SCENARIO-WISE ANALYSIS OF TRANSPORT AND LOGISTICS SYSTEMS WITH A SMILE

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Abstract

Public decisionmakers in transport and logistics are more and more dependent upon strategic information on the expected development of freight flows. This paper reports on the development and the first applications of a new strategic model for freight transport and logistics in and around the Netherlands, called SMILE (Strategic Model for Integrated Logistic Evaluations). The model was constructed in a joint effort of the Transport Research Centre of the Ministry of Transport and the research organisations NEI (Netherlands Economic Institute) and TNO Inro. We explain the structure of the information system, discuss the possible usage of this model for exploring the effects of transport policy upon changes in fraight flows, including the logistic organisation of firms, and describe an application of the model.

INTRODUCTION

With the dynamics of global logistics processes in mind, private and public decisionmakers regularly require strategic information on the expected development of freight flows. The article reports on the development and the first applications of a new strategic model for freight transport and logistics in and around the Netherlands. The need for such a model has emanated from discussions on freight transport modelling that were started in the early nineties. In these discussions it was concluded that a model for policy analysis on the long term, with a low level of detail but with a wide scope was missing. Modelling with a wide scope would involve a treatment of not only sectoral and spatial exchanges together with transport processes but in addition also the logistics processes underlying freight transport.

This implies that the relations between transport and the economy have to be well understood, including the appropriate feedbacks between markets for goods and services at different levels. The development of decision support systems should aid this understanding, in particular when strategic management or public policy analysis requires a systematic sketch of the impacts of certain changes in the system. Here, the term "logistic and transport system" should be clarified. It denotes the economic activities underlying the complete supply chain, including production, sales and sourcing, inventory and transport. Note also that the use of "system" implies that the information about these activities should concern structural issues (about the elements of the system like infrastructure and regions), functional issues (related to economic choice behaviour) and issues related to the dynamics of the markets concerned. The policy issues are treated in more detail in the following section.

The paper describes the background and the intermediate results of a project aimed at the development of a new decision support system (DSS) for public and private decision makers in the transport and logistics sector. The model is being constructed as a joint effort of the Transport Research Centre of the Ministry of Transport and the research organisations NEI (Netherlands Economic Institute) and TNO Inro. The name of the model is SMILE (Strategic Model for Integrated Logistics and Evaluation). We discuss the applicability of this model for exploring the possible effects of transport policy and changes in the logistic organisation of firms and through these on the corresponding freight flows. Also, the design of the information system is explained, covering the specification of the underlying models, the graphical interface by means of which scenarios in SMILE can be prepared, and the databases.

INFORMATION REQUIREMENTS

What will be the specific information needs of policy analysts and decision makers in transport and logistics? We will try to formulate an answer by exploring in short the main topics in policy analysis in this area. Before we do this, however, a number of starting points should be identified which characterise the nature of the decision maker who is in need of information.

Note that information needs differ for the private and public sector in terms of the uncertainties involved, the instruments available and the performance measures. The instruments available to the private sector will primarily focus on direct (des)investment, whereas governments can also resort to fiscal and regulatory policy. Typical for the needs of the public sector is the heterogeneity of the goods and the stakeholders studied, and the system's complexity and uncertainty with regard to changes in the (economic) environment (see e.g. Patton ans Sawicki, 1986). In this paper, we focus on information needs for public policy analysis.

Decision makers have to take in account a large number of factors influencing their decision and a large number of factors influenced by the decisions. This is true for a decisions in several fields, but especially in the field of traffic and transport, as transport is dependent on economical developments (growth and spatial organisation of economic activities). Two key issues can be distinguished when it comes to decision support using descriptive information:

- information on how external factors (e.g. overall socio-economical trends and trend-breaches) affect the performance of logistics and transport systems. Due to the high level of uncertainty, it is helpful to use scenario techniques, by means of which different -plausible but not necessarily congruent- sequences of events can be analysed.
- "what-if?" questions related to measures to improve the system's performance and the impacts of these measures. This information is used for the analysis and comparison of management and policy options.

MODEL STRUCTURE

Essential for a model is the notion that developments in freight flow demand are the result of changes in economic structures that create a demand and a supply of goods in specific geographic regions and form the basis for transport flows between regions. The general aim for the SMILE model is to get a better view on future developments in freight flows that use Dutch infrastructure. Therefore we take two kinds of freight flows into account, each of which we treat differently:

- freight flows that relate to the Dutch production and consumption structure (i.e. relationships to and from Dutch production units)
- freight flows that use Dutch infrastructure but do not have a direct relationship with the Dutch economy (this includes transit flows that could use Dutch ports for transhipment and intermodal change only).

The first category of flows is a direct result of the production structure within the Netherlands and the logistic organisation of flows that exists between these production units. The second category holds the same but these have the extra choice possibility of not using Dutch infrastructure and therefore have to be treated differently. The logistical organisation is defined as the way the goods flows are controlled, both as necessary activities to make production activities possible as well as all the activities necessary to fulfil the demand by customers.

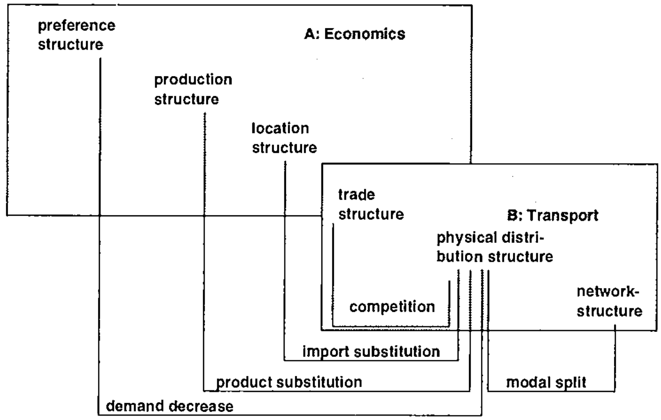

Figure 1 - Global modal structure of SMILE

In general, a distinction can be made between product logistics and transport logistics. Product logistics has to do with the control of good flows from basic products, via inventories and intermediate production activities till the physical distribution of final products to the customers. The whole logistic process as such consists of several repetitious activities involving the basic activities Production, Inventory and Transport. Transport logistics involves the optimisation of the organisation of freight flows so that the utilisation of transport equipment is optimised, considering costs and quality elements such as reliability and speed.

With SMILE, some first steps have been taken to resolve the shortcomings in knowledge about the relationship between production, inventory and transportation by a three level chain modelling approach. The first level concerns the linkage between manufacturing activities within product chains, the second concerns the modelling of stockholding within distribution chains and the third relates to the movement and transshipment of goods within (multimodal) transport chains. Below we explain how these three levels have been operationalised in the model.

Production, Sales and Sourcing

At the first level, Make/Use Tables create the opportunity to set up a production function for each sector (if the sector produces only one commodity group for each commodity). In contrast to the prevailing models of sectoral exchanges of goods, in the SMILE model the conventional Input/Output modelling approach has been abandoned. The available Make/Use tables provide a detailed insight into the production factors connected to the activity of each sector, including the commodities that are produced and consumed. By linking production and consumption, product chains can be built that, when combined further, result in production networks.

One of the main features of the SMILE model is the application of these production functions in the assessment of the effects of a change in final demand for one product group on all the others, through the production network. This new approach allows to trace e.g. the effects of a 20% replacement of steel by composites in the car manufacturing industry on the volumes of freight flows. Moreover, the Make and Use Tables are very helpful in establishing the location pattern of both production and consumption.

After having determined the volume and nature production and consumption at different locations, the spatial distribution of flows between these locations is calculated. This spatial distribution results from the sales and sourcing processes at each location. As trade theory tells us it is a result of comparative price differences and the resistance of geographical, organisational and institutional differences that have to be bridged. This part of the model provides the user with the trade relations in connection with the Netherlands.

Inventory

The main function of the second level is to link trade relations to transport relations by considering warehousing services. Here, distribution chains are described by a logistic choice model. Several configuration options for distribution chains are investigated (see figure 2), which are characterised by the number and location of distribution centres.

In the choice model, total logistic costs are calculated that account for handling, inventory and transport costs for homogeneous product categories denoted as logistical families. A survey on product characteristics has been undertaken to support the model with real-life data; its results clearly show the relevance of distribution chains for modelling freight transport demand, as for almost half of the 300 products investigated, the same type of distribution centre (continental, national or both) was in use.

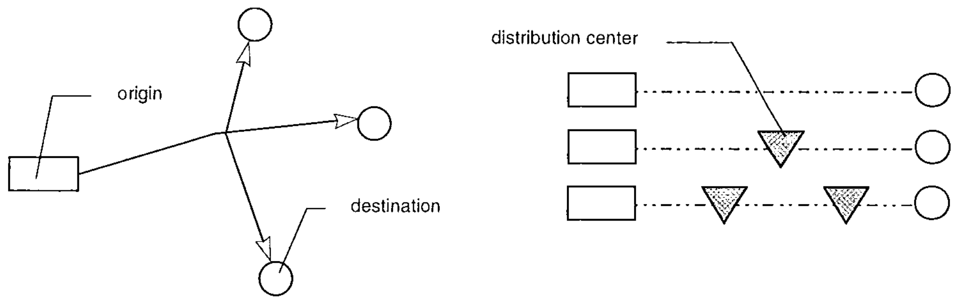

Figure 2 - Optional distribution structures

Following the survey, new groups of products and market conditions were identified in which it is reasonable to assume that within these groups logistic choice behaviour is homogeneous. At present logistic families are distinguished using a large number of product and market characteristics, as pictured in figure 3 below.

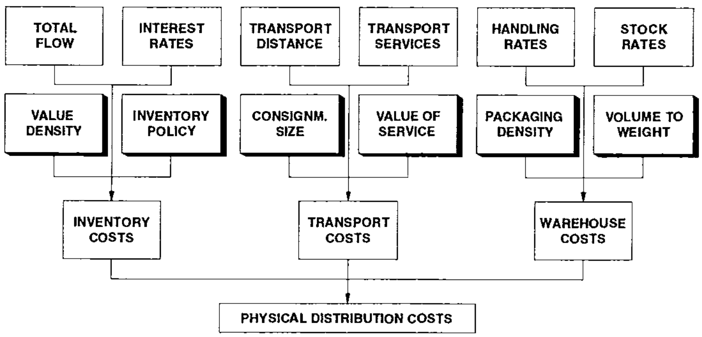

Figure 3 - Calculation of logistics costs

The authors would argue that in aggregate freight transport system modelling, this issue has not received the attention it deserves, particularly if one looks at the ongoing trend of "reconfiguring European logistics systems". The existing aggregate modelling approaches that combine production and network modelling do not represent this second level. Neglecting this level may adversely affect the accuracy of modelled freight flows as well as the policy sensitivity of the model.

Transportation

At the third level, a multi-modal network for 6 modes of transport is available in SMILE. It is a strategic network which means that only the network structure is modelled. Not all alternative links between regions are visible to the user, but only one representing all alternatives.

The underlying network however (that is used for calculations) is modelled in analogy with the physical network. The figure above illustrates this network type for three modes. The optimal route in SMILE will be sought for every commodity type, and for every element in the logistics chain. The route choice disutility has a mode abstract (see Quandt and Baumol, 1966), weighted cost formulation where a combination is made of the physical distribution costs and time spent during transportation.

The weights which are used are specific per goods type and reflect the opportunity costs of the resource "time" within the entire logistics process. Comparing this model with existing approaches in physical distribution (see e.g. Goss, 1991, Higginson, 1993; Mc.Ginnis, 1989; Jourquin, 1995, Vieira, 1992) this formulation is new within this complex setting (using empirical values for 50 logistical families, reflecting total logistic costs including estimated random preferences).

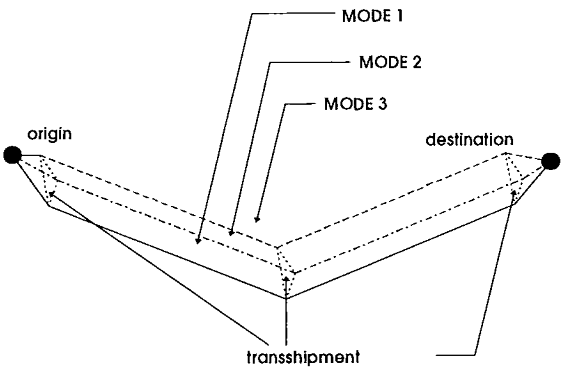

Figure 4 - Multimodal network

Dynamics

Do we wish to give a forecast for one point in time or do we need information on the growth patterns of system variables? Insight in growth patterns gives insight in the existence of saturation levels and equilibrium mechanisms. Although two scenarios may produce similar results for a specific forecast year, they may show a completely different development in the years before and after the forecast year. The understanding of these dynamics is at least as important as the exact prediction of the levels in the horizon year under study.

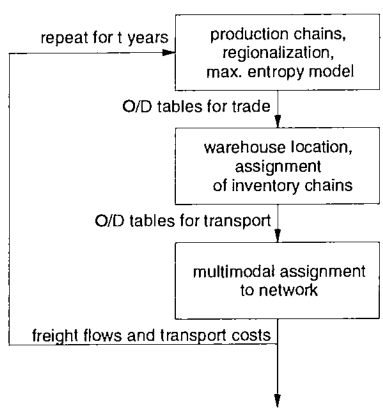

Figure 5 - Simulative modelling approach

The above stages of production, distribution and transportation form three steps in the calculation process that are repeated in a cyclical simulation process, as illustrated in the figure above. Each simulation cycle represents a time span of one year; a complete simulation results in time series data related to transport flows and costs. Naturally, the intermediate output concerning economic activities concerning the exchange of goods and the logistics service markets are obtained in a similar way and stored in the SMILE database.

PRACTICABILITY

The above examples give an idea of the structure of the SMILE model. In this section we will treat in more detail the possibilities for interaction between the DSS and the user. In order to use the model, its should provide sufficient possibilities to specify and analyse different scenarios, related to socio-economics as well as transport and logistics. Therefore, attention has been devoted to modules which smooth the input/ output interaction between user and the system (a scenario module and a presentation module) a database management system and the graphical interface. The transport and economy modules form the logistics model and have been discussed in the previous sections; below we concentrate on the other facilities of SMILE.

Database

The database was implemented in Microsoft Access and can be accessed in three different ways: firstly, the processing of data for the calculations; secondly, through the graphical interface and thirdly, data can be accessed by means of a number of commercial database packages. The relational database contains data on:

- structural elements, concerning topological, physical and logistical characteristics of
- 542 types of products, sorted into 50 logistical families
- networks of road, rail, inland waterways, air, pipelines and sea transport
- around 77 regions in the world, of which 40 in the Netherlands
- variables concerning relationships
- sectoral and spatial exchanges (production functions and O/D tables)
- parameters of logistics choice functions

Scenario design

By means of the graphical user interface, the DSS assists the user with designing his/her own scenarios for simulations up to 35 years ahead and shows the impacts of policy measures on freight flows and the environment. Scenarios can be stored as a complete database of all variables used by the model, i.e. including a complete specification of the modelled world of the user. In order to assist the user in his steps with specifying the transport system for a 35 year period, reference scenario's were built. When specifying a scenario the user is guided in choosing variables by means of selection screens and input screens, where the baseline or reference scenario's chosen are shown.

These reference scenarios are derived from general economic scenario's as have been developed by the Dutch Central Planning Agency (CPB). They represent the economic environment in which the freight demand model is further specified. The user is assumed to define certain policy options or exogenous interventions in the system that create specific changes in the cost structures and choice options available. These exogenous changes are checked upon internal consistency and then used to create a scenario, if available, using outcomes of earlier scenario calculations as reference.

A (geo)graphical interface

SMILE operates within a Windows 95 or Windows NT environment. Beside the standard Microsoft interface, specific applications were developed to aid the user in specifying the input to the calculations. In order to picture regions and networks throughout the world, a geographical interface is required. The main development concerns an application that compares to a Geographic Information System (GIS) environment. In fact, the main practicality of a GIS, an integrated treatment of geographical database with processing and visualisation facilities is available in SMILE, not in the least due to the relational structure of the database. Figure 6 gives a view on the features that will be provided by these applications.

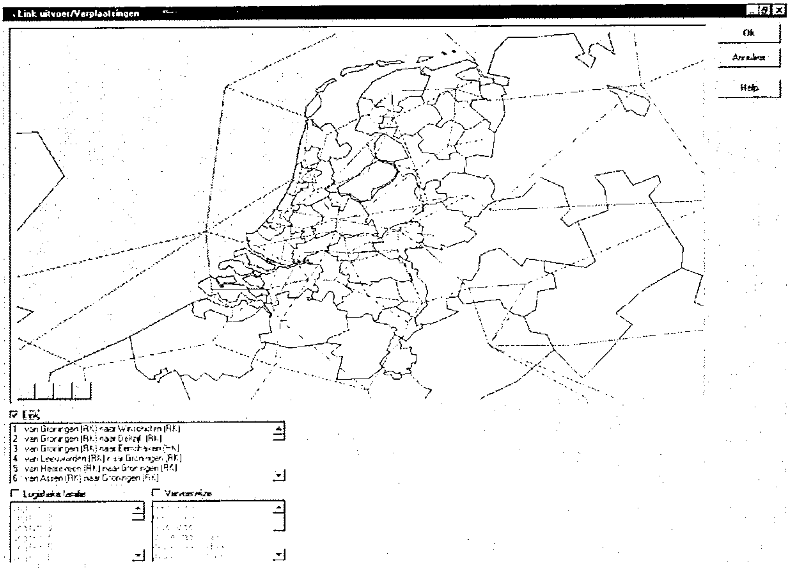

Figure 6 - Interface to region and transport network selections

Possibilities for policy analysis in SMILE

Recent research in the Netherlands has indicated that existing models - although fairly sophisticated in the sense of the detailed description of the transport system - lack policy sensitivity in terms of the ability to be used for calculating the impacts of alternative policy measures (Tavasszy, 1994). In order to support policy analysis, one should be able however, to intervene at certain points in the model that reflect real world elements like infrastructure, regulations, or services.

The forecasting of transport flows is the main task of SMILE. In addition, SMILE make it possible to analyse logistical choices. This is an important improvement compared with traditional models based on transport flows. In this way anticipated behaviour, like the use of a Central European Distribution structure can be incorporated.

The scenario and import/export modules allow changes to be made in several variables related to prices, capacities, service performance levels or the users' preferences in the system. A listing of the input and output variables for policy analysis is given in the table below. These variables can be changed per year and per commodity group (at the product or logistical family level), where applicable.

Table 1 - Input and output variables of SMILE

INPUT
• supply aggregates (production value, consumption, export)
• structural economic changes (import share, production functions, supply categorisation)
• spatial aggregates (domestic production, consumption, wholesale, import, export)
• elasticities (spatial interaction, distribution channel choice)
• cost factors (storage, inventory, transport, handling)
• product characteristics (value density, packaging density, perishability, delivery time, shipment size, demand frequency)
• traffic and network characteristics (access and egress, transport and transshipment performance variables, link lengths, capacities, unitisation and loading degree factors)
OUTPUT
• regional production and consumption
• trade
• logistics activities
• transport and traffic
• associated integral transport costs
• environmental impacts of freight flows.

AN APPLICATION: QUESTA

In 1998 the first major application of SMILE has taken place. *Questa, Transportation in the Future* is a project of the Ministry of Transport in the Netherlands [Ministry of Transport, 1998] which resulted in four scenarios of possible futures in the Netherlands in the year 2030:

- Free state, a scenario in which the economic growth is modest and the European integration was not very successful;
- Unrestricted, A scenario in which the Netherlands realise a high economic growth and the world trade is growing at a high rate;
- Quality of life, a scenario in which sustainable growth is very important, the economic growth is above the current trend and the European integration is successfully;
- Polderland (consensus), a scenario in which the Netherlands realises a moderate economic growth while the European integration is successful

These four scenarios describe the changes to take place within the Dutch society, including changes in the technological, social, cultural, demographic, economic as well as environmental systems. As far as these developments were deemed to be relevant for the economic, logistical and transportation sector, they were translated into model variables. This phase of the project, the translation of the scenario developments into model variables was the most critical step to come to the description of scenarios for transport and logistics. The fact that SMILE has a wide scope and an extensive number of variables made it possible to implement the four scenarios.

To give an impression of the results of the *Questa* project figure 7 and figure 8 show the development of vehicle kilometres and the tonkilometres in the Netherlands. The difference in the growth pattern between vehicle and tonkilometres in the scenario's Quality of life and Freestate is caused by the increased efficiency in these scenario's. For example: in Quality of Life and Freestate the utilisation rate (empty milage and load factor) increases over the years. Explaining the difference between the two growth patterns in Polderland is more complicated. Two dominant factors cause this discrepancy: the use of distribution centres in the chain or the mode/route choice.

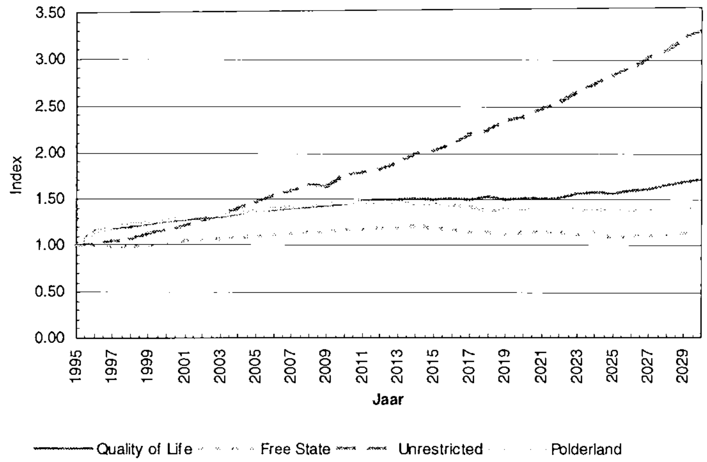

Figure 7 - Simulation results: vehicle kilometres in the Netherlands 1995-2030

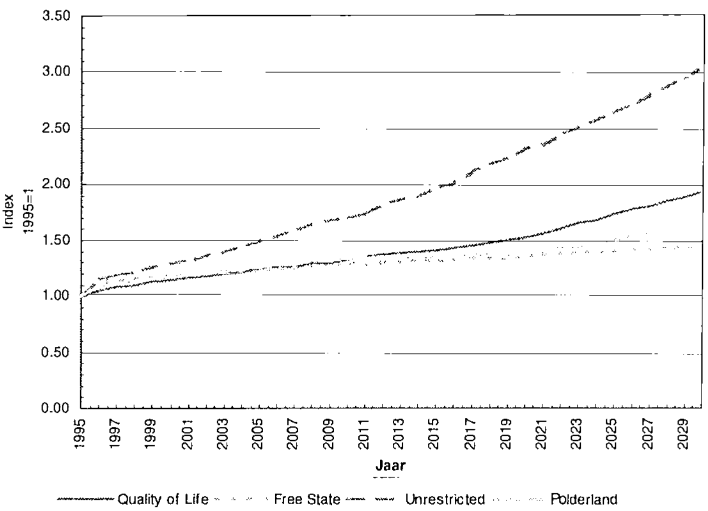

Figure 8 - Simulation results: tonkilometres in the Netherlands 1995-2030

Forecasting the transport flows and the modal split was the main objective in this project. In addition, SMILE made it possible to analyse the impacts of the economical and logistical choices of companies as hypothesised in each scenario. This proved to be a an important improvement compared with traditional models of transport flows. In this respect we were able to study changes in determinants of transport demand, including the cost sensitivity of consumers, transportation efficiency and the use of distribution centres.

CONCLUDING REMARKS

The conclusions of this paper are as follows.

- We have proposed a Decision Support System for freight transport and logistics which aims to fulfill many requirements of policy makers with respect to studying complex problems in freight transport policy analysis.
- We have shown that SMILE fills a gap in present modelling practice, emphasising, however, that the state of research conceming the representation of logistics processes in freight transport modelling can be improved further.
- We have presented the results of an application of the model for the Dutch Ministry of Transport, which shows that this type of modelling research satisfies actual demands of policy makers when it comes to long term scenario building.

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