SUSTAINABLE TRANSPORTATION IN CANADA

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Introduction: Historical Background

The concept of sustainable development has been known to economists for many years. Originally the economic approach to sustainability was based on the Fisher (1906), Hicks (1939) and Lindahl (1933) concept of income as the maximum that we can consume without reducing our wealth. This principle was further generalized and developed in works of Hartwick (1977) and Solow (1986, 1992). In the 1990s, the concept of sustainable development was formalized as the maximization of net benefits of economic and social development subject to maintaining the stock of natural resources over time (Munasinghe, 1993). Although the framework of analysis has changed over the years, its general structure has been preserved by economists as the one that involved an economic criterion reflecting net social benefits plus sustainability constraints.

It appears that the development of models of sustainable transportation mostly ignored this structure. Only recent studies came close to the original interpretation of the sustainable development as it evolved in economic literature. To understand this statement, it is necessary to take a brief historical tour into sustainable transportation.

Substantial interest in sustainable transportation can be dated back to the early 1990s. While recognizing the three dimensions of sustainable development, namely the economic, social and environmental, the focus of early research was on the economic and environmental dimensions. This was due to the fact that transport activity was seen as a major concern from the viewpoint of the following three global environmental impacts:

- emissions of greenhouse gases;
- emissions of compounds that thin the stratospheric ozone layer;
- transport-related production of Persistent Organic Pollutants (POP) and their effects on biological systems.

The initiative of early studies in sustainable transportation came from the Organization for Economic Cooperation and Development (OECD) who in 1994 set in motion the so-called Environmentally Sustainable Transport (EST) project. Nine countries contributed to the project with the case studies based on internationally recognized and accepted six criteria: (i) noise, (ii) land use, (iii) emissions of carbon dioxide, (iv) emissions of nitrogen oxides; (v) volatile organic compounds, and (vi) particulate matter. The case studies were based on a scenario approach with respect to the "business-as-usual" projections for the year of 2030 in relation to conditions in 1990.

Basic results of the EST project were presented at the International Conference on Environmentally Sustainable Transport in Vienna (Austria) in October 4-6, 2000. Essentially, the EST project reflects the mainstream understanding of sustainable transportation, which is discussed later in this paper.

A turning point in the history of sustainable transportation was the OECD Conference "Towards Sustainable Transportation" in 1996 in Vancouver (Canada). The so-called Vancouver Principles for Sustainable Transport were formulated, which included such criteria as equal access to transportation networks, individual and community responsibility, health and safety, education and public participation, integrated planning, land and resource use, pollution prevention, and economic well-being.

Based on these principles, strategic directions in transportation with respect to its sustainability were identified. The final message of the Vancouver Conference was: "… *Every effort should be made to encourage and invite further work on the development and wider dissemination of this set of principles".* The message was heard in Canada and that year the Centre for Sustainable Transportation was created by Environment Canada and Transport Canada. Since 1996, the Centre has sponsored two major projects: (i) the Sustainable Transportation Performance Indicators (STPI) project, and (ii) the University Curriculum project. However, the major achievement of the Centre to date is its internationally recognized definition of a sustainable transportation system because unlike other definitions it incorporates all three dimensions of the sustainability with respect to transportation.

Development of international issues of sustainable transportation continued in 1998 with the Workshop on Sustainable Transportation in Ottawa (October 20-21, 1998). In the Vancouver Conference and Ottawa Workshop, the social dimension began to play a larger role in the concept of sustainable transportation (Pearl, 1998).

Presently, any national or international conference on transportation includes a section on sustainability of transportation. The latest example is the International Conference on Transportation Operations and Planning, held in Chennai (India) on February 18-20, 2004. Five papers were directly associated with sustainability of transportation. The inclusion of sustainability highlights the significance of this issue in different parts of the world. This, in turn, signifies that we should pay greater attention to the sustainability of the Canadian transportation.

Economic, environmental and social impacts of transportation in Canada

Apart from its strategic role, the size of the transportation service industry in Canada is significant. This sector is larger than the agriculture, fishing and trapping, logging and forestry industries combined. According to the annual report of Transport Canada, in 2002 commercial transportation industries in Canada accounted for $39 billion or 4 percent of the value-added GDP. In turn, transportation expenditures amounted to $161 billion or 14.1 percent of total expenditures in the Canadian economy. Besides, investment in transportation made up 3.3 percent of the GDP, which shows a 0.2 percent increase compared to 2001. Over the last five years until 2002, the number of full-time jobs related to transportation totalled more than 800,000.

However, over time as population has increased, cities have grown, and globalization and free trade have increased the regional and international movement of people and goods, our transportation infrastructure and systems have expanded dramatically. The cars, trucks, buses, subways, trains, airplanes, ships and ferries that we use to move ourselves and our goods today have significant implications in terms of energy and material resource use, environmental pollution, noise and land use at local, regional and global level.

Transportation in Canada has been a chief consumer of energy for years as shown in figure 1. The figure shows increasing energy consumption by transportation over time.

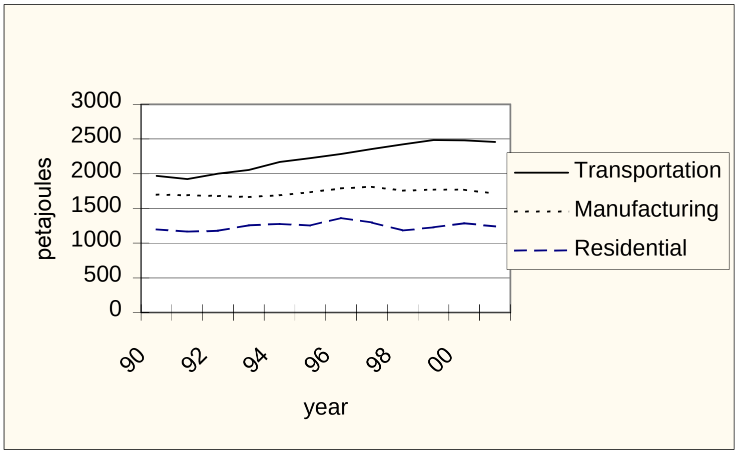


Fig.1. Energy Consumption by Sector (1990-2001)

The high energy consumption by transportation eventually resulted in significant negative environmental impacts. First of all, transportation is one of the major contributors to climate change, which is caused by the so-called greenhouse gases (GHGs) that trap heat reflected from the surface of the planet in the lower atmosphere causing the greenhouse effect. The primary GHG is carbon dioxide, which is responsible for about two thirds of human-induced climate change.

Figure 2 shows that in 2000, GHG emissions from Canada's transportation sector accounted for 163.4 megatonnes or 34 percent of total emissions from secondary energy use. This sector is the single largest source of GHGs in Canada. Of total transportation-related GHG emissions in 2000, road transportation accounted for almost 77 percent, the aviation sector 10.3 percent, and rail and marine combined for less than 9.5 percent.

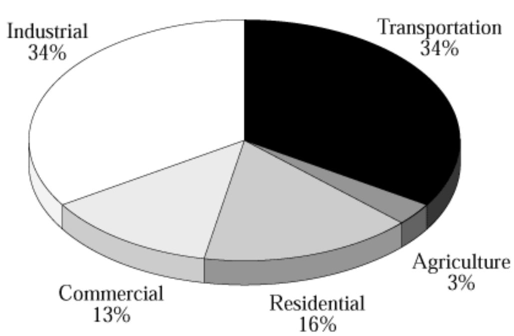


Fig.2. GHG Emissions from secondary energy use in Canada, 2000

Table 1 shows the amount of transportation-related emissions in Canada other than GHG that contribute to local environmental problems, such as acid rain and fog.

TABLE 1. Transportation-related emissions (except GHG emissions)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
CO (kt)	5,562	5,329	5,173	5,170	5,116	5,067	5,036	4,973	4,882	4,947	4,998
SO_2 (kt)	62	62	60	58	51	52	52	53	53	48	49
NO_x (kt)	735	700	698	701	708	710	703	723	717	719	720
VOCs (kt)	609	591	578	585	582	580	584	586	579	587	590

In addition, development of transportation requires vast areas of land. Table 2 shows the estimated portion of land devoted to roadways in Canada and other North American countries. These values are relatively small when measured as a portion of total land area, but roads and parking facilities tend to be concentrated in urban areas where their impacts and opportunity costs are relatively large.

TABLE 2. Land area devoted to roadways

Country	Roadway Rights of Way, hectare	Portion of Total Land Area	Area per capita, m^2	Area per Motor Vehicle, m^2
Canada	2,276,656	0.2%	734	1319
United States	15,920,615	1.7%	573	746
Mexico	863,832	0.4%	87	1100

Among the negative social effects of transportation, injuries and fatalities arising from different accidents are of major concern. Table 3 shows injuries and fatalities arising from road transport activity in Canada.

TABLE 3. Injuries and fatalities arising from road transport activity

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Injuries	262,680	249,217	249,821	247,588	245,110	241,935	230,890	221,349	217,614
Fatalities	3,963	3,690	3,501	3,615	3,263	3,351	3,091	3,064	2,927

These negative environmental and social impacts of transportation lead to the overall conclusion that the transportation system in Canada may not be following a sustainable path. Therefore, it was necessary to develop a comprehensive framework of socio-economic analysis to address these issues as soon as possible.

Methodological flaws of the existing framework in Canada

It is necessary to note that until now the most of the work on sustainable transportation, especially in Canada, has been done by non-economists, mainly by civil engineers who pay little attention to economic side of the concept. That is why early studies treated sustainable transportation as:

- anything that reduces emissions by automobiles; and
- anything that increases transport safety.

As a result, two interpretations of sustainability were introduced by the Canadian Centre for Sustainable Transportation: (i) comprehensive sustainability, and (ii) sustainability as a combination of any two out of three dimensions of sustainable development. Even though comprehensive sustainability, defined by the Centre coincides with the general economic notion of sustainable development, unfortunately the second interpretation gained priority in the field of transportation.

As literature review shows, so far the assessment of transportation's sustainability in Canada has been subject of a positive analysis, associated with the question of whether or not our current transportation system is on a sustainable path. At large this approach conforms to the following three principles:

1. Sustainable Transportation Performance Indicators (STPI)
2. Isolated impacts of transportation on the economy, the environment and society

3. Benefit-cost analysis as analytical framework

Currently in Canada, six different sets of indicators measuring sustainability of transportation are being issued by six different institutions. Environment Canada uses the set of four indicators: (i) ecological life support systems, (ii) natural resources sustainability, (iii) human health and well-being, and (iv) pervasive influencing factors. The National Round Table on the Environment and the Economy developed a set of sustainability transportation principles that include access, equity, individual and community responsibility, health and safety, education and public participation, integrated planning, land and resource use, pollution prevention, and economic well-being. The Ontario Round Table on Environment and Economy developed a set of 21 indicators that fall under four categories -- environmental, economic, social and systemic. The Transportation Association of Canada proposed 13 principles associated with sustainable transportation systems in Canada. The Victoria Transport Policy Institute produced a set of 19 sustainability indicators focusing on the ability to reach goods, services and destinations rather than on the transportation system's ability to move vehicles. Finally, in December 2002, the Canadian Centre for Sustainable Transportation produced a set of 14 sustainability indicators.

This approach has some obvious disadvantages. First, selection of a set of "good" indicators is a difficult task, both in terms of ensuring the number is manageable and that each indicator conforms to as many of the characteristics as possible. Second, some sets of indicators may send conflicting messages when different indicators point in different directions making it difficult to understand and interpret the overall result. Therefore, we don't know, in general, whether the development of our transportation system is on a sustainable path or not and at what speed. Third, it is very difficult to use a set of indicators to model a sustainable transportation system.

Next, a sustainable system implies interaction of three components: the economy, the environment and society. Applied to transportation, this points at the necessity to establish interactive links of transportation with the economy, environment and society over time. However, the benefit-cost analysis, used in the traditional approach to evaluate sustainability, results in all expected developments in the transportation system being treated as consequences of isolated and once-and-for-all impacts. This is a one-directional process that does not take into account feedbacks between transportation and the economy, environment and society.

And finally, the benefit-cost analysis was designed to evaluate specific projects or it was designed to assess marginal changes within an existing system over short period of time. However, the time frame, associated with the sustainable transportation system, involves more than one generation. Hence, evaluation of sustainability of transportation must be viewed in terms of structural (system) changes rather than marginal changes which points at methodological inapplicability of the benefit-cost analysis.

All these shortcomings point to the necessity of approaching the problem of transportation’s sustainability differently. It does not, however, mean that all the work on sustainability of transportation in Canada has to be put aside and forgotten. Simply a new framework of analysis is needed to reflect the accumulated experience in this field.

Alternative approach to sustainability of transportation in Canada

The novelty of the proposed approach is the addition of a normative aspect to the assessment of transportation’s sustainability. It is designed to develop a methodology that not only evaluates current performance of a transportation system in Canada in terms of its positive and negative impacts on economy, environment and society, but also allows us to derive a set of policy recommendations for the design of the sustainable transportation system (STS).

In this approach, the modeling of the STS is based on the following principles:

1. Aggregate sustainability measure instead of the sustainability indicators
2. Treatment of sustainable transportation as a part of a three-dimensional system economy-environment-society instead of separate evaluation of transportation impacts on economy, environment and society
3. System dynamics approach instead of benefit-cost analysis

With respect to the first principle, the use of aggregate measures instead of a set of indicators simplifies modelling of a sustainable transportation system. There are several known aggregate sustainability measures in the literature. In this study, the Genuine Progress Indicator (GPI) was chosen to capture changes in social welfare due to transportation (see Friends of Earth and Redefining Progress web-sites). The GPI takes into account more than twenty aspects of our economic lives that GDP ignores. It includes estimates of the economic contribution of numerous social and environmental factors, which GDP dismisses with an implicit and arbitrary value of zero. It also differentiates between economic transactions that add to the well-being and those which diminish it. The GPI then integrates these factors into a composite measure so that the benefits of economic activity can be weighed against the costs.

With respect to transportation, GPI includes the value of services provided by the transportation infrastructure, the cost of commuting, the cost of automobile accidents, the cost of air and noise pollution by transportation, the loss of farmlands and wetlands and some other items. The ability of this aggregate measure to capture long-run trends along with the short-run fluctuations makes it very attractive for the use as sustainability criterion to model a sustainable transportation system.

The second principle is associated with what is called s*ystems approach to sustainable transportation.* Sustainability is not about partial equilibrium analysis but about systems analysis. Specifically, it is about how environmental, economic, and social systems interact to their mutual advantage or disadvantage at various space-based scales of operation. In the approach developed in this study, a system that consists of three elements (i) economy, (ii) environment and (iii) society is established first. Then the approach places the transportation network within the economic component of the system and develops its links with environment and society. Structurally, the transportation network is incorporated in such a system through vertical and horizontal linkages (see Yevdokimov, 2003).

Horizontal linkages are links of a transportation network with environment and society outside the economic component. Examples of these links are (i) environmental links: emissions, noise pollution, land use, etc., and (ii) social links: safety, mobility, accessibility, etc.

Vertical linkages are links of a transportation network with other sectors of an economy within the economic component. These links reflect the idea that transportation network does not exist on its own. It is an integral part of an economy, and demand for transportation is demand by other sectors of the economic system. Hence vertical links capture interactions of the transportation network with other sectors of the economy as well as some social values of transportation not included in GDP.

The third principle is associated with the s*ystem dynamics approach.* The approach is based on the statement that a system must evolve according to the state-flow relationships organized in feedback loops. The system dynamics approach captures interaction between the system's components as well as the system's feedbacks. Instead of the forced, one-directional design of the benefit-cost analysis, in the system dynamics approach intrinsic dynamics of the system drive it through time. As a result, the system under study evolves over time. The approach is perfectly applicable to the modeling of the STS as part of the economy-environment-society system since all the vertical and horizontal linkages of the transportation network can be captured through state-flow relationships over time.

Furthermore, according to the concept of sustainability developed by Vester (1995) within the system dynamics approach, a system that evolves exponentially is not sustainable. Hence, if sustainability constraints were added to the system's dynamics, the system would produce the required time path for the STS plus a set of necessary conditions to achieve this path.

Therefore, the following structure to model the STS was proposed:

(i) specification of the initial conditions;

(ii) description of the system dynamics;

(iii) aggregate sustainability constraint.

Initial conditions include initial values of major economic variables as well as economic fundamentals and policy variables. Economic fundamentals describe the economy's existing state of technology and current preferences of the society. In turn, policy variables include the existing institutional foundations that underlie economic fundamentals.

System dynamics is based on a set of the state-flow relationships of the type:

$$V_{t+1} = V_t + \Delta V_t(F, P) \tag{1}$$

where V_{t+1} is the state of the transportation system next period, V_t is the sate of the transportation system now and ΔV_t is the change in the state of transportation system as a function of economic fundamentals F and policy variables P. This is a mathematical model, which captures vertical linkages of a transportation network as defined previously.

The aggregate sustainability constraint is

$$\Delta GPI_{t+1} \geq \Delta GPI_t \tag{2}$$

where ΔGPI is the change in the GPI due to transportation. The constraint requires a non-decreasing ΔGPI over time which is consistent with the general notion of sustainability. In the way it is defined, GPI reflects social well-being. According to Arrow (2002), sustainability is defined as *"the maintenance or improvement of well-being over time"*. It implies that the basic principle of sustainable development is a non-decreasing social utility or social welfare function over time (see, for example, Stavins, Wagner and Wagner, 2003).

By design, GPI includes economic, social and environmental effects. Therefore, the aggregate sustainability constraint will capture horizontal linkages of the transportation network as a part of economic system with environment and society. If the aggregate sustainability constraint is satisfied, the system dynamics will drive the system over time. If the aggregate constraint is not satisfied, changes to economic fundamentals F and/or policy variables P must be imposed. In the end, the system dynamics will produce a sustainable path of the transportation system under study plus a set of the required changes to economic fundamentals and policy variables over time.

Results of computer simulation

Based on the framework discussed in the previous section, a mathematical model of a sustainable transportation system in Canada was designed. The dynamics of the transportation system in Canada over the study period of 1990-2002 in terms of changes in GPI due to transportation is presented in figure 3

Fig.3. Changes in GPI over 1990-2002

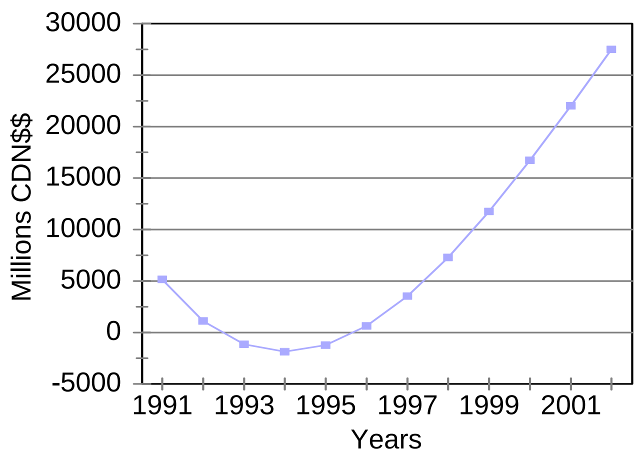
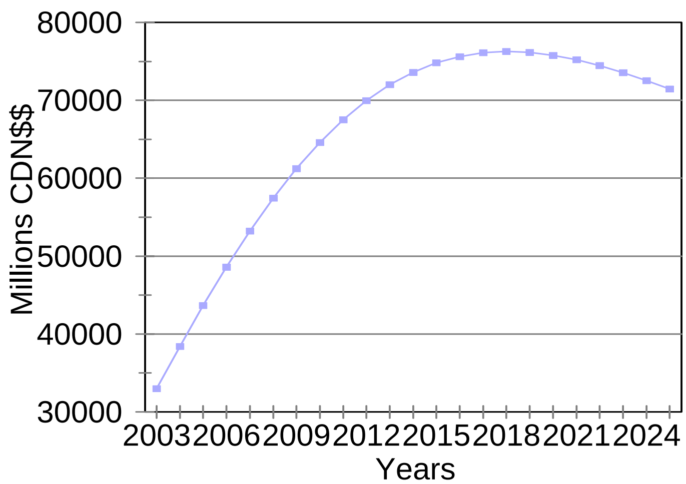


Figure 3 shows that additions to GPI by transportation were decreasing during 1990-1994 but increasing during 1995-2002. Moreover, additions to GPI were negative in 1993-1995, which means that contribution of transportation to the social well-being was negative in those years. Overall, the diagram shows that our transportation system over the entire 1990-2002 period was not on a sustainable path according to the non-decreasing GPI requirement. In this regard, the graph is consistent with the conclusion obtained by other researchers in the field and first of all by the Canadian Centre for Sustainable Transportation.

The next question asked was: If the existing dynamics of transportation system in Canada prevails, what would happen in the nearest future? Figure 4 shows the time path of ΔGPI_t over the 2003-2025 period:

Fig.4. Changes in GPI over 2003-2025

Base case

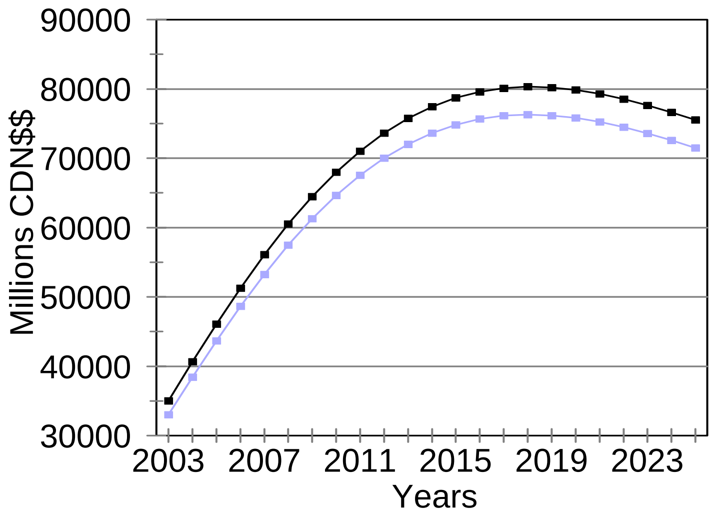


As the diagram shows, the aggregate indicator of transportation's sustainability ΔGPI_t increases over 2003-2018 period, however, it starts to decline beginning from year 2019. Therefore, based on the dynamics of the designed model it is possible to argue that our current transportation system is not on a sustainable time path because it does not satisfy the sustainability constraint of the non-decreasing welfare. This time path was further used as the base case to evaluate different policy alternatives.

Since the designed model included two sets of exogenous variables, describing economic fundamentals and the existing policy framework, changes to them were applied to obtain a sustainable path of a non-decreasing ΔGPI_t . The model has two variables reflecting economic fundamentals: (i) the social rate of people's time preferences, and (ii) the rate of technological progress. The social rate of people's time preferences, expressed as growth factor, was initially assigned the value of *0.96*. It means that people discount the future with respect to the present at the rate of 4.16% per year. The value of this parameter was taken from the literature on real business cycles in which this parameter was a very important part of the model calibration. The sustainable development concept assumes the intra- and inter-generational equity expressed in the famous Brundtland Report (1987) as follows: *"Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs… Even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation"* (page 43).

Therefore, if we are to achieve social equity within and between generations, people must treat the future in the same way they treat present. Quantitatively, it means that ideally the social rate of time preferences should be zero or no discounting of the future. Figure 5 compares the time path of ΔGPI_t under zero social rate with the base case:

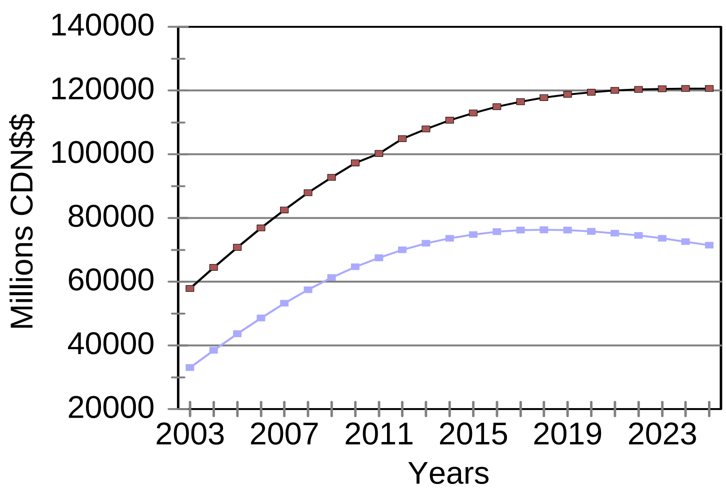
Fig.5. Change in GPI over 2003-2025
Time preferences



As figure 5 shows, a decrease in the social rate of time preferences increases welfare but does not change its pattern over time. Therefore, a change in this economic fundamental alone will not be able to produce sustainability of the transportation system.

Next an increase in the rate of technological progress has been modeled, and the following figure 6 summarizes the results of this simulation exercise:

Fig.6.Change in GPI over 2003-2025
Technological progress

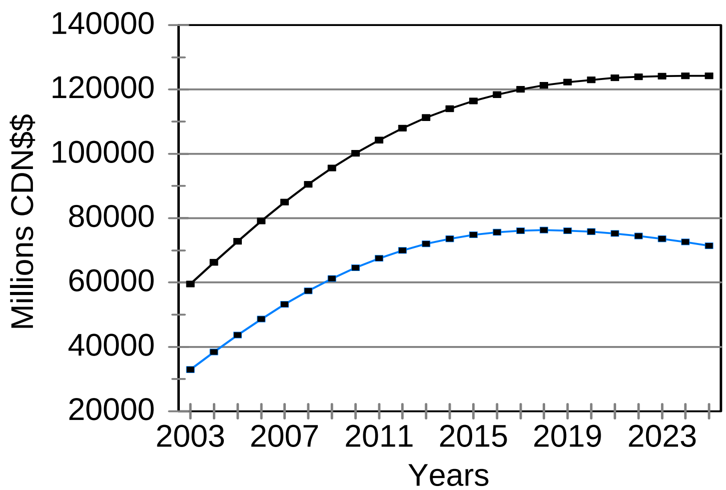


It appears to be that under current social rate of people's time preferences, it is necessary to achieve a 26% annual increase in technological progress to stay on the sustainable time path.

Finally the combination of the changes in both economic fundamentals was modeled, and the following figure 7 shows the results:

Fig.7. Changes in GPI over 2003-2025

Time preferences and technology



As figure 7 shows, the combination of zero social rate of people's time preferences with 23% annual rate of technological progress would result in a non-decreasing, sustainable path of ΔGPI_t .

Given the above results, it is possible to make the following conclusion: In principle, sustainability of the transportation system in Canada can be achieved through changes in economic fundamentals, namely time preferences of society and technology, simultaneously. However, it requires a dramatic change in technology, which involves a break-through than incremental (marginal) improvements in productivity. That is why the next consideration was given to changes in the existing policy framework towards transportation.

The existing policy framework reflects current government regulations with respect to transportation. They include environmental standards, taxes on gasoline, vehicle registration fees, tolls, fines, etc. Society as a whole ended up with current levels of fuel consumption, environmental pollution, ozone layer depletion or negative externalities, caused by the transportation system, as consequences of the existing regulations.

Therefore, the next simulation exercise was designed to answer the following question: How much of a reduction in the current level of negative externalities is required to bring the transportation system on a sustainable path? The result of this exercise is shown in figure 8:

Fig.8. Changes in GPI over 2003-2025

Reduction in externalities

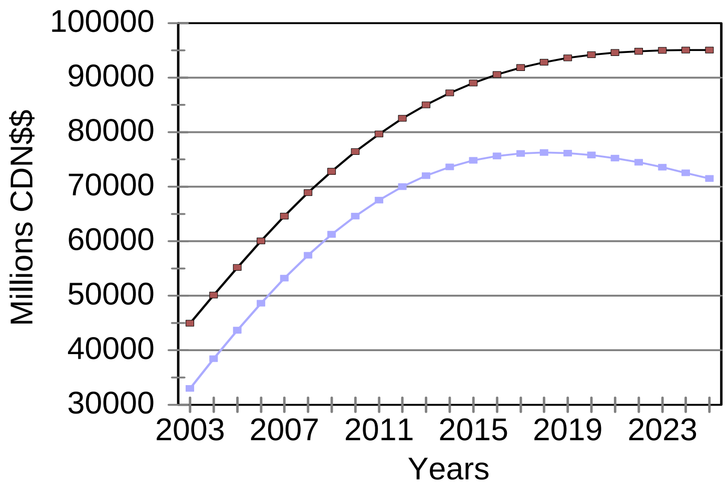
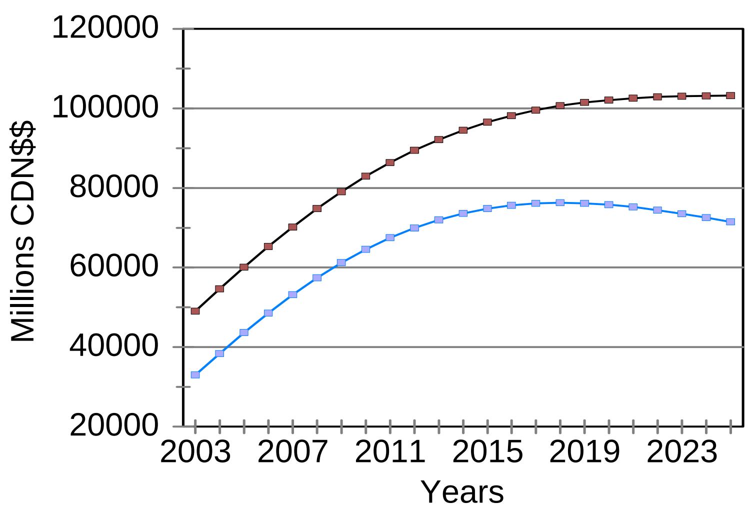


Figure 8 shows the time path of ΔGPI_t associated with the 17.5% reduction in negative transportation externalities in comparison with the base case. It means that the minimal 17.5% reduction in negative transportation externalities is required under existing technology and people's time preferences to bring the transportation system onto sustainable time path.

Finally, both possibilities – change in economic fundamentals and change in policy framework – were brought together in order to show the practical importance of the designed methodology and the associated model. Figure 9 shows one potential scenario to achieve sustainability of the transportation system under study compared to the base case:

Fig.9.Changes in GPI over 2003-2025

Fundamentals and policy variables



Specifically, figure 9 shows the time path of ΔGPI_t associated with zero social rate of people's time preferences, 4% annual technological progress and the minimal required 15% reduction in negative transportation externalities. From this scenario, it is obvious that technological progress speeds up the transition to a sustainable time path. Moreover, it appears to be that every 2% increase in the rate of technological progress decreases the minimal required reduction in negative transportation externalities by 1%. This is because technological improvements directly contribute to the reduction in negative externalities.

Conclusion

This paper summarizes the existing approach to measuring sustainability of transportation in Canada as well as describes an alternative approach based on aggregate sustainability measure. As a result of the approach, a mathematical model of a sustainable transportation system is discussed. The model then was used to model sustainability of the Canadian ground transportation system.

Based on computer simulation, it appears to be that the best way to achieve sustainability of the existing transportation system in Canada is to use a combination of the two basic instruments available to policy makers - changes in economic fundamentals and changes in the policy framework. Since it is not possible to change economic fundamentals in the short-run, a two-stage change is required: (i) in the short-run, changes to the existing policy framework must be introduced and implemented to significantly reduce negative transportation externalities. At the same time, incentives for changes in economic fundamentals must be created; (ii) in the long-run, changes in economic fundamentals must be realized.

This structure underlies the required public policy strategy towards sustainable transportation in Canada. For example, in order to reduce the social rate of people's time preferences in the long-run, advantages of sustainable development must become obvious for the general public in the short-run. It can be done through education and media. In order to achieve a higher level of technological progress in transportation in the long-run, a system of incentives towards research and development must be developed in the short-run. Both must be accompanied by continuous changes to the current transportation practice to reduce negative externalities.

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