ITEM is the model framework developed within the research project OPERATION ORIGIN-DESTINATION awarded by the Cooperative R&D Grant (CRD) program of the National Science and Engineering Council (NSERC/CRSNG) of Canada in partnership with the Railway Association of Canada (RAC/ACFC), financed over the period 1999-2001, with complementary support from *Transports Québec* in 2000-2001 and, during a part of 2000, from Transport Canada. The software modules necessary to support the implementation of ITEM components are regrouped under the name **IMPETUS**.

**ITEM: an Integrated Transport Economy Modelling System**

A Summary Description of the OPERATION ORIGIN-DESTINATION Research Project Design

by

Marc Gaudry

| The ITEM system | 1 | Agora Jules Dupuit (AJD)  
Université de Montréal  
www.ajd.umontreal.ca |
|-----------------|---|--------------------------------------------------|
|                 | 2 | Département de sciences économiques  
Université de Montréal  
marc.gaudry@umontreal.ca |
|                 | 3 | Bureau d’économie théorique et appliquée (BETA)  
Université Louis Pasteur  
Strasbourg |

This is an abridged form of the research project proposed to the National Science and Engineering Council (NSERC/CRSNG) of Canada on 22nd October, 1998, **Dossier CRD 21 7967-98**, Gaudry, Marc, PIN 14 235. Although, amazingly, the project, started in 1999, was terminated in 2000 before even Phase I had been completed and evaluated, supporting comments received from world-class researchers in Belgium, France, Germany and in many other countries suggested making the design, as well as first year outputs (notably AJD-12 and AJD-13, but see also AJD-19 and work on the economic interpretation of volume-delay curves and the valuation of congestion), available to the community at large. This was done with the September 2000 version of this summary; also, first research results were presented at numerous conferences and seminars, starting in October 2000 in Montreal at the First International conference on ITEM studies. The first of a series of books on integrated transport and economy models, edited by Marc Gaudry (U. de Montréal) and Stef Proost (K. U. Leuven), is at the planning stage.

Agora Jules Dupuit — Publication AJD-35

September 2000, August 2002
0. Objective and framework

0.1. The problem: the size and importance of transportation

0.2. The urgency: efficiency and competition among modes, the environment and the economy

0.3. The framework: combining economic, transportation, accounting and evaluation models

0.4. The solution

1. Methodology: the Integrated Transport Efficiency of Modes (ITEM) approach

Submodel 1. A General Equilibrium model with Transportation (GET)

1.1. STEP-1. Transportation as a sector of the economy: modal transport demand equilibrium

1.2. STEP-2. The regional effects of transportation

Submodel 2. A Modal Accounting System for Transport (MAST)

1.3. STEP-3. From modal transport demand to spatialized modal transport demand on network links

1.4. STEP-4. Infrastructure Cost Allocation and Recovery

1.5. STEP-5. From Infrastructure cost allocation to Full Direct Cost Accounting

Submodel 3. A Derived Transportation Efficiency Results (TER) model

1.6. STEP-6. Indicators of transport or economy efficiency performance

2. Algorithmic developments and tests on real data

3. References

4. Appendix 1. General expression of the total infrastructure cost per kilometre by class of vehicle

List of tables

Table 1. Direct cost recovery calculated by RCNPT for 1991

Table 2. Necessary new tools for ITEM approach

Table 3 Royal Commission network accounts format, extended to multiple jurisdictions

Table 4 Program starting point streams to develop ITEM

Table 5. ITEM-1 and ITEM-2 tests of new methods on real data, 1999-2002

Table 6. Participation in 4 modal data committees
0. OBJECTIVE AND FRAMEWORK

0.1. The problem: the size and importance of transportation.
Transportation matters, as much and perhaps more than ever. Since 1984, almost all countries have initiated major reforms in all three components of the transportation system: fixed infrastructure provision and maintenance, traffic control supply and management, and transport carrier service operating conditions. Why? Some reasons are:

Efficiency: transportation costs are at the heart of global competitiveness and their considerable decrease in a generation forces much economic restructuring in the global economy. But as transportation costs are a significant fraction of the cost of anything and define market reach, the identification of transportation subsidies is slowly coming into every discussion of free trade because the amounts of subsidies involved, and the potential unfairness and inefficiencies among modes are considerable. There is little doubt that transportation subsidies are relatively large and have implications for the allocation of resources, i.e. imply significant welfare “deadweight” losses.

Financial subsidies. In Canada, the Royal Commission on National passenger Transportation (RCNPT, Hyndman et al., 1992) has fully identified passenger subsidies and partially identified freight subsidies in the intercity Canadian road network: for instance, the RCNPT estimated an average subsidy of 20% for air passenger services (and 30% on the Toronto-Montreal link!) and 13,000 $ yearly per “typical” 62-ton 8-axle truck making 100,000 km per year in 1991; the RCNPT did not compute any urban network subsidy and neglected most freight subsidies, as the following table makes clear:

<table>
<thead>
<tr>
<th>Network</th>
<th>Passenger market, by mode</th>
<th>Freight market, by mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interurban</td>
<td>Calculated in full</td>
<td>Partially calculated for roads</td>
</tr>
<tr>
<td>Urban/municipal</td>
<td>n.e.</td>
<td>n.e.</td>
</tr>
</tbody>
</table>

Because of their size, both transportation taxes or fees and subsidies have large impacts on government budgets: so major reforms cannot be considered without evaluation of budgetary impacts. Similarly, transportation is a major polluter and green taxes (or the purchase of emission permits) could influence the price of different modes in different ways, as the RCNPT showed.

Ecological subsidies. The RCNPT calculated that reasonable environmental charges on modes would have increased air passenger fares by 7% and bus passenger fares by 3% in 1991.

Size of transportation: there are two measures of the size of transportation: in terms of GNP share and in terms of total resources used. Neither is known precisely due to the partial nature of national economic accounts, where transportation is underidentified. In all developed countries, computations of the first measure typically yield 12-15% of GNP, a percentage that appears to be growing.

Economic size. In Canada, the RCNPT calculated 12-16% of GNP, as compared to 4% for communications and 8% for health in 1991. The RCNPT also calculated, using the second measure (total activity) that, if transportation were a single firm, its yearly sales would have been of the order of 160 Billion $ in 1991. The lack of precision everywhere concerning the size of perhaps the largest “firm” of the economy is generating corrective measures: the U.S. Department of Transportation has started to develop a Transportation Satellite Account (TSA).

Ecological size. The RCNPT calculated that transportation contributes about 40% of Canada’s non-natural emissions of volatile organic compounds (VOC), 60% of its nitrogen oxides (NOx). Transportation is also responsible for a large share of other greenhouse gases: 25% of carbon dioxide (CO2) emissions from non-natural sources and a growing share of chlorofluorocarbons (CFCs) leakage from air conditioners (that themselves contribute about 25% of total Canadian CFC emissions).
0.2. The urgency: efficiency and competition among modes, the environment and the economy.

It is clear that there is a demand for a tax/fee treatment of different modes on a comparable basis, taking due account of the constraints imposed by the actions of our competitors, notably the United States. This is true both on the economic and financial side and on the ecological side. Recently, Canada has recognised efficiency, environmental and general economic concerns of transportation explicitly in The Canada Transportation Act, 1996, and implicitly in the Kyoto protocol. The legal requirements are:

A. Level playing economic field efficiency. Section 52 (a, b and c) obliges the Minister to report to Parliament on the financial viability of the modes and on all resources provided directly or indirectly at public expense to all carriers and modes of transportation.

B. The environment. A broad view of this requirement could include “the environmental subsidy” calculated in some way. But the Kyoto protocol requires Canada in any case to have in place a national system of measuring greenhouse emissions to furnish data “to be reviewed by expert review teams”.

C. The economy. Section 52 (a) obliges the Minister to report, for each mode, “on its contribution to the Canadian economy...”. And the Kyoto protocol requires Canada to “formulate, implement, publish and regularly update” programs to mitigate climate change in “the energy, transport and industry sectors, as well as agriculture, forestry and waste management”.

In addition to these legal requirements, the evaluation of economic dead-weight losses naturally arises.

0.3. The framework: combining economic, transportation, accounting and evaluation models.

There is a clear need for tools that allow evaluation of transport scenarios, but simultaneously respect the general equilibrium constraints of the economy and present the results clearly.

Transportation flows are normally modelled conditionally upon the level and spatial distribution of activities in space and are by their very nature spatialized. They normally contain sets of procedures that determine Total Flows (Generation-Distribution), Modal Flows (Mode Choice) and Path Flows (Assignment). With these models, changing either the Activities, or the transport network conditions, would yield new flows that can be evaluated. Scenarios pertain to infrastructure (a new highway, transportation mode or intermodal facility, etc.), policy (fuel tax, deregulation, privatisation, etc.), or economic (Free Trade agreements, ...) changes.

By contrast, macroeconomic models are not explicitly spatialized or, to the extent that they may implicitly be spatialized in International Trade models, use simplistic measures of transportation “cost”, such as distance. However, they incorporate and account for the interactions among different sectors. Advanced forms of these models, Computable General Equilibrium (CGE) models, determine prices and other quantities (imports, exports, etc.) as they derive producer and consumer adjustments to modifications of taxes or other parameters.

Many studies have calculated either modal recovery or environment externalities of transportation, but the development of integrated network accounts is everywhere in its infancy. In Canada, the first set of integrated economic and ecological accounts are those of the RCNPT. A number of countries, for instance Chile, are considering developing network accounts, as is the European Commission for the Trans-European Networks.

Various efficiency measures derived from network accounts or CGE models exist and embody a wide spectrum of approaches, from simple cost recovery to welfare and employment changes in the sectors and firms affected.
0.4. The solution.
Our framework purports to combine these four solitary streams to make possible the calculation of the overall efficiency or performance (economic and ecological) of transportation modes. As transportation models will be included within both macro-economic and network accounting parts of the model, the Integrated Transportation Efficiency of Modes (ITEM) model consists in 3 principal sub-models, all defined at a middle-aggregate, or “meso-aggregate”, level, as shown in Table 2, and accomplishes the desired integration in 6 steps, each of which requires research and the development of new tools, as outlined in Gaudry and Laferrière (1997).

1. METHODOLOGY: THE INTEGRATED TRANSPORT EFFICIENCY OF MODES (ITEM) APPROACH

Submodel 1. A General Equilibrium model with Transportation (GET)
The conceptual foundations for such a system exist for the economy as a whole in Computable General Equilibrium (CGE) models and the challenge is to combine information from transportation networks with economic models of middle-level type, or meso-type, aggregation, in order to satisfy Transportation Act requirements A and B (efficiency and environment), meeting requirement C (economy) as well.

1.1. STEP-1. Transportation as a sector of the economy: modal transport demand equilibrium
Over the last 20 years, Computable General Equilibrium (CGE) models have been developed and used to evaluate macroeconomic policies. This modelling is very appealing as it captures the relevant market mechanisms. Such models incorporate production at a level of aggregation that permits the analysis of structural change and also captures the essential interdependent nature of production, demand, and trade within a general equilibrium system. Equilibrium conditions imply several constraints on the economic system. Recently, McKitrick (1995) has shown that equilibrium conditions play a major role in limiting the macroeconomic impact of a policy shock. Both consumers and producers are explicitly represented.

Task 1. Explicate transport demand by mode in CGE models
Consumers. Demand functions would account for the choice between final consumption goods and for transportation demand required to support those choices. Transportation can be both of an intermediate and of a final nature. When the time comes to specify a particular utility function, and its associated demand function, a prime candidate would be the Constant Elasticity Substitution (CES) Utility function and its associated CES demand functions for all goods. Indeed, CES utility functions are convenient as they generalise other functions, for instance the Cobb-Douglas and the Leontief function. In transportation, the Logit model is predominant (McFadden, 1974, Winston, 1983) and numerous generalisations based on the Box-Cox (Gaudry and Wills, 1978) and Box-Tukey forms (Gaudry, 1993) have proven more credible that the simple linear form. Interestingly enough, the Box-Cox transformation makes it possible to construct a CES-Logit function that includes both as special cases (Anderson et al., 1988, 1992, de Palma and Sanchez, 1998).
### Table 2. Necessary new tools for ITEM approach

<table>
<thead>
<tr>
<th>Integrated Transport Efficiency of Modes</th>
</tr>
</thead>
</table>

**GET**
- General Equilibrium with Transport
  - The economy with explicit transport sector

**MAST**
- Modal Accounting System for Transport by network and region
  - Network O-D flow models by mode
  - Infrastructure cost and revenue allocation by mode and user class
  - Carrier and Externality costs by mode and user class

**TER**
- Transport efficiency results
  - Derived network user, government and economy indicators

<table>
<thead>
<tr>
<th>Meso-aggregate methods to be developed</th>
<th>Year</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New METHODS or Models</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Explicate transport demand by mode in CGE</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>2. Introduce land and time in CGE</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>3. Introduce environment in CGE</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>4. Endogenize zonal activity distribution among zones in CGE</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>5. O-D matrix estimation</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>6. Multipath assignment</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>7. Road cost/revenue allocation</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>8. Rail cost/revenue allocation</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>9. Maritime cost/revenue allocation</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>10. Air cost/revenue allocation</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>11. Accident modelling : road</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>12. Emission modelling : road</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>13. Carrier cost modelling: road</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>14. Cost recovery efficiency</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>15. Dead-weight taxation loss efficiency</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

**Part I : partial tests :** Land+maritime

**Part II full tests :** + air mode
Producers. Much transportation demand is of an intermediate nature. A first simple view of this is to state that total transportation demand, or transportation demand by mode, is derived in a straightforward manner as an additional sector among input-output relationships. Recent CGE modelling that includes transportation in this way can be found in Buckley (1992), Dixon et al. (1991), François et al. (1996), and Wigle (1992). It should not be thought that, even with the built-in assumption of fixed proportions between transportation and its uses, this view is without interest, because it rules out the simplistic views of proportionality between the growth of Gross National Product (GNP) and transportation demand.

But the fixed proportion assumption of input-output analysis is too restrictive to analyse at least long run effects of policies affecting the transportation sector. We propose to replace it by a more elaborate transportation demand formulation. This formulation has to allow total and modal demands to respond to price and service conditions. Several approaches are possible, including the CES-Logit approach (including utility indicators from “lower level” choices for different transport services), if it can be shown to be consistent with the expenditure flows, for instance by combining an equation to determine total transportation demand with Logit functions to derive the proportion of total demand that is allocated to each mode of transport. These equation pairs could be applied to the whole economy or alternatively, distinct pairs could be applied to specific sectors of the economy.

Another approach consists in deriving the demand for freight transport as an input to a profit-maximising firm: a translog cost function and derived input demands (including demand for modal transport services) are then specified (Oum 1979).

Tasks 2-3 Introduce land, time and environment in CGE models

Adding Resource Factors. The economy is usually described with two resource factors: capital and labour. Mode choice models relate transportation demand to the nature of goods to be transported and modal characteristics such as transportation price, travel time and other intrinsic modal characteristics. Therefore, it is difficult to conceive of transportation demand analysis without giving explicit recognition to time and land.

• Time: Some authors have derived transportation demand by treating time as a fixed resource to be allocated (Bruzelius, 1979). The role of time is obvious for travellers, but it is also crucial for firms that face trade-offs between inventories and transportation demand.

• Land: Land values play a major role to evaluate infrastructure transport projects. The model should take into account competing demands from general economy activities and transport infrastructures for land.

The environment. It has to be remembered that emissions can be associated to all activity levels and flows in an economy-wide model, and then summed in a particular way of interest. For instance, the David Suzuki Foundation and the Pembina Institute estimated than in 1990, Canada’s greenhouse-gas emissions could be distributed between industrial sources (30.8 %), transport (26.5 %), electricity generation (16.9 %), agriculture and waste-disposal (13.5 %), residential (7.8 %) and commercial (4.6 %) activities. The point of CGE models is to make possible the representation of adjustments, by both consumers and producers, to policy changes, and consequently to make such emission outputs responsive.

Overall, the properties of this first STEP-1 procedure have to yield modal demand for transport in a way that is consistent with the macroeconomic aggregates, including total expenditure on transportation. At this point, the results are not be spatialized. Clearly, it is possible to spatialize the input-output matrices but this might not be advisable. The interactive SAGE (Studies Using Applied General Equilibrium) database (http://paradi1.ecn.ulaval.ca), that has more than 700 references, will be helpful in establishing our strategy. Resulting equations should be expected to contain economies of scale and to be solved with the GAMS solver (Brooke et al., 1996), taking due account of state-of-the-art techniques, well summarised by Mercenier, 1997).
1.2. STEP-2. The regional effects of transportation

As mentioned in the Introduction, spatialized modal transportation demands are modelled conditionally upon the spatial distribution of activities in space. Even though aggregate productions and consumptions are derived in STEP 1, spatialization of those activities is not effected within this step. The goal of the second step is to represent the impact of transportation networks on the location of some activities, in addition to reflecting the regional effects of changes in the transportation networks on the level of local activities, using transportation distribution and share models, and to solve these equations simultaneously with those of STEP-1.

Task 4: Endogenize zonal activity distribution among zones in CGE

The methodology on this point is not yet determined as this task belongs primarily within the second period of research, after first components have been established and tested with a Land-Maritime model (without a refined air sector).

Submodel 2. A Modal Accounting System for Transport (MAST)

The RCNPT and derived work for and by Transport Canada have laid the foundations for such a system to track and compute the financial and ecological performance of modes with sufficient realism to satisfy A and B requirements (economic efficiency and the environment). These foundations have to be extended to derive the O-D matrices and to improve the cost/revenue allocation equation and the carrier externality cost calculations by mode and user class.

1.3. STEP-3. From modal transport demand to spatialized modal transport demand on links

The general approach represented in Table 2 is bi-directional because measures defined over the network (price and service measures) are used in the demand equations of the GET model. During the first two years, the procedure will be top-down oriented, i.e. transportation demand is first derived in a fashion consistent with the general economy interactions and then is used as an input to more specific types of procedures resulting in spatialized flows on actual networks. The second part of the research is intended to study the impact of transport on the general economy.

Task 5. O-D matrix estimation

Spatialized flows. Modal transportation demands from STEP-1-2 are consistent with macroeconomic aggregates. In this context, certain properties of classical Distribution models to spatialize modal transportation demands could be useful, for instance the implicitly constant value of the total transportation cost in the system as a whole in doubly-constrained distribution models. Using this property for each mode, the resulting flow structure is consistent with well-known transportation planning models. By contrast, if the input-output matrix is spatialized in STEP-1, difficulties arise with data availability (as national input-output matrices are not available at a sufficient zonal level matching the network, say the interurban level (NUTS 3 in Europe). It is possible to derive the O-D matrices in many ways, notably by making them consistent both with the national totals and with link counts, an approach we are likely to choose. Gaudry (May 1998) recently surveyed these methods for the Transportation directorate (DGVII) of the European Commission.

Task 6. Multipath assignment

Link flows. Given spatialized total or modal demand, traffic flow models derive link flows per mode using operations research techniques, sometimes allowing the demand for transportation to vary with transportation conditions and assuming that the rest of the economy is not affected by the proposed transportation changes. Examples of these type of models are EMME/2 or VISEM-VISUM for passengers and FNEM (Friesz et al., 1986) or STAN for freight. These models naturally take into account the user link charges in deriving the link flows. This means that the total spatialized flows (by mode for passengers)
obtained above can be transformed into link flows by an assignment procedure assumed to be coherent with the total (spatialized) demand and mode choice procedures.

The output of STEP-3 is therefore path flows using links. The various flows can be regrouped by subnetworks corresponding to different jurisdictions and by road type on each of these networks, but we refer to them as “link flows” nevertheless for expository purposes. Before formal algorithms are used, fixed-structure matrices based on existing information can be used for the road mode and rail shipment data for the rail mode.

**Our problem.** For the purposes of “meso-aggregate” modelling, it is less the refinements of assignment procedures that matter than the consistent interaction with Origin-Destination matrix estimation procedures. The reason for this is the fact that, for roads at the very least, the estimation of matrices from link counts (perhaps with some explicit O-D information as well), is essential in order to obtain cheap and easily updatable results: such estimation poses problems of joint or simultaneous determination of link flow times (and costs) and demand by origin-destination pair. This “jointness” poses non-trivial questions of unicity, consistence and convergence that have just been addressed (Galvan, 1994).

**1.4. STEP-4. Infrastructure Cost Allocation and Recovery**

A first concern is to determine and allocate infrastructure costs among its user classes. The goal is to calculate costs by vehicle category for a system of different users (modes) sharing infrastructures of distinct physical characteristics (different roadways or bridges). Each vehicle type generates specific costs and is allocated a portion of joint and common costs of infrastructure provision, management and control. These cost allocation procedures in effect weigh vehicle-kilometres in different ways, using principally Gross Vehicle Weights (GVW), Equivalent Single Axle Loads (ESAL) and reference vehicle equivalence or “footprint” to assign or “distribute” costs that vary with traffic and those that do not, as shown in Appendix 1., drawn from Gaudry and Mallet (1997).

Considering the road mode, for instance, the RCNPT developed such a classical procedure which we recently documented and applied to the Quebec road network (Gaudry et al., 1996b) by jurisdiction (federal, provincial, municipal), writing the system of non-linear equations used in full. We also derived the marginal vehicle costs by mode, and the associated cost elasticities, implied by these equations with 6 user classes and 5 roadway types, with respect to the 45 different factors that influence the own marginal costs and elasticities. This gave, apparently for the first time, knowledge of the analytical properties of a system of “shared cost” equations (that found in Appendix 1). The absence of other procedures documented in full as to their implied analytical derivatives and elasticities, is making it a lead contender for the establishment of evaluation procedures for the Trans European Network (Gaudry, August 1998). In the procedure, called “Royal Commission-Transport Canada 1991” (or RC-TC 1991, see Gaudry and Mallet, 1997), the elasticities for both the interurban Canadian road network and for the Quebec provincial road network are evaluated.

**Tasks 7-10 Modal cost/revenue allocation by user class**

As the RC-TC system is quite general, it is in principle applicable to any multi-user, multi-roadway transportation infrastructure cost allocation problem, such as those of railways and airports. Some adaptations for maritime infrastructure and air traffic control applications are required.

In the extension of the RCNPT table format that was defined for the Quebec road accounts, shown in Table 3, STEP-4 yields values for the 3 cells indicated by a “√” on the first row.
Table 3. Royal Commission network accounts format, extended to multiple jurisdictions

<table>
<thead>
<tr>
<th>Type of cost</th>
<th>Users</th>
<th>Others</th>
<th>Federal</th>
<th>Provincial</th>
<th>Municipal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure and control</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special trans. Tax/fee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle/Carrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.5. STEP-5. From Infrastructure cost allocation to Full Direct Cost Accounting

Infrastructure and control costs are a central part of the evaluation of network costs by mode. However, it is of interest both to consider other costs and to find who bears them and who pays specific transportation taxes and fees and how much the population also bears transportation externalities, such as pollution, noise, and to some extent accidents, all shown in Table 3, that also contains a row for carrier (vehicle) costs.

Tasks 11-13 Accident, emission and carrier cost modelling by mode and user class

This format can be applied to a particular mode, or to a group of modes, and can be adapted to distinguish clearly among values obtained by different evaluation methods (for instance financial, economic or other) used to transform the different “social” costs into money. STEP 5, leads to filling more cells in Table 3.

The RCNPT used elaborate models to determine these carrier and externality costs. In this project, meso-aggregate models will be developed, starting with land and sea modes. Conceptually, the establishment of such tables does not require assignment procedures, as one can clearly derive values from existing O-D matrices, as shown in Part I of the project. However, the point of Part II is precisely to link previously separated modelling component streams, and requires assignment procedures to that end.

Submodel 3. A Derived Transportation Efficiency Results (TER) model.

There already exist a number of professional and scientific indicators to obtain quantity, value and welfare efficiency indicator variations for proposed changes to transportation system or economy, parameters, but none linked to an integrated model such as ITEM and clearly distinguished from network accounts.

1.6. STEP-6. Indicators of transport or economy efficiency performance

Tasks 14-15. Professional and scientific indicators of efficiency

In addition to the financial (cost recovery) and economic (cost-benefit or welfare; and their distribution in space) indicators, we expect, after Shawn et al. (1996) to add transport network performance indicators of service (output) and resource consumption (input) as well as indicators of externalities (noise, pollution, safety). In the tables, we only specify the first two of these. They may be defined over time and regions: cost recovery measures, usually applied to firms, networks or government accounts; and welfare measures derived from consumer and producer surplus “net burdens”. Interesting scenarios include changes in infrastructure charges, fuel and green taxes (perhaps revenue neutral) and property taxes (e.g. on railways).
2. ALGORITHMIC DEVELOPMENTS AND TESTS ON REAL DATA

All steps involve programming and testing on real data. The programming activities will develop an ITEM user-friendly transferable and usable by Transport Canada, provincial departments of transport and transportation firms or associations. The streams to be integrated are shown in Table 4. Tests on real data will be carried out with the collaboration of Transport Canada, Statistics Canada, the railways and provinces. Modal DATA responsibility committees will be established as suggested in Table 6. Table 5 shows the scheduling of these activities, that parallel the development of the new procedures.

<table>
<thead>
<tr>
<th>Program name</th>
<th>Purpose</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>GAMS</strong> solvers (Brooke et al., 1996)</td>
<td><strong>GAMS</strong> solvers that compute an equilibrium with supplied parameters and data values in CGE models</td>
<td>STEP-1</td>
</tr>
<tr>
<td>2. <strong>TRIO</strong> program (Gaudry et al., 1996a)</td>
<td>Fully documented algorithms for demand model estimation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LEVEL algorithm</td>
<td>STEP-3</td>
</tr>
<tr>
<td></td>
<td>PROBABILITY and SHARE algorithms</td>
<td>STEP-2-3</td>
</tr>
<tr>
<td>3. Network assignment (method to be determined, for instance as in Gaudry et al., 1994)</td>
<td>Assignment may be implicit in years I and II and explicit afterwards.</td>
<td>STEP-3</td>
</tr>
<tr>
<td>4. <strong>RC-TC 1991</strong> (Gaudry and Mallet, 1997)</td>
<td>Will be extended to other modes than road</td>
<td>STEP-4</td>
</tr>
<tr>
<td>5. <strong>BRQ-1</strong> (Gaudry et al., 1996b)</td>
<td>Will be refined</td>
<td>STEP-5-6</td>
</tr>
<tr>
<td>6. To be determined</td>
<td>To compute performance and welfare measures</td>
<td>STEP-6</td>
</tr>
</tbody>
</table>
### Table 5. ITEM-1 and ITEM-2 tests of new methods on real data, 2000-2004

**ITEM**

<table>
<thead>
<tr>
<th>Integrated Transport Efficiency of Modes</th>
<th>ITEM-1 tests</th>
<th>ITEM-2 tests</th>
</tr>
</thead>
</table>
| **GET**
  General Equilibrium with Transport<br>The economy with explicit transport sector<br>Spatialization of activities | Step 1. A. Information gathering and programming<br>B. Tests<br>C. Reports | GET-1<br>Old Stat. Can. data<br>— New data<br>------------ Maquette ------<br>------------ Simple scenarios | GET-2<br>Add substitution: modes, land, time, environment<br>Regional effects with given distribution of activities<br>Affected by transport |
| **MAST**
  Modal Accounting<br>Network O-D flow models by mode<br>System for Transport by network and region<br>Infrastructure cost and revenue allocation by mode and user class<br>Carrier and Externality costs by mode and user class | Step 2. | MAST-1<br>Land and maritime modes<br>By province and network<br>Given matrices<br>No assignment algorithm | MAST-2<br>Add air mode<br>Estimate O-D matrices and assign to paths |
| **TER**
  Transport efficiency results<br>Derived network user, government and economy indicators | Step 3. A. Information gathering and programming<br>B. Tests<br>C. Reports | TER-1<br>Professional measures: cost recovery of modes<br>Government cost recovery: federal, provincial, municipal<br>| TER-2<br>Add Scientific welfare measures |

### Sequence of tests of new meso-aggregate methods on real data

1. **GET**
   - **Step 1.**
     - A. Information gathering and programming
     - B. Tests
     - C. Reports
   - **GET-1**
     - Old Stat. Can. data
     - New data
     - Maquette
     - Simple scenarios
   - **GET-2**
     - Add substitution: modes, land, time, environment
     - Regional effects with given distribution of activities
     - Affected by transport

2. **MAST**
   - **Step 2.**
   - **MAST-1**
     - Land and maritime modes
     - By province and network
     - Given matrices
     - No assignment algorithm
   - **MAST-2**
     - Add air mode
     - Estimate O-D matrices and assign to paths

3. **TER**
   - **Step 3.**
   - **TER-1**
     - Professional measures: cost recovery of modes
     - Government cost recovery: federal, provincial, municipal
   - **TER-2**
     - Add Scientific welfare measures

4. **Step 4.**
   - **Step 5.**
   - **Step 6.**

**Part I**

Disjoint components

**Part II**

INTEGRATED SCENARIOS
Table 6. Participation in 4 modal data committees

<table>
<thead>
<tr>
<th>Participants</th>
<th>Functional data committees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rail</td>
</tr>
<tr>
<td>Industry</td>
<td></td>
</tr>
<tr>
<td>Railways</td>
<td>X</td>
</tr>
<tr>
<td>Trucking</td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td></td>
</tr>
<tr>
<td>Shipping</td>
<td></td>
</tr>
<tr>
<td>Air navigation</td>
<td></td>
</tr>
<tr>
<td>Airlines</td>
<td></td>
</tr>
<tr>
<td>Government</td>
<td></td>
</tr>
<tr>
<td>Statistics Canada</td>
<td>X</td>
</tr>
<tr>
<td>Transport Canada policy</td>
<td>X</td>
</tr>
<tr>
<td>Transport Canada (modes)</td>
<td>X</td>
</tr>
<tr>
<td>Provincial departments (modes)</td>
<td>X</td>
</tr>
</tbody>
</table>

3. REFERENCES


- Tome I. Les comptes virtuels de deux agences, (256 p.).
- Tome II. Les sources logiques et statistiques, (266 p.).
- Tome III. La répartition: méthode d'origine et application à l'année 1994, (405 p.).


Part I. Theory, Analytical Expressions, Data Values and Results, (527 p.).

Part II. Detailed Partial Derivation and Elasticity Calculations, (269 p.).


4. Appendix 1. General expression of the total infrastructure cost per kilometre by class of vehicle

\[
\text{INFRA}_{TC} [v_p] = \text{CTRL}_{TC} [v_p] + \text{HCAP}_{TC} [v_p] + \text{LAND}_{TC} [v_p] + \text{TC}_M [v_p] \quad \text{Total infrastructure cost} \quad (1)
\]

where

\[
\text{CTRL}_{TC} [v_p] = \frac{\text{CTRL}}{\text{VKM}_{[R_{\text{sup}}, V]}} \cdot \frac{\text{VKM}_{PCE}}{\text{VKM}_{[R_{\text{sup}}, V]}} \quad \text{Total cost of control} \quad (1-A)
\]

\[
\text{HCAP}_{TC} [v_p] = \frac{\text{CAP} \cdot \text{P}_{\text{HIGH}} \cdot \text{R}_{\text{OCK}}}{\text{VKM}_{[R_{\text{sup}}, V]}} \cdot \frac{\text{VKM}_{PCE}}{\text{VKM}_{[R_{\text{sup}}, V]}} \quad \text{Total cost of highway capital} \quad (1-B)
\]

\[
\text{LAND}_{TC} [v_p] = \frac{\text{LAND}_{\text{RESID}} \cdot \text{R}_{\text{OCK}}}{\text{VKM}_{[R_{\text{sup}}, V]}} \cdot \frac{\text{VKM}_{PCE}}{\text{VKM}_{[R_{\text{sup}}, V]}} \quad \text{Total cost of land} \quad (1-C)
\]

\[
\text{TC}_M [v_p] = \frac{\sum_{q=1}^{4} \text{TC}_M [r_q, v_p] \cdot \text{VKM} [r_q, v_p]}{\sum_{q=1}^{4} \text{VKM} [r_q, v_p]} \quad \text{Total cost of highway construction and maintenance} \quad (1-D)
\]

and

\[
\text{VKM}_{PCE} [R_{\text{sup}}, v_p] = 365 \cdot \sum_{n=1}^{4} \text{AADT} [r_n] \cdot \text{LENGTH} [r_n] \cdot \text{TRAF} [r_n, v_p] \cdot \text{PCE} [v_p] \quad (1-E)
\]

\[
\text{VKM}_{PCE} [R_{\text{sup}}, V] = 365 \cdot \sum_{n=1}^{4} \text{AADT} [r_n] \cdot \text{LENGTH} [r_n] \cdot \sum_{m=1}^{6} \text{TRAF} [r_n, v_m] \cdot \text{PCE} [v_m] \quad (1-F)
\]

\[
\text{VKM} [r_q, v_p] = 365 \cdot \text{AADT} [r_q] \cdot \text{LENGTH} [r_q] \cdot \text{TRAF} [r_q, v_p] \quad (1-G)
\]

\[
\text{VKM} [R_{\text{sup}}, V] = 365 \cdot \sum_{n=1}^{4} \text{AADT} [r_n] \cdot \text{LENGTH} [r_n] \cdot \sum_{m=1}^{6} \text{TRAF} [r_n, v_m] \quad (1-H)
\]

\[
\text{TC}_M [r_q, v_p] = \quad (1-I)
\]

\[
\left[ \text{MAINC} [r_q] \cdot \left( \text{P}_{\text{TR}} + \text{P}_{\text{NRPT}} + \text{P}_{\text{RP}} \cdot \text{ENVIR} [r_q] \right) + \left( \text{RESURF} [r_q] + \text{RECAST} [r_q] \right) \cdot \text{ENVIR} [r_q] \right] \cdot \text{LENGTH} [r_q] \cdot \text{PCE} [v_p] +
\]

\[
\frac{365 \cdot \text{AADT} [r_q] \cdot \text{LENGTH} [r_q] \cdot \sum_{m=1}^{6} \text{TRAF} [r_q, v_m] \cdot \text{PCE} [v_m]}{\sum_{n=1}^{4} \text{AADT} [r_n] \cdot \text{LENGTH} [r_n] \cdot \sum_{m=1}^{6} \text{TRAF} [r_n, v_m]}
\]

\[
\left( \text{ADM} + \text{BRID} \cdot \text{P}_{\text{BF}} \right) \cdot \text{PCE} [v_p] + \frac{\text{BRID} \cdot \text{P}_{\text{BV}} \cdot \text{GVW} [v_p]}{\text{VKM}_{PCE} [R_{\text{sup}}, V]}
\]

\[
\left[ \text{MAINC} [r_q] \cdot \text{P}_{\text{RP}} \cdot \left( 1 - \text{ENVIR} [r_q] \right) + \left( \text{RESURF} [r_q] + \text{RECAST} [r_q] \right) \cdot \left( 1 - \text{ENVIR} [r_q] \right) \right] \cdot \text{LENGTH} [r_q] \cdot \text{ESAL} [v_p] +
\]

\[
\frac{365 \cdot \text{AADT} [r_q] \cdot \text{LENGTH} [r_q] \cdot \sum_{m=1}^{6} \text{TRAF} [r_q, v_m] \cdot \text{ESAL} [v_m]}{\sum_{n=1}^{4} \text{AADT} [r_n] \cdot \text{LENGTH} [r_n] \cdot \sum_{m=1}^{6} \text{TRAF} [r_n, v_m]}
\]