ASTRA

Assessment of Transport Strategies

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Abstract

The ASTRA project is part of the research studies awarded by European Commission Directorate General VII - Transport - in the IV Framework Research Programme.

The ASTRA project is in charge for enhancing present abilities of analytical tools and models to support strategic assessment of non-marginal impacts of transport policies and infrastructure investments. In order to investigate such impacts, the interaction among the different sector tools - transport, environment, location and regional economics, macroeconomics - cannot be ignored. In fact the more transport policies and investment are deemed to be important for society and economy, the higher is the degree of integration required to allow for sector tools to exchange relevant inputs and outputs. This interaction could also guarantee that the assessment of the overall range of costs and benefits is operated in a consistent and cost-effective way.

A Systems Dynamics approach has been then adopted to represent how specific impacts are passed through different sectors of the overall system under analysis, also to handle feed-backs between functions as well as time dependence of critical functions.

1. Introduction

The ASTRA project started in October 1997 and will end in January 2000. It is carried out by a consortium composed by IWW, Institut für Wirtschaftspolitik und Wirtschaftsforschung, Universität Karlsruhe, Germany (project co-ordinator), TRT Trasporti e Territorio, Italy, Marcial Echenique & Partners, United Kingdom and CEBR, Centre for Economics and Business Research, United Kingdom. The project is also co-funded by Federtrasporto, Italy.

The aim of ASTRA is to develop a tool for analysing the impacts of the Common Transport Policy (CTP) including secondary and long-term effects. For this purpose the System Dynamics modelling method is applied. By using the commercial system dynamics software package *ithink* the ASTRA System Dynamics Platform (**ASP**) is developed. The ASP integrates key relationships of state-of-the-art models in the fields of macroeconomics, regional economics and land use, transport and environment. It is composed of the four sub-modules: macroeconomics sub-module (**MAC**), regional economics and land use sub-module (**REM**), transport sub-module (**TRA**) and environment sub-module (**ENV**). Results of the conventional[1] models are used for calibration of the ASP sub-modules.

For reasons related to the schedules of the ASTRA project and the Conference, it is possible in this paper to describe the methodology only, while results will be covered in the oral presentation.

2. Overview on the model structure

In sciences real systems usually are split up and allocated to different disciplines. This way of scientific division of research - often referred to as the Descartes-type of structuring scientific analysis - abstracts from the interrelationships between the elements of the system and the dynamics, which are induced by feedback mechanisms. E.g. this concerns many of the available tools and models for assessment of different types of impacts from transport policies and investments. These conventional models are constantly up-graded to support assessments in terms of analysing and forecasting impacts that are internal in the transport sector - such as on transport demand and modal choices, modal capacity and traffic level and patterns. Also, in an increasingly number of applications transport models are being used to assess transport related impacts on environment as well as on location choices of both families and firms. But other interrelationships e.g. between transport and macro-economics or between location choices and the transport system (vice versa then mentioned before) are often treated as exogenous or not existing. Here lies the field of application of system dynamics (Forrester, J.W.) because it is one of the few tools, which are able to re-establish these interrelationships and to tie together the elements of reality in one model again.

For instance the development of GDP will usually be taken exogenous for all conventional models except the macroeconomic models. But in ASTRA GDP is modelled endogenous within the macroeconomics sub-module and results are passed onto the regional economics sub-module. This may influence transport demand, while the changes in transport may change GDP. This is only one example of an interface between the four ASTRA sub-modules. These interfaces form an added value of the project besides the application of a system dynamics approach and the long-term perspective of the assessment.

The ASTRA System Dynamics Platform (ASP) is not designed as a stand-alone system dynamics model. Instead it integrates for sub-modules, which are regarded to be the most important systems of reality that have an impact on the assessment of the Common Transport Policy (CTP) of the European member states. The four real systems are:

- **Transport system** as a basis for modelling transport infrastructure and traffic volumes.
- **Regional economics and land use** because of the relationships between regional development (business, housing), transport and environment.
- **Macroeconomics** to integrate national or continental level influences into the model.
- **Environmental system** because of the relationships to the transport system and the importance for the national welfare position.

The development of the ASP is based for each of the sub-modules on state-of-the-art model, that are developed by the partners independently from the ASTRA project. Therefore one of the basic tasks of the ASTRA model development is to identify the key functions of these models and to transfer them into a format that can be applied within a system dynamics model. This approach is shown in figure 1:

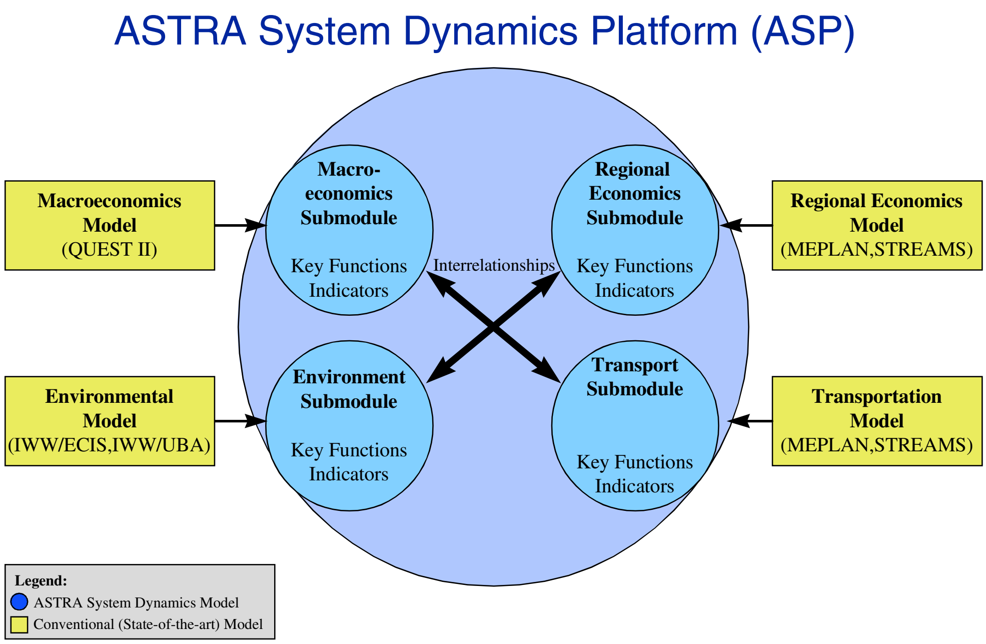

Figure 1: Structure of the ASTRA approach

The demand for spatial representation of these four sub-modules is very different. The macroeconomics models work on a highly aggregated basis, while the transport models use a network approach. The environmental models could be applied as well on aggregate models as on disaggregate network models. Therefore creating the ASP a very important task of the modelling process is to define the spatial representation within the model.

For the MAC a clustering with 5 *Macro Regions,* which are aggregations of the EU15 member countries together with the rest of the world is applied.. For the models including the transport model (REM and TRA) two different representations for passenger and freight transport are applied, because they depend on different characteristics (e.g. population and industrial production). The ENV also reflects in part this division into a passenger and a freight model. For the passenger model within REM, TRA and ENV a clustering with 6 *Notional Zones* is applied that is based on the settlement patterns of the EU NUTS II zones. For the freight model the zoning system is based on the 5 Macro-regions. The transport system is represented by *Distance Bands*, which consider different modal choice alternatives and different driving patterns in dependency of the trip length.

3. The dynamic process

In general, the ASTRA System Dynamics Model Platform (ASP) is working as follows. The macroeconomics sub-module (MAC) estimates the economic framework data of the EU respectively the member countries. The results of the MAC key indicators (e.g. GDP, employment) are transferred to the regional economics and land use sub-module (REM). Within the REM basic data for transport demand modelling (e.g. car-ownership) is calculated. This forms the input of the first two steps of the classical 4-stage transport model: trip generation and trip distribution on the basis of the previously described spatial representation.

The resulting transport demand is transferred to the transport sub-module (TRA), which includes the final two stages of the transport model: modal split and assignment. The environmental sub-module (ENV) is mainly fed by data from the TRA (e.g. traffic volumes). It includes the vehicle fleet models. Environmental indicators (e.g. CO_2 emissions) are calculated and the welfare consequences performed by the environmental impacts are estimated.

It has to be emphasised that the data between the sub-modules is not transferred as a complete time series over the whole simulation period. Instead data calculated at a certain point of time - called integration period DT - is transferred between the sub-modules. The data can be used in the other sub-modules for the calculation of variables within the same integration period, of variables in the next integration period or, if there are time lags included in the model, of subsequent integration periods. That means, the MAC does not calculate all GDP values between 1986 and 2026 in one time series before the transfer to the REM. Instead it calculates the GDP, for instance, for the third quarter of the year 1987. This value is transferred to the REM and the TRA, which calculate the transport demand and the transport cost in the third quarter of 1987. Assuming that there is no longer time lag included in this feedback structure the transport cost of the third quarter are transferred to the MAC. Within the MAC they form an input of the calculation of GDP of the fourth quarter of 1987.

4. The spatial structure

In the passenger model, six functional zones were defined based on settlement type, bearing in mind the need to distinguish origin/destination pairs which have a specific transport relevance (Verroen, 1993). The functional zoning scheme implemented for the passenger model is as follows (acronyms in parenthesis are those used within the SDM):

- Large Stand Alone Metropolitan Centres (**LSA**).
- Metropolitan Areas Plus Hinterlands (**MPH**).
- High Density Urbanised Areas (**HDU**).
- High Density Dispersed Areas (**HDD**).
- Medium Density Regions (**MDR**).
- Low Density Regions (**LDR**).

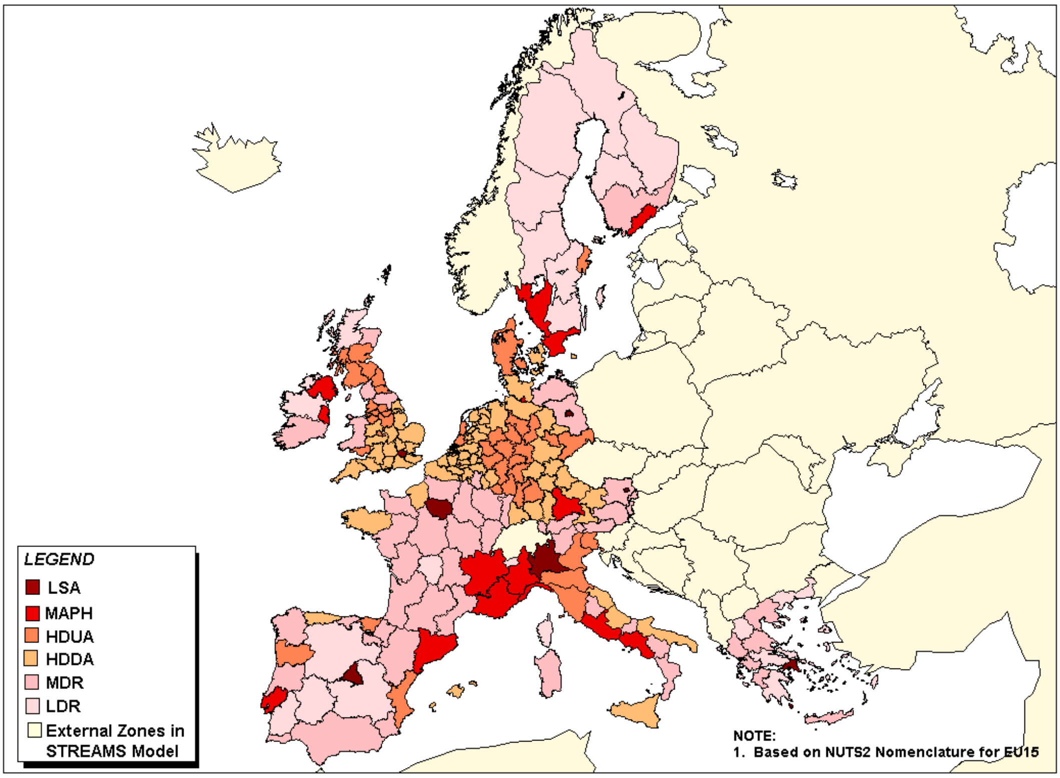

Figure 2: Functional zoning scheme for ASTRA System Dynamics Model Platform (ASP)

5. The distance bands

When applying a classical transport model based on a geographic zoning system, modal split is performed for each origin destination pair according to the attributes of the transport modes: distance, cost, time, modal constant, etc. Among these characteristics, travel distance plays a significant role as both time and cost of the passenger or freight movements depend on it. At the same time, the amount of transport demand between two zones depends also on the existing distance (or better on the travel time): the closer the two zones, the more they will exchange passenger and transport flows.

When adopting a functional zoning system, distance between functional zones is no longer significant. Indeed functional zones represent clusters of zones which are homogenous with reference to population density, city dimensions, etc. Hence the distance between different functional zones (a cell of the functional zones matrix) would be represented better by a distribution function more than by a single average value, according to the actual couples of geographic zones belonging to the two clusters.

The operational solution adopted in the ASTRA model was to break the distance dependence of the travel pattern into slices. In this way it is possible to work with the single slice using average values without losing significant information. The trip distribution component of the REM sub-module and the transport sub-module TRA were divided into sectors differentiated according to distance classes: transport demand is generated by the REM for the different purposes and for the different distance bands corresponding to each origin/destination pair of the functional zones, this data is then used by the transport sub-module.

Different distance band sets were used for the passenger and freight models. This is justified from statistical evidence that the modal split by distance for passengers and freight demand are very different, such that for freight it is not necessary to make reference to disaggregate distance bands below a certain threshold. However for passengers the modal split for short distance journeys, which makes up a large proportion of passenger trips, is very important.

In the passenger model, five distance bands were derived from the analysis of the National Travel Surveys of European member states (STREAMS, 1999):

- local (distances below 3,2 km),
- very short (distances between 3,2 and 8 km),
- short (distances between 8 and 40 km),
- medium (distances between 40 and 160 km),
- long (distances longer than 160 km).

In the freight model four distance bands have been selected according to a statistical analysis of the trends in length of freight movements in the EU15 which revealed a general increase in the length of freight trips. The four distance bands are as follows:

- short (distances below 50 kms),
- short medium (distances between 50 and 150 kms),
- long medium (distances between 150 and 700 kms),
- long (distances longer than 700 kms.)

6. The four ASTRA sub-modules

6.1 Macroeconomics Sub-module (MAC)

The macroeconomics sub-module is divided in two main parts: the description of the demand and the supply side. Both can be used to get the national income, as it is conventionally defined. At the moment, demand is split in the four main demand sectors: investments, consumption, state expenditures and foreign trade. Supply is split in the three production factors natural resources, labour and capital and there is also an influence of productivity on the supply side. Probably this broad approach could be broken down further by splitting the demand sectors as well as the production factors with the result of a rough macroeconometric dynamic model approach.

6.2 Regional Economic and Land Use Sub-module (REM)

The purpose of the REM is to represent the fundamental mechanisms that generate the demand for travel. The primary hypothesis that underlies the form of models of this type is that:

> *For most journeys travel is not and end in itself. Rather, travel is a derived demand. In order to carry out a variety of discretionary and compulsory activities it is necessary for people to travel or for goods to be transported.*

Therefore the REM should represent these underlying activities in sufficient detail to enable the resulting demands for transport to be estimated to the level of precision required. The implication here being that the model should contain sufficient detail on:

- the location of the actors which give rise to the demand/ consumption of activities (households, firms);
- the location of the supply/ production of the activities that meet these demands (shops, schools, labour, goods);
- the characteristics of the transport required between production and consumption

Such that the demand for, and supply of, transport is segmented into reasonably homogenous categories to allow patterns of demand for travel to be estimated realistically.

6.3 Transport Sub-module (TRA)

The transport sub-module is composed by five passenger sectors and four freight sectors. Sectors are built according to distance bands in order to retain the different travel patterns occurring in passenger trips or freight shipments with different average distances. Within each trip distance related sector, the relevant trip purposes or freight categories are analysed separately, i.e. a specific modal split is modelled for each purpose/ category.

Three passenger travel purposes (commuting&business, tourism and personal) have been selected. The passenger transport sub-module tries to represent all transport flows - from local movements to long distance journeys - and includes: slow modes, car, bus, train and air. Obviously not all modes are represented in each distance band sector, i.e. tourism flows are modelled for long distance movements only.

The four freight sectors are aggregated into a set of homogeneous handling categories on the basis of the value of time, the handling and the carriage requirements of each commodity. Transport modes modelled are: trucks, rail/inland-waterway and shipping. For the need of simplification, minor modes have been ignored.

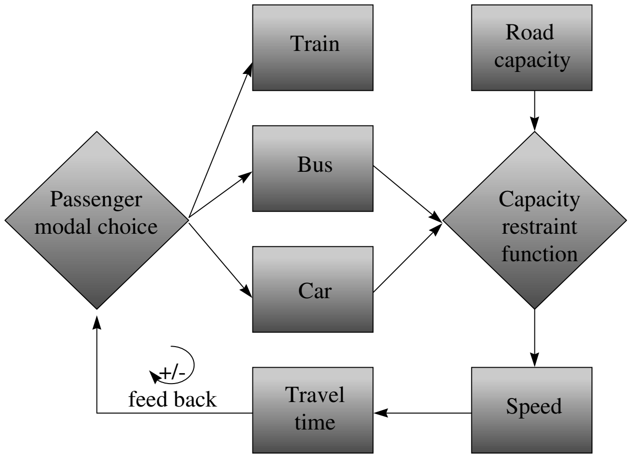

Figure 3: Interaction among passenger sectors and road network sectors

The modal choice is based on the generalised costs associated to each mode of transport which in turn are calculated according to transport times and costs. The choice process is simulated using a multinomial logit model (MNL). In each distance related sector and for each trip purpose or freight category, the calculation of the generalised cost derived from the monetary cost, which depends on the specific average distance, and the time, which is either exogenous for non road modes or calculated endogenously for road modes - according to the ratio between the number of vehicles and the road capacity in the previous year (T-1).

Two different sectors are devoted to the modelling of road congestion: the local road network sector and long distance road network sector. Each of the sectors simulates the congestion at its own scale.

6.4 Environment Sub-module (ENV)

The objective of the ASTRA environment sub-module is to calculate the environmental burdens caused by transport in the EU respectively in the notional zones of the ASP and to provide information for the assessment of the effects of these burdens on the whole economy and the development of regions. For this purpose three kinds of environmental impacts should be treated by the environmental sub-module:

- Global Impacts,
- Impacts on Human Health and
- Ecological Impacts.

Different environmental burdens are effecting different spatial scales: global, regional and local. The estimations of global environmental impacts are simple to integrate in a system dynamics model, because there is no spatial dispersion for the effect to be quantified. But regional or even local effects will be more difficult to integrate them in a system dynamics model, because spatial dispersion has to be modelled.[2] Integrating these effects increases complexity of the model or needs simplification and therefore might decrease accuracy of the model.

The described structure of the environment sub-module is shown in figure 4:

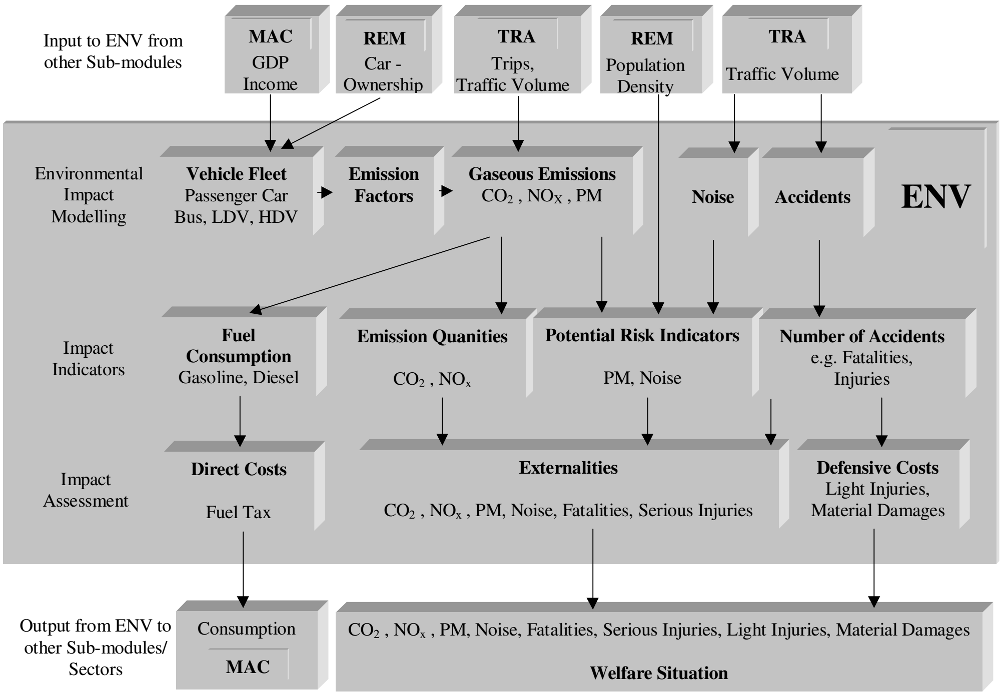

Figure 4: Structure of the Environment Sub-module (ENV)

7. Interfaces between sub-modules

The flows of information among the different sub-modules of the ASTRA system dynamic platform are extremely important. Through the exchanges of input and output among the sub-modules it become possible to model the reciprocal impacts and the feed-backs among the different sectors.

Between MAC, REM and TRA there exist several interfaces that are characteristic for either the passenger model or the freight model. Therefore the interfaces are presented within two different diagrams. The first diagram (figure 5) presents the main relationships that influence the passenger model.

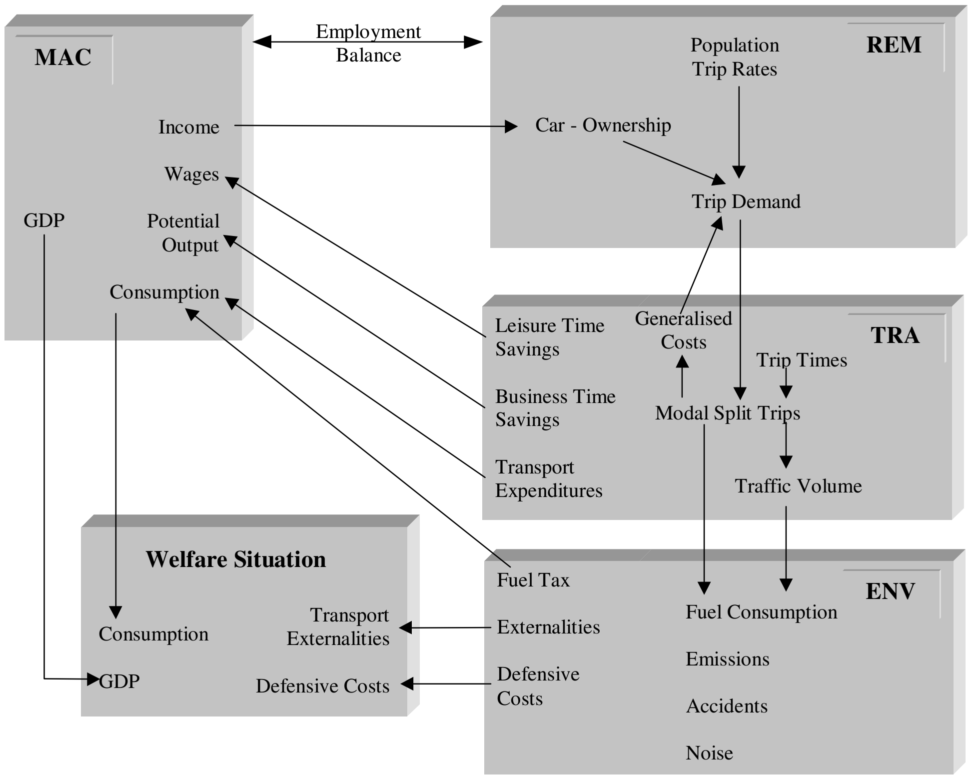

Figure 5: Aggregated Relationships of the Passenger Model

Mainly the development of disposable income influences the car-ownership. Together with the population development (distinguished into age classes) and the trip rates (dependent on household types) the car-ownership drives the trip demand. The demand is transferred to the TRA where the modal-split (dependent on times and costs) and assignment is determined. The output is the number of trips and the traffic volume of the different passenger modes. Based on this output transport expenditures, business and leisure time savings are calculated and transferred to the MAC. Within the MAC the time savings form an input for the calculation of potential output and wages. The transport expenditures are part of consumption. Trips and traffic volume are also transferred to the ENV where indicators for fuel consumption, emissions, accidents and noise are calculated. Based on the fuel consumption the fuel tax is calculated and transferred to the MAC where it forms part of the consumption. Externalities and defensive costs of emissions, accidents and noise are estimated and form a part of the welfare situation. Within the MAC the other indicators that describe the welfare situation are calculated. These are GDP and consumption.

The second diagram (figure 6) presents the main relationships that influence the freight model.

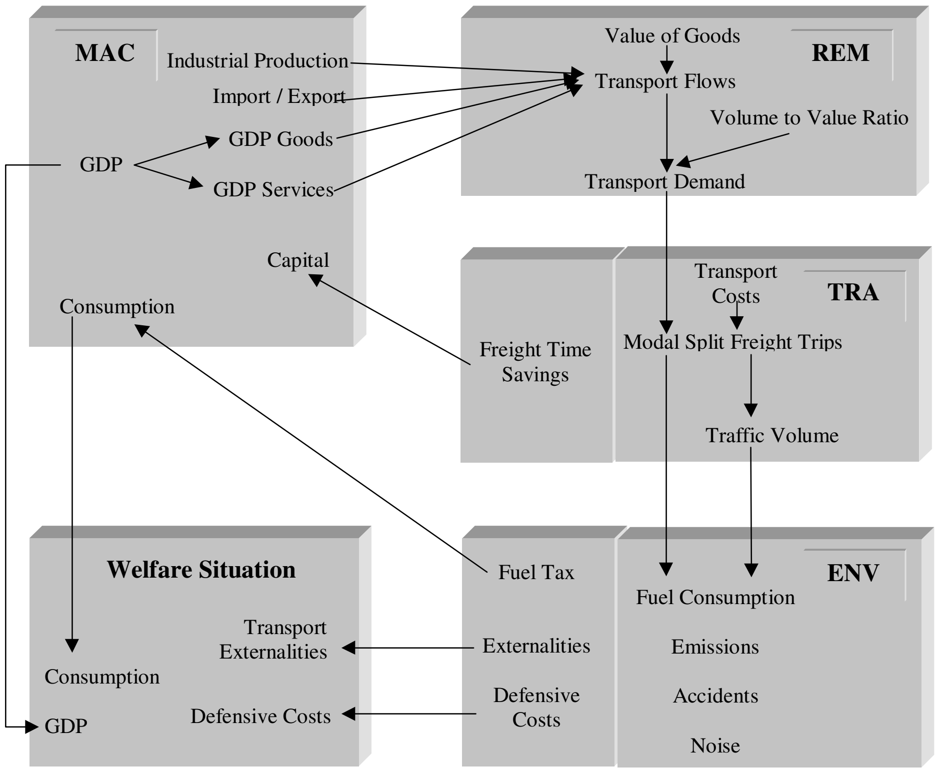

Figure 6: Aggregated Relationships of the Freight Model

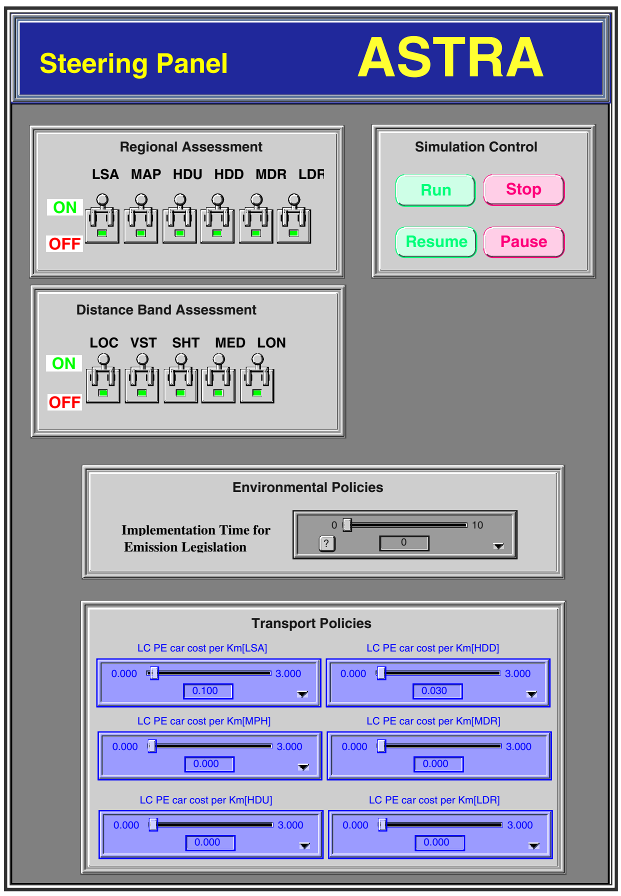

Figure 7:Screen shot of ASP steering panel

7. Implementation and results

The implementation in *ithink* now comprises all four sub-modules (MAC, REM, TRA and ENV) as well as a special sector to present the development of the welfare situation. The presentation of the *ithink* model has to be done by normal but aggregated diagrams.

Ithink provides three levels for model development. On the top level it is possible to create a user-interface with a user-friendly handling to test different policies. For the assessment of policies a control panel is in parts developed on the top level of the ASP. The control panel consist of a steering panel, a display panel, a logic analyser panel and a parameter panel. With the steering panel model simulation runs are started and controlled. Also the policies can be varied on this panel. The current version of the panel that is shown in figure 7 consists of the main simulation control box, the environmental policy box, the transport policy box and the regional and distance band assessment boxes. The simulation control box is used to start, pause and stop simulation runs. The other boxes are used to set model parameters or policy parameters. For instance the distance band box consists of five switches to set the model parameters such that the environmental indicators are only calculated for the distance bands that are switched on. The regional assessment box behaves similar.

9. References

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[1] The state-of-the-art models are referred to as *conventional models* in contrast to the denotation *system dynamics models*.

[2] Examples for the spatial modelling of local effects on a regional scale are presented in IWW et al. (1998)