in TAC's data, and the last class in Table A.5 is roughly comparable to the "Gravel" roads shown for Saskatchewan in TAC's data. The higher percentage of trucks in the traffic for this fourth category is accounted for by the large number of resource roads in Saskatchewan: just over 40 percent of the total 5,812 kilometres where, for example, logging trucks account for a high percentage of the total volumes. "Trucks" in the last column of Table A.5 are defined as "one tonne or more," compared to the "4.5 tonne or more" used in this report to distinguish between large and small trucks.

Table A.5
Traffic Volumes on Saskatchewan Roads

Road class	Length (route km)	AADT (1989)	% Trucks (1 tonne or more)
Arterial highways	3,515	2,475	15
Collector highways	6,332	770	13
Local highways	9,831	360	11
Provincial roads	5,812	no data	19

Source: Saskatchewan Department of Highways and Transportation.

Ontario: Information on VKT from Ontario is shown in Table A.6. To compute AADTs, it is necessary to make assumptions about the classification scheme used by TAC and that used by Ontario. "Freeways" is used in both sources: the length in the third column, however, is the two-lane equivalent from the TAC data. For the second row of Table A.6 — "highways" or, in the source, "other King's highways" — there is more guesswork involved. The Ontario source shows a total length of 14,268 kilometres; TAC shows a total of 16,394 "paved rural roads" on a two-lane equivalent basis. If these two lengths (14,268 in total and 16,394 in two-lane equivalents) were synonymous, the AADT would be as shown in the fourth column of the Table (3,441).

However, it is more likely that Ontario's "other King's highways" represent about 15,200 kilometres on a two-lane equivalent basis. The result is that the length for "Highways" on Table A.6 is probably overstated and the AADT shown in the last column is probably understated. The third line probably contains a better estimate of average traffic volumes on Ontario's "other King's highways." What Ontario refers to as "secondary highways" are shown on the last line of the Table. These, presumably, correspond with what TAC shows as "Gravel," "Surface-Treated," and a small portion of "Paved (rural)." The total length shown on Table A.6 of 5,725 kilometres is from the Ontario source; these are assumed to be the same as two-lane equivalents. TAC shows a total of 4,243 kilometres of gravel and surface-treated roads for Ontario; therefore, there are presumably 1,482 kilometres of paved rural roads included in the last line of Table A.6.

Table A.6
Traffic Volumes on Ontario Roads

Highway class	Total 1989 VKT (million)	TAC length (two-lane equiv.)	AADT
Freeways	23,842	3,754	17,400
Highways	20,592	16,394	3,441
		15,200	3,712
Secondary	912	5,725	436

Source: Ontario Ministry of Transportation, 1991, Part I.

Quebec: Information on traffic volumes on Quebec highways is available at a very detailed level. Without a lot of work, however, it was not possible to use this with the highway classes employed here. In lieu of this, here are some observations (without converting to a two-lane equivalent basis):

- Autoroutes — traffic volumes range from over 40,000 vehicles per day in the Montreal area to less than 10,000 in some of the less populated regions.
- Highways — few of the highways (non-autoroute) have volumes exceeding 10,000 vehicles per day. Many of the major routes have volumes in the 1,000 to 5,000 range, while the many less-travelled highways have volumes of less than 1,000.

Information used to calculate broad average volume levels for Quebec are shown in Table A.7. As shown, autoroutes have an average volume, on a two-lane equivalent basis, of just over 10,000 vehicles per day, while other highways have an average volume of just over 1,000. Unlike other provinces, provincial roads account for a much higher proportion of all roads in the province and often include very low-volume roads.

Table A.7
TRAFFIC VOLUMES ON QUEBEC ROADS

Highway class	Total 1989 VKT (million)	TAC length (two-lane equiv.)	AADT
Autoroute	16,813	4,557	10,108
Other highways	21,759	56,087	1,063

Source: Information from Québec Ministère des Transports.

New Brunswick: Information on New Brunswick's "arterial highway network" — roughly 10 percent of total provincial roads, which are assumed to be the busiest roads in the province — has been published recently in a discussion paper (New Brunswick Department of Transportation, 1988). The points to note here are:

- Traffic volumes, in AADTs, on these arterial highways range from 1,000 to 10,000 vehicles per day, although there are a few four-lane sections near Saint John where the volumes are actually as high as 20,000, or 10,000 on a two-lane equivalent basis.
- The busiest highway in the province, the Trans-Canada Highway, has an average of 6,000 vehicles per day, whereas many of the other arterials are in the range of 2,000 to 3,000 (these are rough estimates as they are made on the basis of a quick inspection of a map showing highway sections and volumes).

Estimated AADTs

This information from the NHS and five provinces can be used to estimate AADTs *on a two-lane equivalent basis* for the whole 292,003-kilometre network (the results are shown on Table 4.2):

- Freeways — All sources indicate AADTs above 5,000 vehicles per day. Ontario information suggests a province-wide average of 17,400, and Quebec sources indicate a province-wide average of 10,108. Ontario and Quebec together account for 63 percent of all freeways (two-lane equivalent lengths) in Canada. The combined average for the two is 13,402. However, the very high volumes in Ontario — in some places through Toronto, Highway 401 has over 40,000 vehicles per day on a two-lane equivalent basis — are not typical of volumes elsewhere. Therefore, a Canada-wide average of 12,000 is used here.

- Paved urban roads — Paved urban roads represent a tiny fraction of the TAC network (0.4 percent) and, other than the NHS data, there is not much information on traffic. For here, an average of 4,000 is assumed.

- Paved rural roads — This is by far the most important component of the network and, for that reason, traffic volumes were estimated in terms of three different types: high, medium and low volume. The NHS data seem to indicate there may be 5,000 kilometres of these roads with volumes in the range of 3,000 to 5,000. The province-wide data for British Columbia suggest a figure of between 5,000 and 10,000. Saskatchewan's data give averages of 770 and 2,475 for two different components of the network. Ontario's data suggest a province-wide average of 3,500 to 3,700 (with some sections of paved road, which fell into the next lower highway classification, having lower volumes). Quebec's data indicate a provincial average of just over 1,000 vehicles a day, but this includes all paved, surface-treated and gravel roads. New Brunswick's information, for roughly 2,000 kilometres of (mainly) two-lane paved roads — out of a province-wide total of 4,200 — suggests volumes in the range of 1,000 to 10,000. It was assumed that the balance of New Brunswick's paved rural roads have volumes considerably less than this. For this research, these are the volumes assumed:

- First, there are the high-volume rural highways with volumes assumed to be 6,000 vehicles per day. It was also assumed that these roads account for 10 percent of the total (that is, just under 13,000 kilometres across Canada).

- Second, another 30 percent of the rural paved roads (39,000 kilometres) were assumed to have volumes of 3,000 vehicles per day.

- Third, the remaining 60 percent of the rural paved roads (78,000 kilometres) were assumed to have volumes of 700 vehicles per day.

- Surface-treated roads — The figures for British Columbia suggest an average of, perhaps, 500 vehicles per day; Saskatchewan's data indicate an average of 360; and the information from Ontario shows an average of 436, although this is on the high side as it is known that the road category with these volumes includes some paved roads. For here, surface-treated roads were assumed to have 350 vehicles per day.
- Gravel — Gravel roads were assumed to have 50 vehicles per day.
- Earth — Earth roads (all 4,903 kilometres within the federal/provincial/territorial domain) were assumed to have 10 vehicles per day.

To check the reasonableness of these estimates, the AADTs can be multiplied by highway lengths. The product can then be compared with the estimate of total VKT (245.6 billion) with an allowance made for the split in VKT between federal, provincial, territorial roads and municipal roads. Data from Ontario can be used for this, although it is recognized that travel patterns in other provinces or, indeed, the distinction between municipal and provincial roads, may well differ from one jurisdiction to another.

In 1989 in Ontario, there were an estimated 76,917 million VKT of which 45,360 million, or 59 percent, occurred on provincial roads (Ontario: Ministry of Transportation, 1991, p. I-003).[4] Multiplying the AADTs shown on Table 4.2 times the lengths shown on Table 3.1 and the resulting product by 365, produces the estimate of 157.9 billion VKT which is 64 percent of the estimated total 245.6. In other words, the estimated AADTs are reasonable in light of the estimated total VKT and the assumption that the split in travel between provincial and municipal roads in Canada is similar to that found in Ontario.

Another, partial, check on the procedures is a comparison of the estimated VKT derived by multiplying AADTs by lengths with the data (that is, excluding municipal roads) from an individual province. This has been done, but the results are not good. In effect, what happens is that the estimated national average AADTs overestimate VKTs in provinces with low volumes and underestimate VKTs for provinces with high volumes (Ontario).

A.5 TRUCK TRAFFIC

Data from three provinces have been obtained on the proportion of total traffic accounted for by trucks. Saskatchewan's information, on trucks "over one tonne," is shown in Table A.5. Ontario's information is not as concise: it is a large colour-coded map showing sections of the road network in terms of the proportion of truck traffic (Ontario: Ministry of Transportation and Communications, 1985). Without a lot of work, it is impossible to "add" these sections up to develop provincial averages. Nevertheless, the Ontario data can be used to make the following observations:

- The major freeways have large sections coded in the 15 to 19.9 percent and the 20 to 40 percent truck range. The exceptions are for those freeways around Toronto where commuters dominate or for those freeways heading to resort country.
- Generalizations about two-lane major provincial highways are difficult. In Northern Ontario, many have very heavy truck traffic: large portions of Highway 17 are coded 20 to 40 percent. But in Southern Ontario, there is considerable variability: many highways are coded "less than 8 percent," while many others sections of other highways are in the 8 to 10.9 percent and 11 to 14.9 percent range.

Only partial information on truck volumes has been obtained from New Brunswick: on the Trans-Canada Highway (TCH), the busiest highway in the province (except for the freeways near cities) with an average AADT of 6,000, truck volumes are 1,000 per day, or 17 percent, on average. Since the TCH is a major truck route, it was assumed that this figure represents the high end of the range for two-lane paved rural roads in Atlantic Canada.

With only these Saskatchewan, Ontario and New Brunswick data to rely on, and with either inconsistent definitions of "trucks" or definitions which cannot be related to the "4.5 tonne" demarcation line, assumptions made about truck traffic were obviously speculative. The procedure started with an assumption that truck traffic on freeways was 20 percent of AADTs and that it was 15 percent elsewhere. These were the steps that followed:

- A matrix was set up showing road classes by vehicle classes (see Table A.8). Given the AADTs estimated (Table 4.2) and the percent of trucks (20 percent or 15 percent), the balance of the AADTs were distributed to other vehicle classes roughly in proportion to the total annual VKT (Table A.1).
- The only major adjustment to these procedures was the assumption that trucks spend a larger proportion of their time on provincial (federal, provincial, territorial) roads than cars. This means that the proportion of

total travel on provincial roads is not quite the same as that shown in column 5 of Table A.1.

- Through a series of iterations, "% truck" was adjusted downwards until the final estimate of VKT was *less than* the total VKT shown on Table A.1. Obviously, figures could not be used which suggested that any vehicle class did more travel on provincial roads than it did on all roads implicit in the estimate of total travel in Table A.1.

The results of these steps are shown in Table A.8. The first line under "VKT" is the total travel calculated in Table A.1; the second line is the product of AADT times percent times 365 times road length; and the last line shows the percent of total travel for each vehicle class that is assumed to occur on the provincial road network (the balance being on municipal roads). These are quite speculative numbers.

Table A.8

Traffic, by Road Class, by Vehicle Class

		Distribution of traffic (%)					
Roads	**AADTs**	**Cars**	**Small trucks**	**Large trucks**	**Buses**	**Motor-cycles**	**Other**
Freeways	12,000	67	17	15	.5	.5	.25
Paved (urban)	4,000	73	18	7	.5	.5	.25
Paved (rural)							
– busiest 10%	6,000	69	17	13	.5	.5	.25
– medium-volume	3,000	73	18	7	.5	.5	.25
– low-volume	700	73	18	7	.5	.5	.25
Surface-treated	350	73	18	7	.5	.5	.25
Gravel	50	73	18	7	.5	.5	.25
Earth	10	73	18	7	.5	.5	.25
VKT 10^9							
Table A.1		178.1	41.6	22.6	1.2	1.4	0.7
Provincial		110.7	27.7	17.5	0.8	0.8	0.4
% Provincial		62.2%	66.6%	77.1%	66.5%	56.4%	54.9%

A.6 LEFS

The number of LEFs for any individual truck varies considerably. However, what is needed for the development of an aggregate national profile of vehicles and traffic is some measure of the "average" truck. The only readily available source on this (again, from Ontario) is a recent paper from the Ontario Ministry of Transportation (Hajek et al., 1991, Table 2). While there are concerns about how this ESAL was calculated and concerns about the suitability of using observations from two highway sites to extrapolate across all of Canada, in lieu of any other information, it is assumed that the average truck produces 1.5 ESALs. As for other vehicles, their numbers or their total VKT are either so small or else their axle weights so low, that all that is required here is a reasonable assumption about LEFs. These are shown in Table A.9.

Table A.9

Assumed Average Vehicle LEFs

LEFs (AASHTO ESALs) per vehicle		Annual ESALs per two-lane km	
Passenger cars	0.00001	Freeway	986,347
Small trucks	0.00007	Paved (urban)	153,585
Large trucks	1.50000	Paved (rural)	
Buses	0.02000	– busiest 10%	427,475
Motorcycles, etc.	0.00000	– medium-volume	115,189
Other	0.03000	– low-volume	26,877
		Surface-treated	13,439
		Gravel	1,920
		Earth	384

To check the reasonableness of these estimates, assumed LEFs per vehicle have been multiplied by total traffic volumes to produce an average loading for each road class. These are also shown on Table A.9 (and, as discussed in Section 2, it is suspected that the measure of LEF used here is not relevant for the last three classes of roads shown). While it is difficult to know how accurate the estimates of loadings are, the numbers appear reasonable.

APPENDIX B: CALCULATION OF EQUIVALENCY FACTORS

For this research AASHTO ESALs have been calculated by estimating the relationships shown in a recent Transportation Research Board (TRB) study (U.S. TRB, 1990, Fig. 4-3). ESALs could have been developed directly from the AASHTO manuals or Figure 2.2 for a typical flexible pavement; however, at the time they were needed, the TRB reference was the handiest material. In that study, for a flexible pavement with a SN of 5 and a terminal serviceability of 2.5, ESALs for various axle loads are shown as indicated in column 3 of Table B.1. In column 4, the predicted ESALs are shown using the following (measured in tonnes):

$$\text{single axle} = \left(\frac{\text{load}}{8{,}163}\right)^4$$

$$\text{tandem axle} = \left(\frac{\text{load}}{15{,}079}\right)^4$$

$$\text{tridem axle} = \left(\frac{\text{load}}{21{,}678}\right)^4$$

Table B.1
ACTUAL VERSUS PREDICTED ESALs

1 Axle type	2 Axle loads ('000 lb)	3 Indicated ESAL	4 Predicted ESAL
Single	9	0.06	0.063
	12	0.19	0.198
	16	0.62	0.624
	19	1.24	1.241
	20	1.51	1.524
Tandem	28	0.50	0.503
	30	0.65	0.663
	32	0.86	0.858
	33	0.97	0.970
	34	1.09	1.093
Tridem	40	0.49	0.500
	42	0.60	0.602

Canadian LEFs are calculated in one of two ways. First, the Canroad LEFs are calculated as they were determined in the original Canroads Study (Canroad, 1986, Part 2). Load, in both these and what follows, is measured in tonnes.

$$\text{single axle} = 0.002418 \times \text{load}^{2.9093}$$

$$\text{tandem axle} = 0.001515 \times \text{load}^{2.543}$$

$$\text{tridem axle} = 0.002363 \times \text{load}^{2.113}$$

Second, Waterloo's method of calculating them is as follows (Rilett, 1988, pp. 57, 60, 62):

$$\text{single axle} = 0.0153598 \times \text{load}^{2.159}$$

$$\text{tandem axle} = 0.001142 \times \text{load}^{2.704}$$

$$\text{tridem axle} = 0.0006205 \times \text{load}^{2.639}$$

The Canroad and Waterloo LEF calculations are based on the same data, but differ because of the way in which the pavement damage was accumulated under multiple axle groups.

For single steering axles, it is assumed for both the Canroads and Waterloo LEFs that the LEFs shown above for single axles are doubled (that is, because they have half the tire contact).

APPENDIX C: ANALYSIS OF MAINTENANCE EXPENSES

Annual reports of the roads departments from all provinces have been reviewed. Information from several of these can be used to develop an estimate of the proportion of maintenance expenses which are pavement related.

The six items in Nova Scotia's maintenance accounts which clearly relate to pavements comprise 9.1 percent of the total. The total excludes "aid to municipalities." Presumably, with some of the other items on the list (for example, "worker's comp") prorated to the various activities (such as pavements), the pavement component of these expenses would be higher. Maintenance expenses for Prince Edward Island are not broken out in as much detail as those for Nova Scotia. Nevertheless, the two broad items which are clearly related to pavements amount to 25.0 percent of the total. What is not known is if there are activities included within these items which are not related to the deterioration of pavements through either axle loads or environmental factors. The three items in Alberta's maintenance accounts for the year 1989-90 which clearly relate to pavements — regravelling, gravel surfaces; crack sealing; and pavement patching — amount to 17.0 percent of the total.

Finally, the maintenance expenses for Ontario for the fiscal year ending March 31, 1991 have been examined. The eleven broad headings used in these accounts are generally self-explanatory. "Roadside" includes everything to do with the side of the road (mowing, cleaning, fences, etc.); "drainage" includes such things as culverts and bridges; and "safety" includes line painting, electrical work, signs and guide rails. The account entitled "surface" amounts to 4.9 percent of the total. Alternatively, if "overheads" are removed from the figures, "surface" accounts for 5.6 percent of all activities.

A summary of this information — that is, total pavement-related maintenance costs — is shown in Table C.1. Because of the various terminology and because of various practices used to "load" certain expenses onto others, this is only a general identification of these expenses. The portion of maintenance expenses related to pavements is assumed to lie between 6 and 20 percent and, in lieu of any better information, 15 percent is used as a broad average in this study.

Table C.1
SUMMARY OF PAVEMENT-RELATED MAINTENANCE EXPENSES

Province	Pavement-related maintenance expense ($ million)	Provincial road length (TAC, two-lane equiv.)	Cost per km ($)
Alberta	11.49	37,847	304
Ontario	11.46	24,391	470
Prince Edward Island	7.28	4,920	1,479
Nova Scotia	8.85	23,458	377

APPENDIX D: COMPUTATIONS OF ROAD COSTS

As a number of the methodologies available for allocating costs use the same variables, Table D.1 summarizes the important information developed from Appendix A.

Table D.1
CANADIAN VEHICLE FLEET, VKT, ESAL-KM AND GVW-KM

	VKT (billion)	ESAL-km (billion)	GVW-km (billion)
Passenger cars	110.7	1.1	110.7
Small trucks	27.7	1.9	41.5
Large trucks	17.5	26,200.3	406.9
Buses	0.8	15.8	5.5
Motorcycles, etc.	0.8	0.0	0.2
Other	0.4	11.8	3.2
Total	**157.9**	**26,231.0**	**568.1**

D.1 FHWA (1982) METHODOLOGY

The methodology employed by the FHWA is concerned largely with the costs of new roads. None of this is applicable to TAC's data. Further, as the FHWA methodology does not consider maintenance (that is, "routine maintenance"), there is no guide to the allocation of these costs. All that could be used from the FHWA study was its method of allocating the costs of existing bridges and existing pavements. Bridges are relatively easy; they are allocated on the basis of VKT, with a resulting cost of $0.002 (Can) for all vehicles. Existing pavement costs are allocated on the basis of distress models which cannot be replicated here. Rather, the best that could be done was to distribute total TAC pavement costs in roughly the same proportion as is done in the FHWA (Table D-4, in the 1982 report). This is a rough approach as there is not a one-to-one correspondence between vehicle classes.

The allocation of existing pavement costs, according to the FHWA method, is shown on Table D.2. The assumption was that the fleet characteristics in Canada are sufficiently close to those in the U.S. to warrant the use of the ratios shown in the second column. This may be a weak assumption. The final allocation of costs, excluding TAC's maintenance and administration, is shown in Table D.3.

Table D.2
FHWA Allocation of Existing Pavement Costs

Vehicle class	FHWA allocation ratios (%)	TAC costs allocated ($ million)	Costs per km
Adjusted TAC costs			
Automobiles	15.40	313.6	0.003
Small trucks	17.51	356.5	0.013
Large trucks	62.72	1,277.1	0.073
Buses	2.27	46.2	0.059
Motorcycles, etc.	0.11	2.2	0.003
Other	1.99	40.5	0.103
Optimal TAC costs			
Automobiles	15.40	251.8	0.002
Small trucks	17.51	286.3	0.010
Large trucks	62.72	1,025.6	0.059
Buses	2.27	37.1	0.047
Motorcycles, etc.	0.11	1.8	0.002
Other	1.99	32.5	0.082

Table D.3
FHWA Allocation of Pavement and Bridge Costs

Vehicle class	TAC costs allocated ($ million)	% distribution	Costs per km
Adjusted TAC costs			
Automobiles	521.4	22.4	0.005
Small trucks	408.5	17.5	0.015
Large trucks	1,309.8	56.2	0.075
Buses	47.7	2.0	0.060
Motorcycles, etc.	3.7	0.2	0.005
Other	41.3	1.8	0.105
Pavement costs — total	**2,332.4**		
Optimal TAC costs			
Automobiles	459.7	19.7	0.004
Small trucks	338.3	14.5	0.012
Large trucks	1,058.4	45.4	0.061
Buses	38.6	1.7	0.049
Motorcycles, etc.	3.3	0.1	0.004
Other	33.3	1.4	0.084
Pavement costs — total	**1,931.5**		

D.2 U.K. METHODOLOGY

It is not possible to make a one-to-one linkage of the expenditure and road categories in the U.K. method with those available in TAC's data. An important difference is that "maintenance costs," as used in the U.K. DoT's organization of expenditures, encompasses all costs included in TAC's data. In fact, it actually includes more items than TAC's (for example, expenses on "footways, cycle tracks and kerbs"), but the point is that none of the parts of the U.K. method which applies to what they refer to as "capital" expenditures can be transferred. These amounts, in the parlance of the U.K. authors, are for "new construction and improvements." Another difference is that the U.K. method applies to all roads, including what would be called local in Canada. Since these are not part of the TAC data used here, adjustments have to be made.

The three primary characteristics used to allocate the U.K. "maintenance costs" are VKT, average GVW-km and the "standard-axle-km." For here, this last variable is defined as an ESAL-km. While not possible to make a direct link between the categories of "maintenance" in the U.K study and those in the TAC data, a close approximation is as follows:

ESAL-km costs: All reconstruction and resurfacing expenses, and a portion of what are included in TAC as maintenance, are allocated on the basis of standard-axle loads times distance travelled. The portion of expenses other than reconstruction and resurfacing which are allocated in this manner are labelled "patching and minor repairs." TAC's costs allocated on the basis of ESAL-km are reconstruction, resurfacing, and 15 percent of maintenance. The following are the resulting ESAL-km costs by road class:

	Adjusted TAC	Optimal TAC
Freeways	$0.020	$0.012
Paved (urban)	0.102	0.071
Paved (rural)	0.130	0.106
Surface-treated	0.515	0.524
Gravel	1.045	1.045
Earth	2.405	2.405

The concept of LEF as calculated here may be entirely inappropriate for the last three road classes.

GVW-km costs: The main expenditure in the U.K. system allocated on the basis of GVW-km is bridge costs. In addition, certain other portions of what in the TAC data would be included under maintenance are also allocated in this manner. For here, then, bridge costs plus 15 percent of maintenance are allocated according to the number of GVW-km for each vehicle class. The following are the results:

Total bridge + 15% of maintenance – adjusted and optimal TAC =	$570,783,688
Cost per GVW-km	$0.0010

VKT: All remaining costs — in TAC's terminology, administration plus 70 percent of maintenance — are allocated on the basis of VKT. In fact, in the U.K. method, some are allocated on the basis of the number of pedestrians but, as these are for local roads, this factor is not applicable to TAC's data. The result is as follows:

	Adjusted TAC	Optimal TAC
Cost per km	$0.0092	$0.0091

Table D.4

Cost Allocation: U.K. Method + Adjusted TAC

	Total costs ($ million)	% distribution	Cost per km
Passenger cars	1,130.4	26.1	$0.010
Small trucks	296.7	6.8	0.011
Large trucks	2,876.8	66.4	0.165
Buses	14.6	0.3	0.018
Motorcycles, etc.	7.4	0.2	0.009
Other	8.1	0.2	0.021
Total	**4,334.0**	**100.0**	

Table D.5
Cost Allocation: U.K. Method + Optimal TAC

	Total costs ($ million)	% distribution	Cost per km $
Passenger cars	1,118.7	28.6	0.010
Small trucks	293.8	7.5	0.011
Large trucks	2,474.6	63.2	0.142
Buses	14.2	0.4	0.018
Motorcycles, etc.	7.3	0.2	0.009
Other	7.8	0.2	0.020
Total	**3,916.6**	**100.0**	

D.3 AUSTRALIAN METHODOLOGY

Expenditures categories in the Australian study are broader than those in TAC's data. A rough comparison of the two is shown in Table D.6; the final four columns show the allocation factors used by the Australians.

Expenditure categories included within the Australian method, but excluded here, are traffic management; "minor asset extensions or improvements" (for example, intersection upgrades, auxiliary lanes); major asset extension; and "other miscellaneous activities" (for example, the vehicle registration and driver licensing system). The mapping of the expenditure categories in the first column with the TAC categories in the second involves some judgement. The first category of maintenance, pavement and shoulders, is roughly analogous with the 15 percent of TAC maintenance which is thought to be related to pavements. The division of bridge expenses between load and non-load is based roughly on the division of these expenditures in the Australian data.

Table D.6
AUSTRALIAN ALLOCATION FACTORS

Australian categories	TAC categories	Separable			Non-separable
		GVW-km	VKT	ESAL-km	VKT
Servicing and operating	Administration				100%
Road maintenance					
– pavement and shoulders	15% of maintenance			60%	40%
– resurfacing	Resurfacing	10%		20%	70%
– other	85% of maintenance		15%		85%
Bridges – load related	42% of bridge exp.	100%			
– non-load related	58% of bridge exp.				100%
Reconstruction	Reconstruction			60%	40%

The separation of TAC's data into the allocation categories suggested by the Australian method are shown in Table D.7

Table D.7
DISTRIBUTION OF TAC COSTS, BY AUSTRALIAN METHOD

Australian allocation factors	TAC adjusted costs % distribution	TAC optimal costs % distribution
Separable		
– ESAL-km	25.1	21.7
– GVW-km	4.6	5.1
– VKT	5.4	6.0
Non-separable		
– VKT	64.9	67.3

Table D.8
COST ALLOCATION: AUSTRALIAN METHOD + ADJUSTED TAC

	Total costs ($ million)	% distribution	Cost per km $
Passenger cars	2,175.5	50.2	0.020
Small trucks	548.8	12.7	0.020
Large trucks	1,567.4	36.2	0.090
Buses	17.8	0.4	0.023
Motorcycles, etc.	15.3	0.4	0.019
Other	9.2	0.2	0.023
Total	**4,334.0**	**100.0**	

Table D.9

COST ALLOCATION: AUSTRALIAN METHOD + OPTIMAL TAC

	Total costs ($ million)	% distribution	Cost per km $
Passenger cars	2,050.6	52.4	0.019
Small trucks	517.5	13.2	0.019
Large trucks	1,308.6	33.4	0.075
Buses	16.8	0.4	0.021
Motorcycles, etc.	14.4	0.4	0.018
Other	8.7	0.2	0.022
Total	**3,916.6**	**100.0**	

Appendix E: Exploratory Cost Allocation

The following allocation methodology is labelled "exploratory" as more work is required to develop many of the underlying variables — such as the traffic and vehicle characteristics presented in Appendix A — before much confidence could be placed in the results. Further, more testing of the calculations — sensitivity analysis and extension of the findings to particular vehicles on particular roads — is needed.

The method starts with TAC's costs as described in Section 3. It then modifies these according to the information in Sections 2 and 5. Owing to the gaps in the knowledge about roads other than those with flexible pavements and owing to the insignificance of urban paved roads (in the data used here), only two classes of roads are considered: freeways and rural paved roads. In TAC's original numbers, these two account for 76.6 percent of total maintenance and pavement costs (Table 3.3). Rural paved roads, however, are separated into three categories according to the AADT estimates in Appendix A.

The first step is to establish the level of unit costs shown in Table E.1:

- Maintenance — Annual costs are as shown in Table 3.7 (adjusted TAC costs) or Table 5.5 (optimal TAC costs, which are the same as the adjusted). However, the amount shown for rural paved roads ($7,743) is adjusted on the assumption that maintenance activities vary with traffic. For the busiest 10 percent of the rural paved roads (AADT of 6,000 on average) maintenance costs per kilometre are $9,292. For the mid-volume rural paved roads (AADT of 3,000), maintenance costs are $7,743. For the lowest-volume rural paved roads (AADT of 700), maintenance costs are $7,485. These amounts, times the TAC lengths, equal the $1.0 billion shown in TAC's original figures. In other words, to reflect the fact that maintenance costs are probably higher on the busier roads than on lower-volume roads, TAC's costs have been assigned to each of the three categories in the proportion 12:30:58, even though total lengths are in the proportion 10:30:60. (This 12:30:58 is arbitrary.)
- Resurfacing — Costs for freeways and the highest-volume rural paved roads are $65,000 per two-lane kilometre. For other roads, they are set at $55,000. Overlays are assumed to last 12 years. These values are as discussed in Section 5.3.

- Reconstruction — Costs, given an initial pavement life of 15 years, are based roughly on the relationships shown in Figure 5.3 and the axle loadings shown for each road class shown on Table A.9.

Table E.1
Exploratory Cost Allocation: Unit Costs
(1989 $, two-lane equivalent basis)

Roads	Maintenance costs/km	Resurfacing costs/km	Reconstruction costs/km
Freeway	10,355	65,000	225,000
Paved (rural)			
– busiest 10%	9,292	65,000	200,000
– medium-volume 30%	7,743	55,000	170,000
– low-volume 60%	7,485	55,000	160,000

Bridge costs have to be dealt with on a system-wide basis as there is no way of separating bridges by road class. Total annual cost remains at TAC's estimate of $296.3 million. Administration costs remain at TAC's estimate of 4.12 percent of other costs.

The costing model is shown in Table E.2, where *E* represents a factor to account for environmental deterioration. Fixed costs and some of the variable costs are allocated according to VKT, rather than PCE-km as the second measure is really related to capacity.

Table E.2
Allocation Procedures
(including assumptions about fixed versus variable costs)

	Fixed costs		Variable costs	
Expense	Amount	Allocation factor	Amount	Allocation factor
Administration	total	VKT		
Bridges	58% total	VKT	42% total	GVW-km
Maintenance	70% total 15% total × *E*	VKT VKT	15% total 15% total × (1 – *E*)	VKT ESALs
Resurfacing	total × *E*	VKT	total × (1 – *E*)	ESALs
Reconstruction	total × *E*	VKT	total × (1 – *E*)	ESALs

- Administration — These expenses are treated as a fixed cost.
- Bridge — Following the example of the Australian study, 58 percent of bridge expenses are assumed not to vary with usage and the balance are assumed to be a function of vehicle weight.
- Maintenance — From Appendix C, it is assumed that 15 percent of these expenses are related to pavement surfaces and, therefore, a function of both axle loads and environmental wear. (As shown in Table E.2, then, if E equals 50%, 7.5% of pavement-related maintenance expenses vary with usage and 7.5% do not.) As for the remaining maintenance expenses, the evidence suggests that some portion varies with traffic (see the Australian study or the discussion in Section 2). Examples of such expenses might be road-side cleaning, litter control, or line striping. For here, this traffic-related maintenance expense is assumed to be 15 percent of the total. Finally, the remaining 70 percent of maintenance is assumed to be a fixed cost. In most provinces, a good deal of this would be snow and ice control, that is, expenses incurred whether one vehicle or thousands of vehicles use the road.
- Resurfacing and Reconstruction — As with the pavement-related portion of maintenance, these expenses are functions of both axle loads and the environment. The amount attributed to axle loads is allocated according to ESALs and the remainder is treated as a common cost.

To allocate pavement costs, the unit costs shown in Table E.1 have to be converted to annual amounts. There are several ways of doing this. If initial pavement lives and overlay lives for the whole network are as follows:

n_1 = initial pavement life
n_2 = overlay #1 life
n_3 = overlay #2 life

then, assuming a steady-state system, in any given year,

$1/\,[(n_1 + n_2 + n_3)/2]$ parts of the network will be resurfaced

and

$1/(n_1 + n_2 + n_3)$ parts of the network will be reconstructed.

For the whole network, this results in an average annual cost per kilometre of the unit costs shown in Table E.1 times these two factors. For example, where n_1, n_2 and n_3 equal 15, 12 and 12 respectively, the average reconstruction cost per kilometre for a freeway is $5,769 (225,000/39) and the average resurfacing cost is $3,333 (65,000/19.5).

This is more or less identical to the methodology employed by RTAC in calculating its expenditure needs. Using this method, the unit costs shown in Table E.1, and the n_1, n_2, n_3 values given in the previous example, average annual costs per kilometre for the network are shown in Table E.3. These result in a total annual cost of $2.211 billion for pavements and maintenance. (This is for all federal, provincial and territorial freeways and rural paved highways.) The comparable figures from TAC's data are:

$3.520	original TAC data, in Table 3.2
$2.812	adjusted TAC data, in Table 3.6
$2.413	optimal TAC data, in Table 5.4

To test this allocation method, here is a listing of the key data and/or assumptions:

- Road lengths — These are as provided by TAC. However, as described in Appendix A, paved rural roads have been separated into three categories according to AADT. This is necessary as it is unrealistic to deal with all paved rural roads in Canada using broad national averages for the critical variables. Even more categories would be preferable.
- Traffic distribution — Five vehicle classes are distributed across road categories as described in Appendix A. The importance of this step is that it distributes both VKT and ESALs to various roads. Among the many critical assumptions here are the figures used to assume how many vehicles out of the total population of registration statistics actually exist and are in use; the (sometimes quite shaky) estimates of annual average distances; and the figures used to measure the percent of large trucks in the total traffic stream.

Table E.3
EXPLORATORY COST ALLOCATION: AVERAGE ANNUAL COSTS
1989 $, TWO-LANE EQUIVALENT BASIS

Roads	Maintenance costs/km	Resurfacing costs/km	Reconstruction costs/km
Freeway	10,355	3,333	5,769
Paved (rural)			
– busiest 10%	9,292	3,333	5,128
– medium-volume 30%	7,743	2,821	4,359
– low-volume 60%	7,485	2,821	4,103

- Vehicle characteristics — Are as described in Appendix A. Among other things, this fixes the average truck weight (GVW, *not* RGVW) at 23.3 tonnes and the average number of LEFs for a truck at 1.5. Given the use of both GVW-km and ESALs to allocate costs, these are two of the more critical aspects of vehicle characteristics.

- Pavements — Although actual designs vary from one section of the 143,296-kilometre network to another (this is just the freeway and rural paved highway component), the rough assumption made here is that pavements are built to handle the following loads (per year):

Freeways	about one million ESALs
Busiest rural highways	about 425,000 ESALs
Medium-volume rural highways	about 115,000 ESALs
Low-volume rural highways	about 25,000 ESALs

- Maintenance costs — Although TAC's numbers are used, the amounts for rural paved highways are altered slightly in recognition of the fact that maintenance activities may vary with traffic.

- Resurfacing and reconstruction costs and frequencies — These are as described above.

- Environmental pavement deterioration — The following amounts for the proportion of pavement deterioration caused by factors other than axle loads are assumed:

Freeways	40%
Busiest rural highways	50%
Medium-volume rural highways	70%
Low-volume rural highways	80%

An even more fundamental assumption, of course, is that the relationships discussed in Sections 2 and 5, based on the OPAC model of pavement performance and typical Ontario construction costs, are applicable to the Canada-wide network.

The first step in the allocation is the treatment of bridge and administration costs as described previously. Total GVW-km are 568.1 billion, the product of total VKT and average weights shown in Appendix A. This results in an annual variable bridge cost of $0.0002 per GVW-km for all vehicles, where GVW is measured in tonnes (bridge costs times 0.42, all divided by 568.1 billion). Cars, for example, incur a cost of exactly $0.0002 as the average weight for these vehicles in Appendix A is one tonne. Large trucks, on the other hand, have an average bridge cost of $0.0047 per kilometre (23.3 tonnes times $0.0002). The remaining bridge costs, assuming it is appropriate to allocate fixed costs according to distance driven, amount to $0.0011 per kilometre (over the whole network, not just the paved roads considered in this Appendix).

The second step is to separate those maintenance and pavement costs which vary with usage from those that do not according to the procedures described in Table E.2. The results are shown in Table E.4.

Table E.4
Exploratory Cost Allocation: Variable versus Fixed Costs (1989 $, two-lane equivalent basis)

Road class	Variable costs/km		Fixed costs/km
	per VKT	per ESAL	
Freeways	1,553	6,393	11,511
Paved (rural)			
– busiest 10%	1,394	4,928	11,432
– medium-volume 30%	1,161	2,502	11,259
– low-volume 60%	1,123	1,609	11,676

In other words, the proportion of costs which are fixed on each class of road is:

	Proportion of fixed costs
Freeways	59.1%
Paved (rural)	
– busiest 10%	64.4%
– medium-volume 30%	75.4%
– low-volume 60%	81.0%

The costs per unit of output — arbitrarily dividing the fixed costs by the total kilometres of travel — are as shown in Table E.5.

Table E.5
Exploratory Cost Allocation: Costs per Unit of Output (1989 $)

Road class	Variable costs/km		Fixed costs/km
	$ per VKT	$ per ESAL	$ per VKT
Freeways	0.0004	0.0065	0.0026
Paved (rural)			
– busiest 10%	0.0005	0.0115	0.0052
– medium-volume 30%	0.0011	0.0217	0.0103
– low-volume 60%	0.0044	0.0599	0.0457

Administration costs for the whole network amount to $145.7 million annually or $0.0009 per kilometre driven by all traffic.

Costs by vehicle class by road class are shown in Table E.6. These include system-wide bridge and administration costs. The multiplication of these costs and the VKT by vehicle class result in the following allocation of total annual costs:

cars	$1,563.1 million	59.3%
small trucks	393.7 million	14.9%
large trucks	651.0 million	24.7%
buses	12.1 million	0.5%
motorcycles, etc.	10.7 million	0.4%
other	6.2 million	0.2%
Total	$2,636.9 million	100.0%

Table E.6
EXPLORATORY COST ALLOCATION: COSTS BY VEHICLE AND ROAD CLASS (ANNUAL CENTS PER KILOMETRE, 1989 $)

Road class	Cars	Small trucks	Large trucks	Buses	Motor-cycles	Other
Variable costs/km						
Freeways	0.06	0.07	1.52	0.20	0.04	0.23
Paved (rural)						
– busiest 10%	0.09	0.10	2.30	0.24	0.07	0.27
– medium-volume 30%	0.13	0.14	3.87	0.30	0.11	0.35
– low-volume 60%	0.46	0.47	9.93	0.71	0.44	0.79
Fixed costs						
Freeways	0.46	0.46	0.46	0.46	0.46	0.46
Paved (rural)						
– busiest 10%	0.72	0.72	0.72	0.72	0.72	0.72
– medium-volume 30%	1.23	1.23	1.23	1.23	1.23	1.23
– low-volume 60%	4.77	4.77	4.77	4.77	4.77	4.77
Total costs						
Freeways	0.53	0.53	1.98	0.67	0.50	0.69
Paved (rural)						
– busiest 10%	0.81	0.82	3.03	0.96	0.79	1.00
– medium-volume 30%	1.36	1.37	5.10	1.53	1.34	1.58
– low-volume 60%	5.23	5.24	14.70	5.48	5.21	5.57

In addition, there is a further $1.03 billion representing either roads not dealt with here (where, in effect, "costs" means as defined by TAC) or bridge and administration costs not assigned to the paved freeways and rural roads.

It is emphasized that while this methodology attempts to incorporate the best data from Appendix A, the best information available about pavement performance in the Canadian context and the best features of other allocation studies, *more work* is required in testing and refining these procedures before they would be suitable for drawing broad policy implications.

APPENDIX F: ESTIMATING MARGINAL PAVEMENT COSTS

The OPAC model determines the required strength (structural number which can then be converted to an equivalent granular thickness) for a given number of anticipated ESALs and for a given initial pavement life. For here, a 15-year period is used. As discussed in Section 5, initial pavement life is not critical. Strength requirements are then converted to construction cost estimates based on a cost of $900/mm for the surface course and $200/mm for base and sub-base courses. Rather than a continuous function, only a few observations have been calculated as shown in Figure 5.3:

Annual ESALs	Construction costs (approx. 1989 $)
0	70,000
50,000	126,695
100,000	135,204
250,000	148,819
500,000	167,010
750,000	181,458
1,000,000	193,863
2,000,000	214,777

From the above, a function has been estimated with a least-squares regression ($n = 8$; $r^2 = 0.802$; and standard errors in parentheses):

$$\begin{aligned} C = {} & 57{,}686 + 19{,}920 \times \log(\text{ESALs}) \\ & (21{,}796) \quad (4{,}043) \end{aligned}$$

To these construction costs, the following resurfacing costs have been assumed (Section 5) with an overlay life of 12 years.

0–250,000 ESALs	= $55,000
250,001–1,000,000 ESALs	= $65,000
over 1,000,000 ESALs	= $75,000

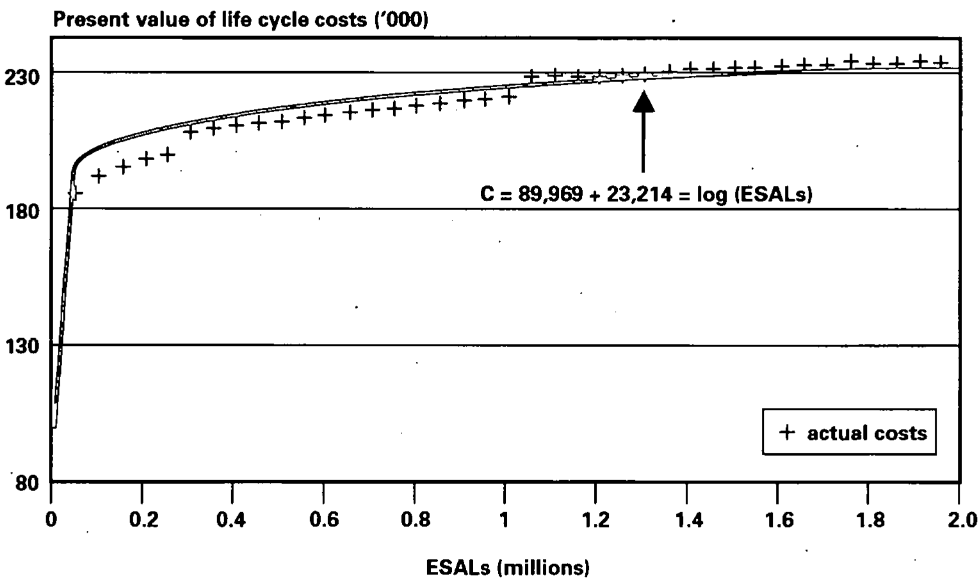
Total life-cycle costs, assuming a time horizon of 39 years, are now estimated as:

$$\text{Life-cycle cost} = C + \frac{R}{(1+r)^{15}} + \frac{R}{(1+r)^{27}}$$

The first term (C) is estimated using the construction cost function described above. Life-cycle costs are shown in Figure F.1, with "+" indicating costs estimated using the above equation and with the line showing the costs estimated from a second regression ($n = 41$; $r^2 = 0.965$; and standard errors in parentheses):

$$\underset{(4{,}417)}{C = 89{,}969} + \underset{(703)}{23{,}214} \times \log(\text{ESALs})$$

Figure F.1
LIFE-CYCLE COSTS AS A FUNCTION OF ESALS



Maintenance costs can be added, given TAC's estimate of $7,743 per kilometre for rural paved highways and the estimate made in Appendix B that 15 percent are related to pavements. However, the addition of the present value of 39 years of an annual expense of $1,161 (15% of $7,743), does not affect the computation of marginal costs. It simply adds a fixed amount to the estimate of life-cycle costs (that is, a fixed amount at any level of annual ESALs); therefore, the derivative with respect to ESALs does not change. What is needed is some way of relating pavement maintenance expenses to the number of ESALs. Since no information on this is available, maintenance expenses are not considered here.

Marginal pavement costs are estimated as follows (and shown in Figure 7.1 in Section 7):

$$MC = \frac{23{,}214}{\text{ESALs}} \times \frac{1}{\ln 10}$$

To put these into perspective, the following shows the marginal pavement costs of the "average" truck with 1.5 ESALs on three classes of rural paved highways (these could also be freeways as the construction costs used here are applicable to both classes of roads).[5]

Class of road (as measured by annual ESALs)	Marginal pavement cost per ESAL	Marginal pavement cost per truck
250,000	$0.040	$0.060
1,000,000	$0.010	$0.015
2,000,000	$0.005	$0.008

Another way of looking at these marginal pavement costs is to consider several typical (not "average") trucks. These are shown in Table F.1. The first column of the table shows three large trucks as follows:

Table F.1
Typical Marginal Pavement Costs

Truck type	Axle loads	Road class		
	a) ESALs b) Canroad c) Waterloo	Low-volume 250K ESALs $0.040/ESAL	Medium-volume 1 million ESALs $0.010/ESAL	High-volume 2 million ESALs $0.005/ESAL
		Cost per truck km		
T3 25 tonne	a) 2.57 b) 3.75 c) 4.88	$0.103 $0.150 $0.195	$0.026 $0.038 $0.049	$0.013 $0.019 $0.024
3-S2 39 tonne	a) 3.37 b) 4.60 c) 5.84	$0.135 $0.184 $0.234	$0.034 $0.046 $0.058	$0.017 $0.023 $0.029
3-S3-S2 62 tonne	a) 4.64 b) 6.38 c) 8.28	$0.186 $0.255 $0.331	$0.046 $0.064 $0.083	$0.023 $0.032 $0.041

T3 is a three-axle straight truck with a load of 25 tonnes distributed as follows: 7 tonnes on the steering axle, 18 tonnes on the drive tandems. This is a typical truck used for construction work in Eastern Canada (it would have lower axle loads in Western Canada).

3-S2 is a five-axle tractor-semitrailer, the most common large truck configuration in Canada. For the purpose of this illustration, it has been given heavy axle loads. There are some in Eastern Canada occasionally exceeding these limits, but the one used here is known as an RTAC configuration and is allowed to operate coast-to-coast. The axle loads shown are the practical maximum. Total weight is 39 tonnes, distributed as follows: 5 tonnes on the steering axle, 17 tonnes on each of the tandem axles.

3-S3-S2 is an eight-axle B-train, having two trailers and a total weight of 62 tonnes. While there are some slightly heavier than this in Eastern Canada, this is the practical upper limit for the RTAC B-train, which is allowed to operate in all Canadian jurisdictions. Axle loads are: 5 tonnes on the steering axle, 17 tonnes on the tractor's tandem, 23 tonnes on the first trailer's tridem axle, and 17 tonnes on the rear trailer's tandem.

The second column shows load equivalency factors calculated in three ways: (a) the traditional AASHTO ESALs, (b) the Canroad LEFs and (c) Waterloo's LEFs. As shown, the various methods of calculating LEFs have a significant impact on the costs attributed to different trucks. There is one point, however, that is not known. The pavement deterioration models are based on AASHTO's ESALs and, hence, the determination of the functional relationship between life-cycle costs and axle loads is also based on AASHTO's ESALs. The marginal costs shown in Figure 7.1 are marginal costs *per AASHTO ESAL*. It is not clear that these same amounts can actually be used to calculate costs for a truck *where load equivalencies are calculated using the Canroad or Waterloo LEFs*. Even though this is an unknown, the calculations in Table F.1 are based on these procedures simply to illustrate how critical the issue of axle load equivalencies is to the estimate of road costs.

The third, fourth and fifth columns of Table F.1 show marginal pavement costs for rural highways at three levels of traffic. For example, the five-axle tractor-semitrailer incurs a marginal pavement cost of 13.5 cents (low-volume) to 1.7 cents (high-volume) per kilometre, using AASHTO's ESALs. If the Canroad LEFs are used, these costs become 18.4 cents, and 2.3 cents per kilometre. Waterloo's LEFs results in even higher pavement costs for each truck.

NOTES TO APPENDICES

1. The resulting estimate of 509,381 compares with Statistics Canada's estimate of 276,184 large (RGVW of 16,000 lb or more) "freight" trucks, in *Trucking in Canada*, Catalogue No. 53-222, 1986. These freight trucks do not include "service" or "utility" or "government" trucks.

2. This information is from John Lawson of the Royal Commission staff.

3. In 1988 Ontario conducted another large-scale roadside survey. To date, however, it has not been possible to use this to develop any of the statistics required here.

4. One oversimplification being ignored here is the presence in Ontario of federal roads. Strictly, since these are included in the TAC data, VKT that occur on them should be included in the number produced by multiplying road lengths by AADT. However, since the "error" in the test is to, by default, assume VKT that occur on federal roads in Ontario belong to the "municipal" category, no harm is done.

5. As discussed in subsection A.4, there are concerns about the accuracy of this estimate of 1.5 ESALs per truck, and there could be some question about the suitability of a figure developed on Ontario highways for extensions to all Canadian roads.

BIBLIOGRAPHY

Alchian, A. A. 1977. *Economic Forces at Work.* Indianapolis: Liberty Press.

Australia. Inter-State Commission. 1990. *Road Use Charges and Vehicle Registration: A National Scheme.* Canberra: Australian Government Publishing Services.

Bailey, E. E. and A. F. Friedlaender. 1982. "Market Structure and Multiproduct Industries." *Journal of Economic Literature* 20 (September 1982), pp. 1024–1048.

Canada. Royal Commission on National Passenger Transportation. 1991. *Getting There: The Interim Report of the Royal Commission on National Passenger Transportation.* Ottawa: Supply and Services Canada.

Canroad Transportation Research Corporation. 1986. *Vehicle Weights and Dimension Study: Technical Steering Committee Report.* Ottawa.

Cheetham, A., and J. T. Christison. 1981. "The Development of RCI Prediction Models for Primary Highways in the Province of Alberta." Edmonton: Alberta Transportation.

Hajek, J. J., J. R. Billing and G. Kennepohl. 1991. "Utilization of Weigh-In-Motion Data for Transportation Planning and Decision Making." Winnipeg: Transportation Association of Canada, annual conference.

Haritos, Z. 1973. *Rational Road Pricing Policies In Canada.* Ottawa: Canadian Transport Commission.

Jung, F. W., R. Kher and W. A. Phang. 1975. A *Performance Prediction Subsystem-Flexible Pavement RR 200.* Toronto: Ontario Ministry of Transportation and Communications.

Kitamura, R., H. Zhao and R. Gibby. 1990. "Evaluation of Truck Impacts on Pavement Maintenance Costs." Washington: Transportation Research Board, paper #890658.

National Highway Policy Steering Committee. 1988. *National Highway Policy For Canada, Phase 1 Report.* Ottawa: Roads and Transportation Association of Canada.

New Brunswick Department of Transportation. 1988. *Adequate Highways: A Key to Regional Economic Development.* Fredericton.

Newbery, D. M. 1988a. "Road User Charges in Britain." *The Economic Journal* 98 (Conference), pp. 161–176.

—. 1988b. "Road Damage Externalities and Road User Charges." *Econometrica* 56, pp. 295–316.

—. 1989. "Cost Recovery from Optimally Designed Roads." *Economica* 56, pp. 165–185.

—. 1990. "Pricing and Congestion: Economic Principles Relevant to Pricing Roads." *Oxford Review of Economic Policy* 6, pp. 22–38.

Nix, F. P. 1989. "Road-User Costs: Report on Exploratory Research." *Proceedings.* Halifax: Canadian Transportation Research Forum, 24th annual meeting.

—. 1990. "The Ontario Trucking Industry." Toronto: Motor Carrier Policy Office, Ontario Ministry of Transportation.

Ogden, K. W. 1988. "Road Cost Recovery in Australia." *Transport Reviews* 8. 2, pp. 101–123.

Ontario Ministry of Transportation. 1991. *Provincial Highways: Traffic Volumes 1989.* TCB-HPO-004. Toronto: Transportation Capital Branch, Highway Planning Office.

Ontario Ministry of Transportation and Communications. 1985. *Commercial Vehicle Travel Data On Ontario Highways — 1984.* Toronto: Municipal Transportation Policy/Planning Branch, Transportation Demand Research Office.

Paterson, W. D. O. 1987. *Road Deterioration and Maintenance Effects: Models for Planning and Management.* Baltimore: The World Bank, The John Hopkins University Press.

Papagiannakis, T. 1990. "Development of Pavement Performance Models for Newfoundland." *Proceedings,* 1. St John's: Roads and Transportation Association of Canada, annual conference.

Perera, M. H. and E. G. Corupe. 1984. *Ontario Commercial Vehicle Survey — 1983.* TDF-84-05. Toronto: Ontario Ministry of Transportation and Communications.

Rilett, L. R. 1988. "Development, Analysis and Application of Load Equivalency Factors from Canroad Test Data." MS thesis, Civil Engineering, University of Waterloo.

Rilett, L. R., B. G. Hutchinson and R. C. G. Haas. 1989. "Cost Allocation Implications of Flexible Pavement Deterioration Models." Washington: Transportation Research Board.

Roads and Transportation Association of Canada. 1987a. *Highway and Transit Infrastructure Study, Background Document.* Ottawa: Roads and Transportation Association of Canada.

—. 1987b. *Roadway Infrastructure Study.* Ottawa: Roads and Transportation Association of Canada.

—. 1990. *Canada's Roadway Infrastructure: Selected Facts and Figures.* Ottawa: Roads and Transportation Association of Canada.

Shubik, M. 1962. "Incentives, Decentralized Control, the Assignment of Joint Costs and Internal Pricing." *Management Science* 8, pp. 325–343.

Small, K. A., C. Winston and C. A. Evans. 1989. *Road Work, A New Highway Pricing and Investment Policy.* Washington: The Brookings Institution.

Statistics Canada. *Road Motor Vehicles: Registrations.* Catalogue No. 53-219. Annual. Ottawa.

—. *Trucking in Canada.* Catalogue No. 53-222. Annual. Ottawa.

Stigler, G. J. 1966. *The Theory of Price.* 3rd ed. New York: Macmillan.

U.K., Department of Transport. *The Allocation of Road Track Costs.* Various years. London.

U.S., Department of Transportation. 1988. *Heavy Vehicle Cost Responsibility Study.* Report of the Secretary of Transportation to the United States Congress Pursuant to Section 931 of the *Deficit Reduction Act of 1984.* Washington, D.C.

U.S., Federal Highway Administration. 1982. *Final Report on the Federal Highway Cost Allocation Study.* Report of the Secretary of Transportation to the United States Congress. Washington, D.C.

U.S., Transportation Research Board. 1990. *Truck Weight Limits: Issues and Options.* Special Report 225. Washington, D.C.

(The) Urban Institute, Sydec, Inc. 1990. *Rationalization of Procedures for Highway Cost Allocation.* Final report, for the Trucking Research Institute.

Vitaliano, D. P. and J. Held. 1990. "Marginal Road Damage User Charges." *Quarterly Review of Economics and Business* 30, 2, pp. 32–49.

Walters, A.A. 1968. *The Economics of Road User Charges.* Baltimore, Md.: The Johns Hopkins Press.