1 Introduction

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 Vensim 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.

The first approach using the ithink system dynamics software package could not successfully be completed with an integration of all sub-modules as the size of the ASP exceeded the size limit of ithink. Therefore the ithink version of the ASP is limited to a core model consisting of MAC, REM, TRA and the car vehicle fleet model of the ENV.

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 macroeconomics 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 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.

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

2 Executive Summary

The purpose of deliverable 4 is to present the ASTRA methodology. A description of methodology includes a representation of the model, called the ASTRA system dynamics model platform (ASP), as well as a portrayal of the usage of the model for demonstration examples. The ASP can be categorised as system dynamics model for integrated long-term assessment of the European transport policy with a spatial representation on a functional basis.

The ASP integrates the macroeconomics sub-module (MAC), regional economics and land use sub-module (REM), the transport sub-module (TRA) and the environment sub-module (ENV) into one model. The passenger model and the freight model are implemented such that they are formed by parts of REM, TRA and ENV. Each sub-module is subdivided into several sectors. This structure of the ASP is shown in figure 1.

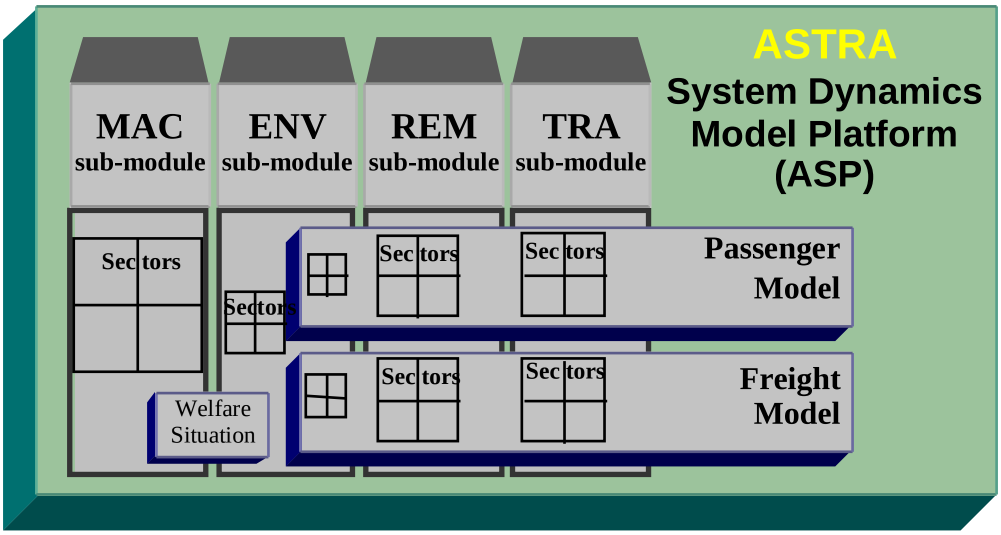

Figure 1: Structure of the ASTRA System Dynamics Model Platform (ASP)

The ASP is implemented in two versions: a full Vensim version and a core ithink version. This was necessary to overcome size limits of the ithink software. The full Vensim ASP integrates all four sub-modules and the welfare situation. It is the final outcome of the ASTRA project and as such the main object described in this deliverable. The core ithink ASP comprises the complete MAC, REM, TRA sub-modules and the car vehicle fleet model from the ENV. Considering policy simulations the capability of the core ASP are restricted to the explanation of transport and economic consequences. Environmental effects, technological improvements and changes in the welfare situation can only be observed with the full ASP.

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 4 *Macro Regions* is applied that is based on the geography of 15 NUTS 0 zones. For the passenger model within REM, TRA and ENV a clustering with 6 *Functional Zones* is applied that is based on the settlement patterns of the 201 NUTS II zones. The transport system is represented by five *Distance Bands*, which consider different modal choice alternatives and different driving patterns in dependency of the trip length. For the freight model within REM, TRA and ENV a clustering with 4 functional zones is aspired. The freight clustering scheme is also based on the macro regions. The freight transport system is represented by four distance bands that consider the different modal choice alternatives for freight transport. The road transport network is divided into an urban-network and a non-urban-network on which passenger and freight transport are competing.

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. population, car-ownership) is calculated. Both data 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 a simplified assignment. The environmental sub-module (ENV) is mainly fed by data from the TRA (e.g. traffic volumes). It includes the vehicle fleet models and models for description of changes in technology. Environmental indicators (e.g. CO_2 emissions) are calculated and the welfare consequences performed by the environmental impacts are estimated in the ENV. Finally the aggregated welfare situation based on economic, social and employment indicators is presented. All model variables (e.g. GDP, transport performances, emissions) are calculated as time series from 1986 to 2026, where the first ten years are used for initialisation and calibration of the ASP and the forecasting period lasts from 1996 to 2026.

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.

The use of the model is explained with the Vensim ASP by undertaking and presenting demonstration examples. The ASTRA demonstration examples cover a reference scenario, five policy packages consisting of sets of policy measures and an integrated policy programme comprising most of the policy packages. The five policy packages can be described as:

- Improved emission and safety policy package,
- Increased fuel tax policy package,
- Balanced fuel tax policy package,
- Rail-TEN policy package and
- All-TEN policy package.

The policy packages are designed such that they fit to the general framework of European transport policy. With the chosen packages it is aspired to take advantage of the special capabilities of the system dynamics methodology. The scenarios address policy decisions in the field of taxation, construction of the TEN, mitigation of air pollution and increase of safety of transport. Briefly summarising the results the integrated policy programme (IPP) produces the best results considering the whole range of economic, environmental and (un-)employment indicators. But it seems that also with the IPP environmental sustainability is not reached.

The deliverable is structured into five parts. The first part introduces the ASTRA project and summarises this deliverable. In the second part the ASTRA methodology is demarcated from and compared to other approaches. In the third part an overview on the model is presented and the features of the model that are used in more than one sub-module are described. In the fourth part a description of the modelling approaches of the four sub-modules, the output of the sub-modules and the calibration approach for each sub-module are given. The fifth part presents the policy framework for the demonstration examples, the results for the base scenario, approach and results for the five policy packages and the integrated policy programme as well as results for some sensitivity tests. In a sixth part the ASTRA-TIP an easy-to-use tool for presentation of the results is described. The deliverable concludes with an outlook on planned work and improvements followed by the conclusion. Additionally to this deliverable detailed information about the sub-modules, the scenario implementation and the ithink core ASP is integrated in one separate appendix with three parts: in the first part additional explanations and input data on the implementation of the four sub-modules is given, in the second part further data for the scenario and policy description is included and in the third part structure and difference of the ithink core ASP are explained.

ASTRA

Methodology

3 Demarcation of ASTRA Methodology

The ASTRA approach can be demarcated from other approaches with four significant criteria. Models can be distinguished at least in two groups: partial or specialised models and global or integrated models. The ASTRA model belongs to the latter group of models, as the model integrates transport with three other research fields (macroeconomics, regional economics and environment) that influence or that are influenced by the transport system.

The second criteria is the time scale. Models can be designed to work on a short-term, a mid-term and a long-term time horizon. ASTRA is constructed such that it can be applied for the long-term time horizon with a forecasting period from 1996 to 2026. With minor completions even longer time horizons might be applied at least for sensitivity testing of policies.

The third criteria is given by the level of spatial detail that is reflected by a model. Herewith disaggregated GIS-based models and models with different levels of aggregation can be distinguished. ASTRA is based on a meso-level of spatial aggregation. So, for spatial representation the whole EU15 is divided into different types of functional zones.

Finally the modelling methodology can be used as demarcation criteria. In this case the group of statistic or econometric models and the group of functional or cause-and-effect based models can be differentiated. With the use of the system dynamics methodology to reflect the complex causal interrelationships of the investigated socioeconomic and environmental systems ASTRA belongs to the latter category. Summarising, the ASTRA model can be categorised as system dynamics model for integrated long-term assessment of the European transport policy with a spatial representation on a functional basis.[2]

3.1 Long-term Assessment

Why is long-term assessment of the consequences of transport policies necessary ? This question arises as one might argue that assessments with a time horizon of more then 5 to 10 years are tainted with high uncertainty or even are speculative. This might be right for some systems for which the framework of the system can be changed completely within short-terms e.g. in financial markets where varying money flows can change the whole system within hours or days. However the framework in which the transport system is embedded behaves different. Major driving forces of the transport system can be changed only in the long-term. For instance the construction and planning of transport infrastructure might take up to 10 years and the usage duration is often longer then 40 years. Human habits that increase the need for transport like the preference to live in green suburban areas instead of the city centers also develop over a long time such that they contribute to the self-image of a generation of people. To change these human habits needs also longer time periods.

[2] ASTRA D2 presents the basics of system dynamics modelling and a categorisation of models according to a set of formal mathematical criteria. ASTRA can be classified with these criteria as formal, abstract, non-linear dynamic model (ASTRA 1998)

Additionally, on the supply side of the transport system huge industrial structures (e.g. fuel producing industries, car manufacturers) have been built. To change these requires changes of the production structures with an enormous scope and therefore also with a long-term time horizon.

Finally, environmental consequences performed by the transport system like the carcinogenic risk caused by particulate matter or the contributions to the greenhouse effect caused by CO_2 emissions from transport have an effect after an activity period of several decades or might even last for decades or hundreds of years. This can be seen at the development of CO_2 concentrations observed at the Mauna Loa observatory, which have been increased from 1958 to 1997 by about 17 % (figure 2). Currently scientists are sure that this increase of greenhouse gases that can be observed worldwide will effect the global climate. But discussions are ongoing if today we can already notice these changes e.g. by the increase of the number of heavy storms during the last years.

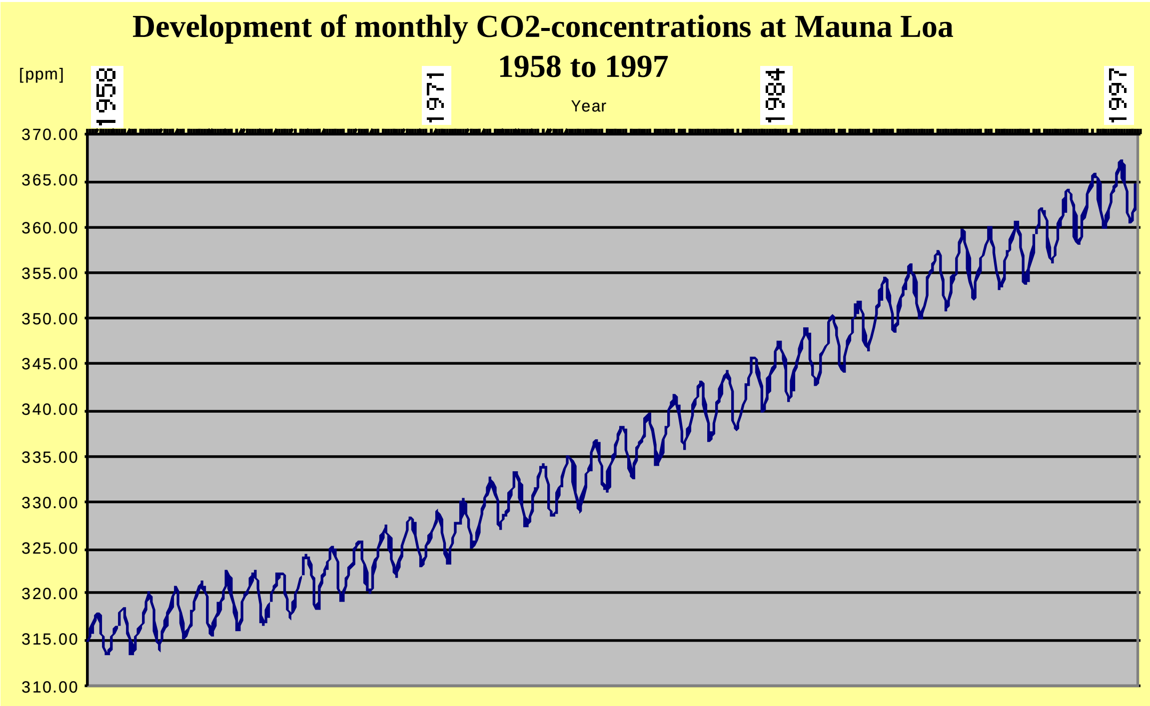

Figure 2: Development of CO_2-concentrations from 1958 to 1997[3]

Coming back to the problem of increasing uncertainty. When the forecasting time horizon is moved further into the future it is important to choose a modelling methodology that diminishes the influence of uncertainty. It is obvious that for methodologies relying strongly on data from the past like econometric or other modelling based mainly on statistical analysis results become less reliable the further into the future these models are applied. Therefore the decision is taken to focus the ASTRA approach on the investigation of functional cause-and-

[3] Graphic based on KEELING/WHORF (1998)

effect relationships between the transport system and the other three connected systems. To implement these relationships, which often are existing in the form of feedbackloops, the system dynamics (SD) methodology is applied, because it is especially created to represent systems consisting of several feedback loops. A second advantage of the SD methodology is that all applied model variables have to be quantified and thus may be reviewed and checked by users for validity and consistency. This provides a major difference to other reasonable methodologies for long-term assessment, which can be found in the group of qualitative approaches.

The basic feature of qualitative approaches is the use of expert judgements about future developments. This approach can be formalised in so-called Delphi studies where a panel of experts is requested to make judgements on long-term developments ("Megatrends"). The composition of the expert panel should be multidisciplinary to overcome inherent bias of the judgements that is given by the focus of the experts on their scientific disciplines. Also the experts should stem from different professions like universities, state administration and business. This approach is e.g. presented by a study on global trends in science and technology with a panel of 2300 experts.[4] With the panel it was able to identify several Megatrends for the next three decades, though the expert assessments are not homogenous. This approach is advantageous in a sense that interrelationships of the different real systems are considered implicitly by the knowledge and experience of the experts. Problems might arise with inhomogenity of the judgements and the qualitative character of results, which makes it difficult to review and check the findings of the experts.

A second group of qualitative approaches for long-term assessment are based on backcasting techniques in the form, which is presented by the POSSUM project.[5] In this project, first different images of the future for the final year of the forecasting period are designed and then possible paths, which lead from the present situation to this future, are investigated. For this investigation lists of policy measures are developed and then grouped to policy packages in which the different measures of one package are expected to cause synergies. The validation of images, paths and corresponding policy packages is then carried out by expert judgements during several expert workshops. However, because of the throughout qualitative nature of this approach difficulties to review and check results in terms of consistency or of adequacy of causal relationships occur.

Therefore an improvement of the backcasting approach can be achieved, when the development paths that lead to the different images of the future at the endpoints of the paths are quantified and modelled such that at least consistency of variables of the images can be demonstrated. This approach is followed in the Sustainable Society Project in Canada where the SERF model (socio-economic resource framework) is used to find paths towards a sustainable future scenario. The authors argue that "*Forecasting takes the trends of yesterday and today and projects mechanistically forward as if humankind were not an intelligent species with the capacity for individual and societal choice. Backcasting sets itself against such*

[4] CUHLS ET AL. (1998)
[5] POSSUM (1998)

predestination and insists on free will, dreaming what tomorrow might be and determining how to get there from today."[6]

3.1 Modelling the Complexity of the Transport System

The transport system forms a complex system with determinants that are changing over different time scales. As shown above some of the determinants are very stable in the short run while others like fuel prices can vary significant in the short-term and mid-term time horizon.

Also the transport system is connected with other complex systems like the society, economy and environment. Improvements of the transport system was in history often a major source of growing welfare of societies. In 1995 in the EU15 countries transport services generated 4% of the GDP and 6.2 million employees - that is 4.2% of all employees - are working in the transport sector. These figures do not include the production of infrastructure and vehicles. Also transport forms a part of the social life of society by providing the basis for personal mobility. This is reflected by the growing passenger transport demand that reached a value of 4500 billion pkm in the year 1995. On the other hand transport is a major source of environmental burdens that influences sustainability in the opposite direction than the positive welfare and the mobility effects of transport. In 1995 road transport caused 44.000 deaths by traffic accidents within the EU15 countries. The World Health Organization (WHO) estimates that additionally 80.000 people in EU15 are killed by hazardous gaseous emissions of transport per year. Also the contributions of transport to global effects like the greenhouse effect is considerable as the CO_2 emissions of transport contribute with a share of 26% to the man made CO_2 emissions.[7] This situation is reflected in figure 3:

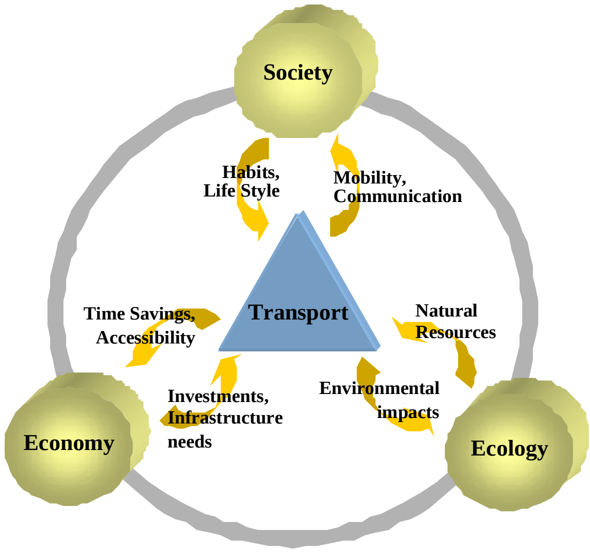

Figure 3: Transport and its Interlinkages to other Complex Systems[8]

[6] ROBINSON (1996)
[7] EUROSTAT (1997a)
[8] SCHADE/ROTHENGATTER (1999)

Modelling approaches that are used for such a complex system should provide an explanatory component, such that users as well as modellers besides the mere results of the model can also get improved insights into the systems relationships from the modelling process and the model structure. Because the whole detailed system can not be captured with a model one main task is to identify the key relationships of the real system that is underlying the model. Subsequent these relationships are formalised and implemented according to the rules of the applied modelling methodology. In ASTRA the SD methodology is applied as well as in three other ongoing respectively just finalised transport research projects. However, the approach by which the key relationships are identified and quantified in functional relationships is different between the projects.

- ASTRA: the ASTRA baseline are existing state-of-the-art models from four research disciplines. From these models the key-relationships are extracted and adjusted such that they can be implemented into a SD model. In addition new interfaces between the four models have to be developed (spatial scope: Europe, time horizon: 2026, passenger and freight transport).
- SIMTRANS: in SIMTRANS the key relationships are mostly qualitative. They are designed based on expert knowledge of the involved transport experts and then transferred into the SD model by SD experts (spatial scope: France, time horizon: 2020, only freight transport).[9]
- MODUM: in MODUM the key relationships, which can be qualitative and quantitative, are derived from discussions on actors workshops. Actors involved the research team and transport companies, administrations and other concerned groups. These key-relationships are afterwards quantified by the project team and then implemented in the SD model (spatial scope: Switzerland, time horizon: 2030, passenger and freight transport).[10]
- EST: within the EST project of the OECD the ESCOT model is developed. In EST the key relationships are derived from existing models as well as from discussions with groups of economic, environmental and transport experts. The key-relationships are then modified and adjusted for the SD methodology and implemented in ESCOT. This project also shows the ability of SD models to provide a quantitative foundation for the backcasting approach. In EST scenarios for an environmentally sustainable transport system are designed and the path to reach these in the future is modelled and checked for consistency with the SD model ESCOT (spatial scope: Germany, time horizon: (2015) 2030, passenger and freight transport).[11]

[9] KARSKY/SALINI (1999)
[10] KELLER ET AL. (1999)
[11] SCHADE ET AL. (1999)

3.2 Equilibrium or "Disequilibrium" Models

This point shall only be touched to highlight an important characteristic of system dynamics. Actually most of the models are based on equilibrium approaches. One major reason may be that for these equilibrium calculations sophisticated tools and rules are provided by mathematics. However, the equilibrium state is rarely existing in socio-economic systems or as Keynes said equilibrium is reached only "by accident or by design". Nevertheless, it can be argued that the systems are not in an equilibrium state, but that they always tend to move towards an equilibrium state.

A different approach would be to look for alternative modelling methodologies for which the existence of an equilibrium state is not a prerequisite. One of these approaches is the System Dynamics methodology for which the development of the system over time is determined by the decision rules that define the transition of the system from one point of time to the subsequent point of time. In this case neither a current equilibrium state nor a future equilibrium state is required.

4 ASTRA System Dynamics Model Platform (ASP)

This section provides an overview on the ASTRA System Dynamics Model Platform (ASP). The ASP integrates key relationships of state-of-the-art models in the fields of macro-economics, 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**) and a model sector that outlines the development of the welfare situation based on a selected set of key indicators. Results of the conventional models are used for calibration of the ASP sub-modules. Basically the ASP is operated on a yearly time basis with a time scale from 1986 to 2026 and a base year 1985. The applied time step DT for the integration period is 0.25, which implies that all model variables are calculated every three months.

In the following the global structure and interrelationships of the model are presented in comprehensive diagrams. The first diagram (figure 4) presents the structure of the models that superimpose each other in the ASP. The structure consists of the four sub-modules MAC, REM, TRA and ENV, the passenger and the freight model that are formed by parts of REM, TRA and ENV and the welfare situation sector that is created by indicators from MAC and ENV. Also the conventional models underlying the four sub-modules are shown. They provide key-relationship and calibration data for the implementation of the sub-modules.

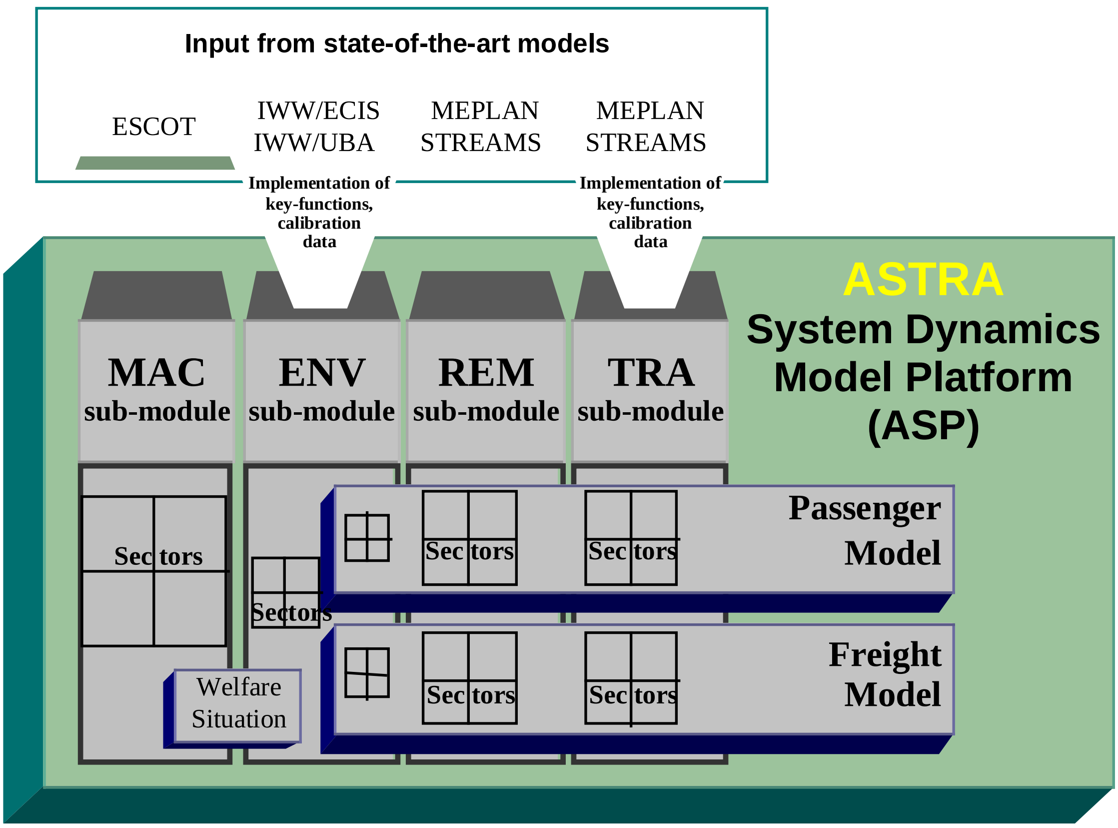

Figure 4: Structure of the ASTRA System Dynamics Model Platform (ASP)

The second diagram (figure 5) presents a global overview on the implemented feedbacks between the different sub-modules. All data that is transferred between two sub-modules is produced endogenously and is provided by the distributing sub-module for every integration period DT to the receiving sub-module. Here, it should be noted that the results of part of the REM and the whole TRA concerning transport variables are calculated on a daily basis while MAC and ENV are working completely on a yearly basis. So, interfaces between the former and the latter group have to consider an annualisation of the data.

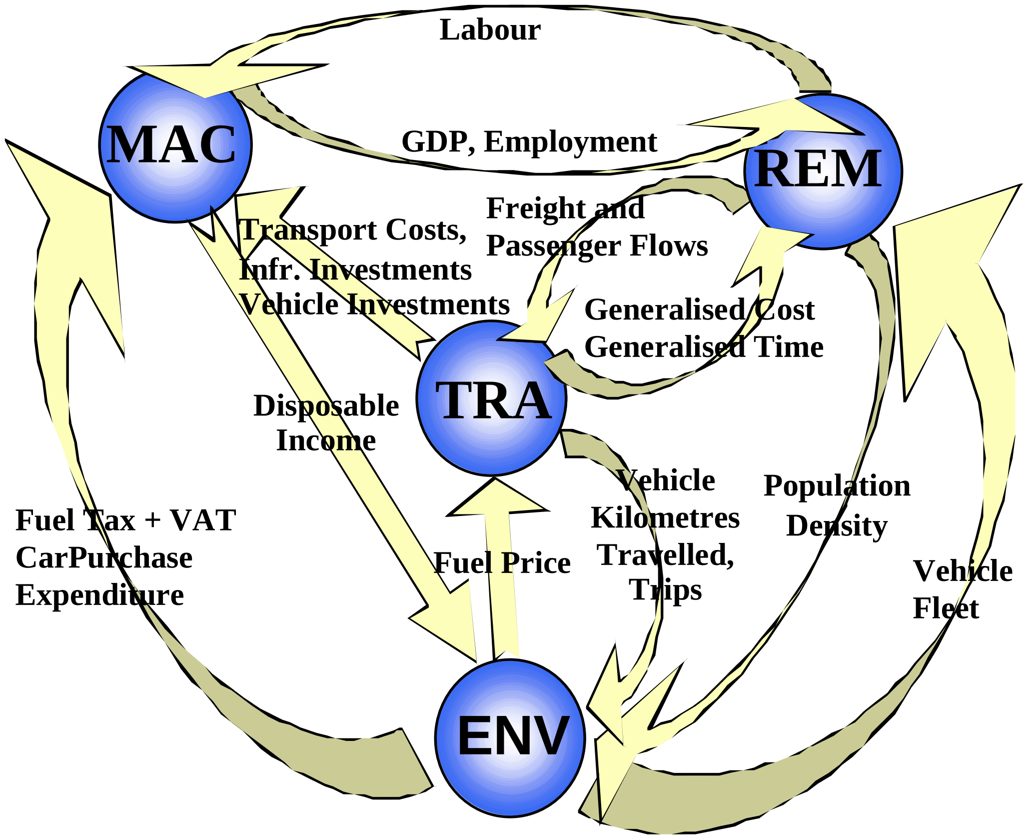

Figure 5: Output data forming the major feedback loops between the ASP sub-modules

The third diagram (figure 6) presents the main relationships that drive the passenger model. Based on potential output and final demand GDP is calculated considering also taxes and transfers. GDP determines the national income, which is used to calculate the level of disposable income. Mainly the development of disposable income influences the car vehicle fleet. Population density and fuel prices are considered to be further influences on the fleet. The actual stock of the cars then provides an input for the car-ownership calculation. Together with the population development (distinguished into age classes) and the trip rates (dependent on household types that e.g. consider different employment situations) 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 TRA calculates the number of trips and the traffic volume for the different passenger modes. Based on this output transport expenditures are calculated and transferred to the MAC. Within the MAC the transport expenditures, which cover for road mode only perceived cost, are part of consumption and also drive employment in the transport service sectors. Trips and traffic volume are transferred to the ENV where indicators for fuel consumption, emissions and accidents are calculated. Based on the fuel consumption the fuel tax is calculated and transferred to the MAC where it forms a part of private consumption. Based on vehicle purchase the fixed costs for car purchase are calculated and added to transport expenditures such that they also influence private consumption. Additionally they have an effect on employment in the transport vehicle manufacturing sectors. Externalities and defensive costs of emissions and accidents are estimated and form a part of the welfare situation. Within the MAC the remaining indicators that describe the welfare situation are calculated.

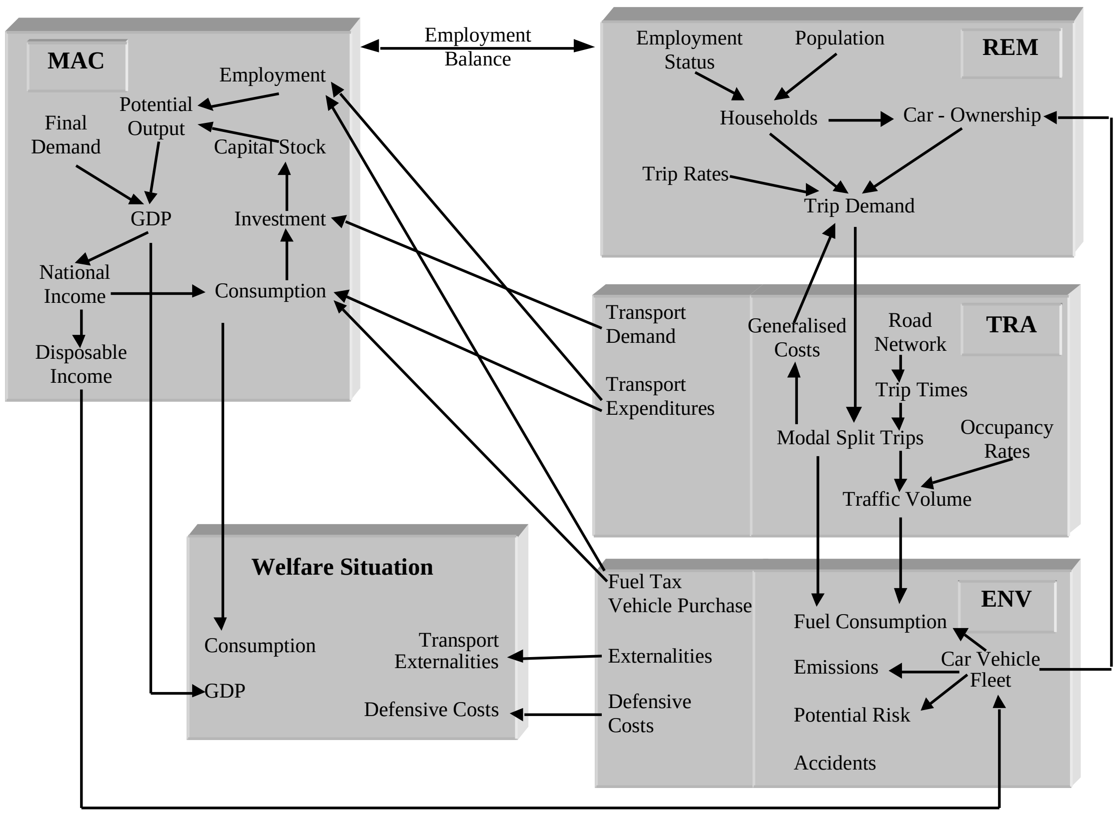

Figure 6: Aggregated Relationships of the Passenger Model

The fourth diagram (figure 7) presents the main relationships that drive the freight model. In the freight model there is a strong relationship between the MAC and the REM. GDP corresponding to goods production is transferred from MAC to REM where it forms an input to generate the transport flows. The resulting transport demand is transferred to the TRA where the modal-split is performed based on generalised cost and the traffic volume for the freight modes is calculated. Based on the traffic volume freight expenditures are calculated and transferred to the MAC, where they influence investments and employment. The traffic volume is transferred to the ENV to calculate the environmental indicators. Also the demand for freight transport expressed by the traffic volume together with the average truck life-time steers the purchase of LDV and HDV and therefore influences the fleet. The vehicle investments for all modes are calculated and transferred to the MAC, where they are a driver of investments and employment. The output relationships of the ENV are similar to the ones in the passenger model.

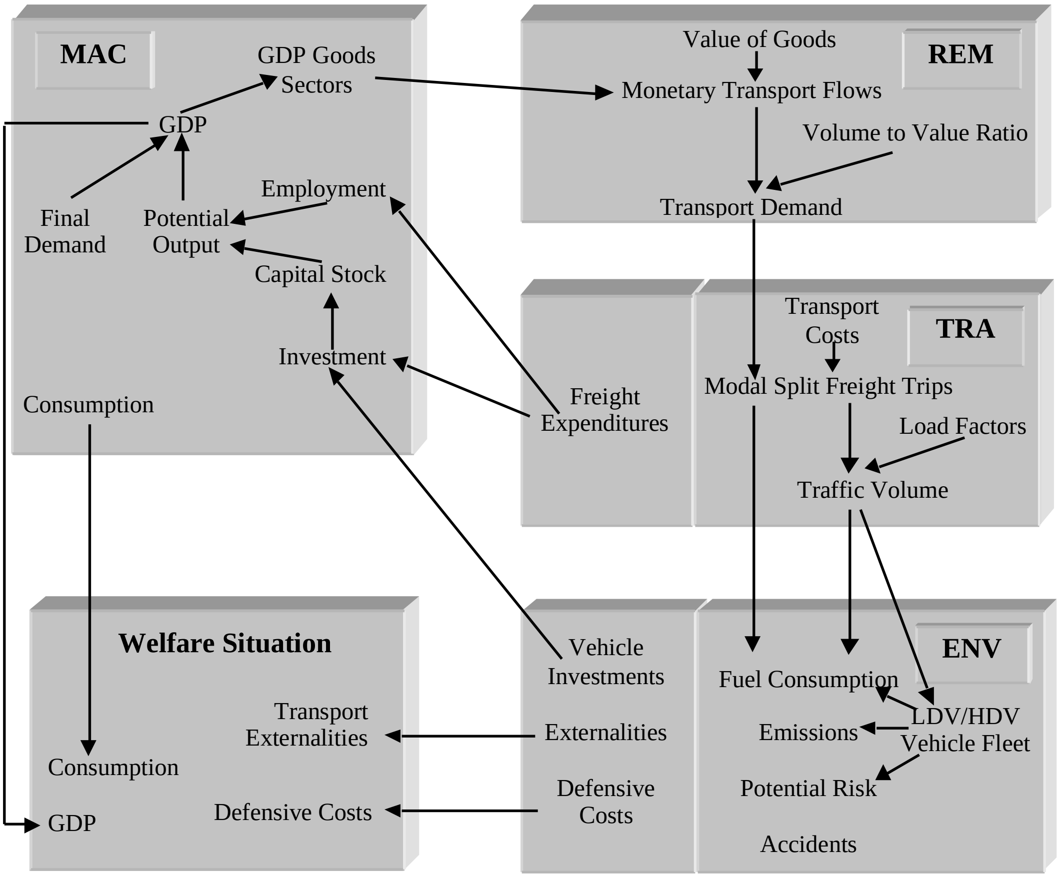

Figure 7: Aggregated Relationships of the Freight Model

4.1 Glance on the Vensim model

The Vensim[12] software provides two levels for model development and usage: the sketch level and the equations level. On the sketch level the model structure is developed and displayed. Also single equations can be edited with dialogue window support. The sketch level is divided into separate views. Each view is representing a model sector. On the equation level all equations are listed and can be edited.

[12] Details about the Vensim software can be obtained from the Vensim documentation distributed by Ventana Systems (VS 1997a, 1997b)

Policies can be implemented in four distinct ways. Simple policies can be introduced by the change of variables (constants or graphs) on the sketch level. Also Vensim provides a simulation control dialog on which the list of constants or graph variables is offered to change their values. Complex policies can be defined in specific policy data files, which can be loaded from the harddisk and then can be tested or modified. Finally with the most recent version of Vensim simple policy steering panels, which are called flight simulators in System Dynamics language, can be implemented. They might consist of switch buttons and sliders.

The results of policy runs can be presented with graphs or tables. Graphs can be used for display of time series data for different variables in the same policy (cross-variable comparisons) or in different policies (cross-policy comparisons). Additionally, with a separate Vensim tool, the Vensim application software (VenApp), easy-to-use applications can be developed for policy testing and displaying of results. As an example in figure 8 a time series of GDP is compared with the time series of CO_2 emissions from transport for the macro regions 1 to 3.

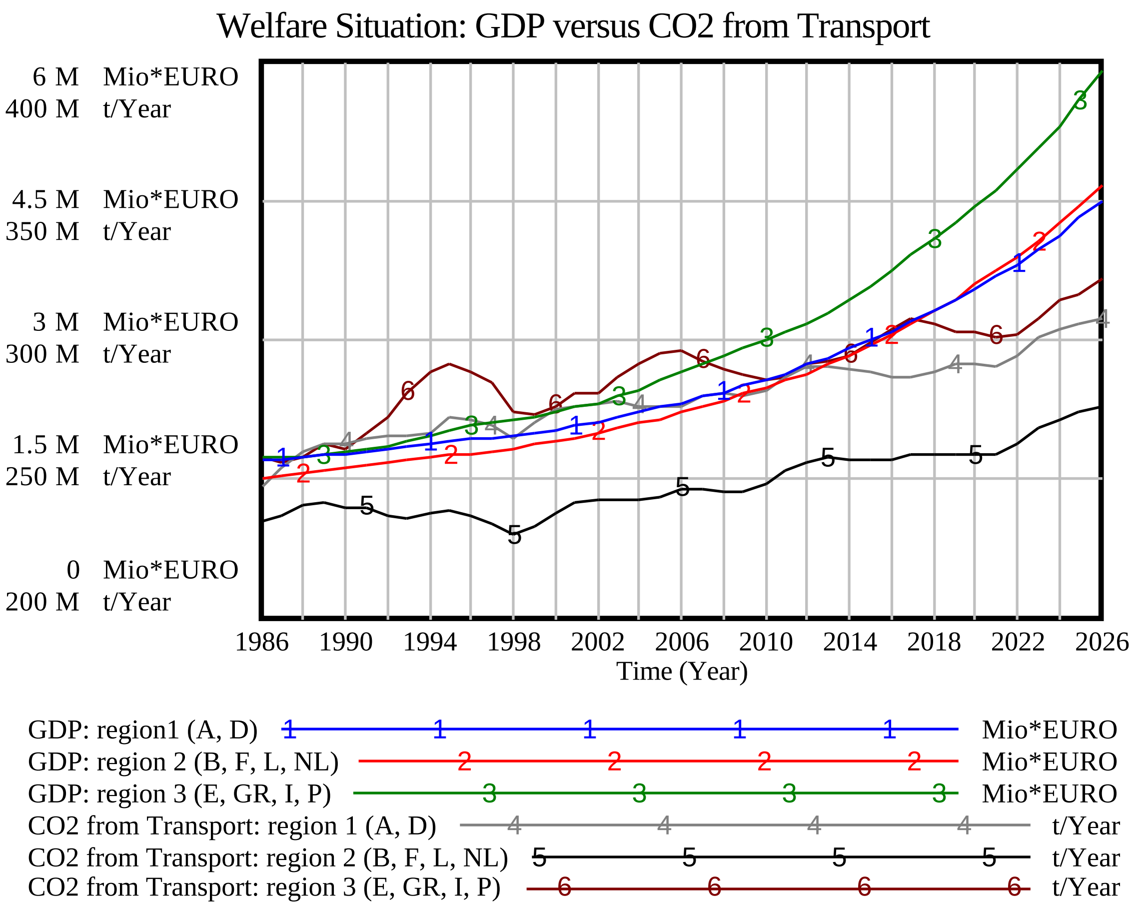

Figure 8: Comparison of development of GDP with CO_2 emissions from transport

Figure 8 consists of three important elements. The first element is the graph displaying the six curves in different grey tones (respectively in different colours) and with numbers assigned to each curve. The numbers can also be found in the second element, which is the legend below the graph. There one finds the variable name, the colour and number of the corresponding curve and the unit of measurement. In case of different policies or scenarios displayed in the graph also an indication is given to which scenario the curve belongs to. The third element are the x- and y-axis, where the x-axis is usually the time and the y-axis presents the unit of measurement and the quantity of the variable. On the y-axis different unit of measurements could be displayed as the variables can differ by their order of magnitude or by their physical meaning in reality (e.g. tons of emissions and monetary values of GDP).

5 General Features of the ASTRA Model

5.1 Introduction

The ASTRA Systems Dynamics Model (SDM) comprises four sub-modules. There are several features of the SDM which are common to two or more of the sub-modules and it is these features that are described in this chapter.

In general the following principles were adopted in the modelling process:

1. In the ASTRA modelling framework the elements of the classical 4-stage transport model have been retained in the modelling of the demand for transport. Trip and freight generation and distribution modelling were considered to belong to the regional economic sub-module (REM) set within the context of the activities which give rise to them, while modal split and assignment are considered as part of the transport sub-module (TRA).

2. The modelling of the demand for passenger and freight travel i.e. trip generation and trip distribution in the REM is done separately as is the modal split in the TRA. The derived road traffic by mode from the passenger and freight models is then assigned together to the transport network in the TRA.

3. The representation of space is treated in two distinct ways by the sub-modules within the SDM.

   i. Macro regions

   The macro-economic sub-module (MAC) works with a concept of “Macro Regions” which are defined in geographical space as aggregates of EU15 member countries. This same representation is used in the modelling of freight demand in the REM and TRA sub-modules. The issue of what was the appropriate spatial unit to be used in the modelling of freight movements was one of the unresolved issues in the model design highlighted in ASTRA D3.

   ii. Functional zones

   The passenger model in the REM uses an alternative representation of the spatial dimension thought to be more suited for modelling passenger demand in this particular application. This representation uses the concept of “Functional Zones” based on settlement type. The functional zones are formed by aggregating NUTS2 regions of the same settlement type together, consequently they are not geographically contiguous.

   Both the “Macro Region” and “Functional Zone” representations of space cover the EU15 countries; see section 5.2 for an explicit description of the spatial dimension in the SDM. The decision on the appropriate spatial units for the modelling of freight and passenger demand was based on an analysis of the characteristics that affect the demand for that type of travel. One of the major influences was the need to derive relatively homogenous geographical areas for which to generate and distribute the demand for travel and carry out the modal split. It was therefore decided on the basis of these considerations in light of analysis of trends in passenger and freight demand what the appropriate spatial unit would be. A fuller discussion of these trends influencing this decision is given in the chapter dealing with the design of the REM, chapter 6.2. The assignment of the travel demand in the TRA is done on the level of the macro regions, a level where it is easier to define the physical transport network. Table 1 summarises the spatial units used in the four sub-modules.

Table 1: Spatial units used by sub-modules in ASTRA Systems Dynamics Model Platform (ASP)

Sub-module	**Spatial unit**
Macro-economic (MAC)	Macro regions
Regional economic and land use (REM)	***Passenger generation & distribution*** - Functional zones ***Freight generation & distribution*** - Macro regions
Transport (TRA)	***Passenger modal split –*** Functional zones ***Freight modal split*** - Macro regions ***Passenger and freight assignment*** - Macro regions
Environmental (ENV)	Macro regions (in parts also Functional zones)

4. The explicit representation of the choice approach was adopted in preference to the accessibility index approach in both the regional economic sub-module (REM) and the transport sub-module (TRA).

5. Distance bands are introduced to reflect both the responsiveness of trip lengths and length of haul to travel supply characteristics, and the different modal choices selected on trips with different average distances between the zones. The definition of the distance bands used are different for passenger and freight travel demand, see section 5.4 for a more detailed description.

5.2 Spatial Structure

The ASTRA SDM combines two concepts of the modelling of the spatial dimension and consequently two different zoning schemes have been adopted. Although this is not ideal, substantial simplifications on the spatial side have had to be made in order to reduce the dimensions within the SDM, which otherwise would place an excessive computational burden on the system dynamics software. This is especially important for the core ASP implemented with the ithink software. However, with the use of the more powerful Vensim software for the full ASP it can be thought about more detailed spatial representation in future versions of the ASTRA model.

The MAC sub-module follows the traditional approach to the modelling of space based on geographical definitions of 4 “Macro Regions” which are aggregations of the EU15 member countries. In the other sub-modules the representation of space relates to whether the passenger or freight demand is being modelled. The passenger demand (REM) and modal split models (TRA) use the alternative concept of space. The functional zoning approach was adopted rather than a classical geographic zoning system, this is described below, see section 5.2.2. For the freight model a more conventional geographical zoning scheme was considered more appropriate and consequently the macro region definition of space was used. It is the view here that it is not necessary for the same zoning scheme to be used in the modelling of both passenger and freight demand, the justification for this being the different nature of the influences that determine passenger and freight demand (see chapter 6.2). Therefore it is the position that in the ASTRA SDM it would be advantageous to make reference to a different set of zones for the passenger and freight models so as to model more accurately the driving forces that influence the different types of demand for passenger and freight transport. This argument is driven by the fact that the choice of the zone clusters then plays a crucial role in the generation of the demand for travel.

The functional zones approach to modelling passenger demand is certainly a significant simplification of the modelling approach on the spatial side, but is necessary in order to relieve some of the computational burden of the model by reducing the memory requirements. The implementation leads to the construction of functional zones that are non-contiguous in the spatial dimension but share similar transportation, demographic and economic structures and which are relatively homogenous, which is an important consideration when deriving the demand for travel. In the freight model it is important to be able to apply differential growth rates for different economic sectors of the economy in each zone and as this will be based on data from the MAC it is important that there is a strong correspondence between the zoning schemes.

5.2.1 Macroeconomic Regions

The macro-economic sub-module (MAC) uses a conventional representation of space based on geographical location and has divided the EU15 into 4 zones with a further zone representing trade with the rest of the world outside the EU15. The zones have been designed such that they are as homogenous as possible with respect to their economic structures. To avoid confusion with the functional zoning scheme these are named “Macro Regions”.

- Macro Region 1 **(MR1).** Germany & Austria
- Macro Region 2 **(MR2).** France, Belgium, Luxembourg & the Netherlands
- Macro Region 3 **(MR3).** Italy, Spain, Portugal & Greece

- Macro Region 4 **(MR4).** UK, Ireland, Sweden, Denmark & Finland
- Macro Region 5 **(MR5).** Rest of the World (ithink core version only)

This representation of space is also used in the REM and TRA in modelling freight demand and modal split. In the freight model the determinants of the demand for travel are somewhat different from those that drive the demand for passenger travel. As described in ASTRA D3 Chapter 2 consideration was given to several alternatives of representing the spatial structure of the EU15 with the final decision made to use a conventional geographical zoning scheme and consequently to use the same macro regions used in the MAC sub-module.

5.2.2 Functional zones

Six functional zones were defined based on settlement type and consisted of aggregates of the 201 STREAMS model zones covering the EU15, which are mainly at the NUTS 2 level, which were each assigned a settlement type. The functional zones defined in the ASTRA modelling framework are[13]:

- 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**).

A full description of these functional zones was provided in ASTRA D3 and a full list of the STREAMS model zones and the functional zones to which they belong is provided in the Technical Annex of that Deliverable.

In a functional zone matrix, each cell represents all relations existing in the transport networks for a pair of geographic zones which belong to the origin and destination district types. The different relations, which build up a given cell, make reference to different distances and thus to different modal choices. Thus the functional zone matrix approach would make it possible to separate *intra-zonal* and *inter-zonal* flows by mode within the ASTRA SDM.

Let us consider a cell representing trips from the peripheral area of a big city to the centres of big cities. These trips might be metropolitan trips, when the two zones actually belong to the same city, as well as regional trips, when the two zones belong to different cities in the same region, or inter-regional trips, when the two zones belong to different cities in different regions. Modal choice of the represented trips is obviously not homogenous and it is strictly related to the distance between zones.

[13] acronyms in parenthesis are those used within the SDM with a slight variation in the Vensim model in which E1, E2, E3 and E4 is used for the four macro regions.

Figure 9 illustrates the zoning schemes as implemented in the ASTRA SDM.

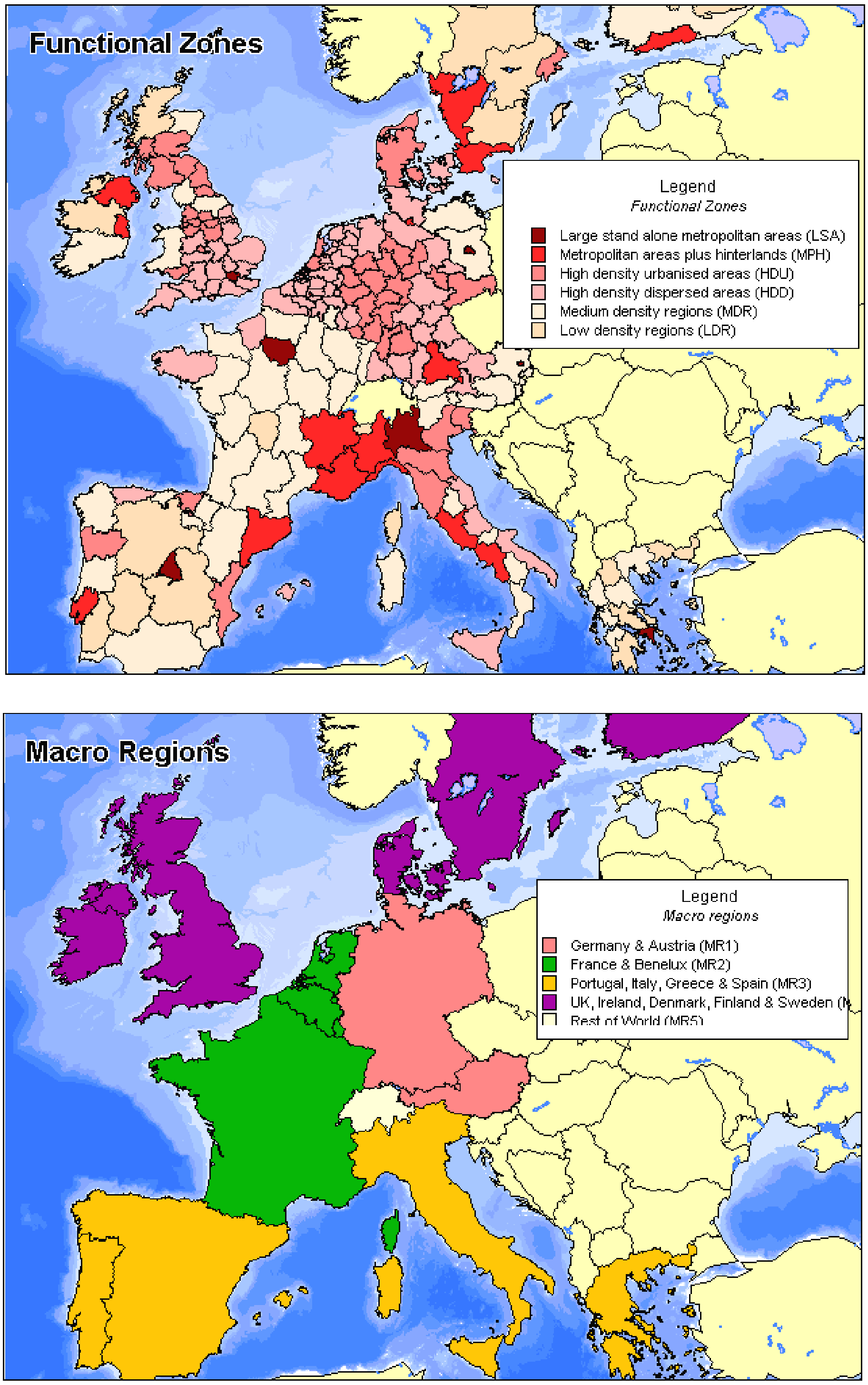

Figure 9: Zoning scheme for ASTRA System Dynamics Model Platform (ASP)

Figure 10 shows the basic relationship between the *macro regions* and the *functional zones.* It should be noted here that within the ASTRA SDM it is necessary within some of the interfaces between the various sub-modules to convert data from macro region to functional zones and vice versa. This is done using sets of co-efficients derived from the STREAMS model.

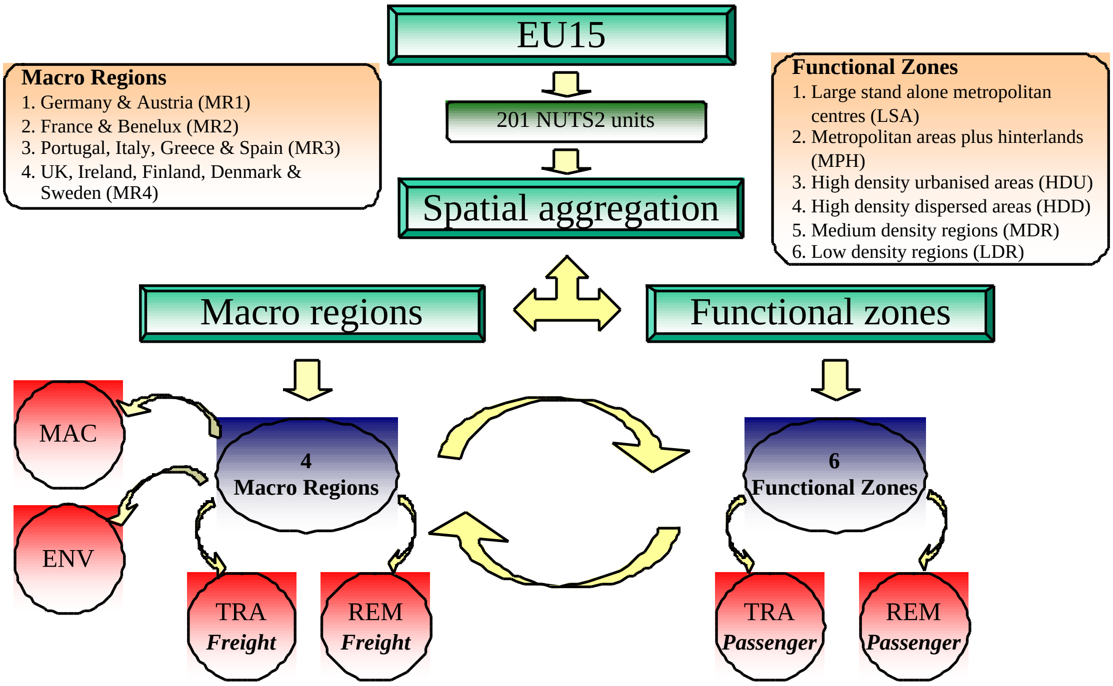

Figure 10: Schematic Representation of Spatial Dimensions of EU15 countries in ASTRA SDM

Note: The fifth "Macro-Region" which is not specified in Figure 11 is external to the EU15 and represents the trading position of the rest of the world with the 4 "Macro-Regions" internal to the EU15 which are explicitly represented in the ASTRA SDM.

5.3 Transport Flows Representation

Within the transport sub-module the movement of persons and freight is modelled as an explicit set of transport flows. In the context of the passenger demand these are represented as a set of trip purposes and for freight demand they are represented by freight categories.

5.3.1 Trip Purposes

In the classical transport model travel demand is considered to be relatively homogenous for different groups within the economy. In order to represent demand accurately it is necessary to correctly segment the market for travel. Many of the issues regarding the segmentation of demand for the purposes of generating passenger trips are issues relating to the design of the REM and are considered in that section of this report. However the definition of trip purposes is of equal relevance to both the REM and TRA sub-modules. The trips are generated and distributed in the REM by defined trip purposes that are sufficiently disaggregated to ensure that the total demand for travel is accurate. It is the number of trips by each purpose between origin and destination zones that are transferred to the TRA for the modal split to be carried out.

In the passenger model three trip purposes were identified:

- commuting and business **(BU)**
- personal **(PE)**
- tourism **(TO)**

These trip purposes represent aggregations of a more disaggregate set of trip purposes used in the STREAMS transport model. Aggregation was necessary to allow this dimension to be included efficiently in the modelling structure but the disaggregate purposes were combined in such a way as to preserve homogeneity as far as possible.

5.3.2 Freight Categories

Within the REM sub-module, the economic sectors of the economy are represented and the value of the output is translated into tonnes that are distributed to destination zones and then aggregated to a number of freight categories that are passed to the TRA. In order to allow the most accurate modelling of relatively homogeneous categories of freight three freight categories were identified;

- Solid and liquid bulk
- Semi-bulk
- Unitised freight

It was originally proposed in ASTRA D3 to model four freight categories with unitised freight being sub-divided into low and high value unitised freight. However principally due to the computational burden on the SDM highlighted elsewhere in this Deliverable it was decided to amalgamate these two categories.

5.4 Spatial Representation

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 transport flows (trips or freight).

When adopting a functional zoning system, distance between functional zones is no longer significant. Indeed functional zones represent clusters of zones that 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. As a consequence it would be extremely difficult to define the correct travel pattern (amount of transport demand and modal split) for a pair of functional zones, as this travel pattern would vary according to the distribution of distance.

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 distribution component of the REM sub-module and the modal split component of the TRA sub-module were divided into sectors differentiated according to distance bands. 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 influenced by the generalised time from the TRA. These demand matrices are then used by the TRA. 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 make up a large proportion of passenger trips, is very important.

5.4.1 Passenger Distance Bands

In the passenger model the distance bands were derived from the analysis of the National Travel Surveys of European member states carried out for the STREAMS passenger model. In each sub-module all transport modes characteristics (time, cost, etc.) for modal split make reference to average figures for that specific distance band on the basis of the results of the STREAMS model. For instance, the business & commuting transport demand between LSA and HDD zones generated by the REM is split among the different distance bands according to the pattern derived from the STREAMS model. This is assumed to represent the actual patterns of EU flows; the TRA then processes separately each distance band data set.

The operational transport sub-module is made up of a number of different modal split models each making reference to different average distances or distance bands. Within a model the relevant trip purposes are analysed and a specific modal split is modelled for each trip purpose. With reference to passengers, five distance bands are defined:

- local (distances below 3.2 km),
- very short (distances => 3.2 and < 8 km),
- short (distances => 8 and < 40 km),

- medium (distances => 40 and 160 km),
- long (distances > 160 km).

5.4.2 Freight Distance Bands

In the freight model four distance bands have been selected according to an analysis of the results from the STREAMS model and also a statistical analysis of the trends over time in the length of freight movements in the EU15 from the Eurostat Carriage of Goods annual survey.

The four distance bands modelled were as follows:

- short (distances < 50 kms),
- medium - short (distances => 50 and < 150 kms),
- medium – long (distances => 150 and 700 kms),
- long (distances > 700 kms.)

The principles of modelling the freight movements by distance are the same as those described in the context of the passenger distance bands such that a specific modal split is modelled for each freight category.

6 Description of the four ASTRA sub-modules

The following chapters describe the internal structure and the output interface of each of the four ASTRA sub-modules. The description follows a sequence from the high level influences within the macroeconomics sub-module (MAC) via trip generation and trip distribution within the regional economics and land use sub-module (REM) and modal split and assignment within the transport sub-module (TRA) to the environmental consequences within the environment sub-module (ENV). The descriptions commence with the aim and basic structure of each sub-module. Subsequently the implementation, calibration and the output interfaces of the sub-modules is explained.

6.1 Macroeconomics Sub-module (MAC)

6.1.1 Aim of the MAC sub-module

The aim of the MAC sub-module is to provide an aggregate macroeconomic environment in which the REM, TRA and ENV sub-modules are embedded. With this macroeconomic information national and continental level influences can be integrated into the ASP. Also feedback loops, which commence on the micro- or meso-level in one of the other sub-modules (e.g. transport expenditures for one mode in one distance band) and then resume with an effect on the national level, can again influence the original sub-module such that the feedback loop is closed by the integration of the MAC sub-module.

6.1.2 Basic Structure and Future Expectations

The MAC sub-module is constructed as an extended Keynesian model. It follows a similar approach as the macroeconomic model within the ESCOT model, which has been developed as part of the project on Environmentally Sustainable Transport (EST) of the OECD.[14] It consists of three major elements:

- supply side model based on supply of production factors,
- demand side model based on the elements of final demand and
- sectoral interchange model based on an input-output table.

For the purposes of analysis the EU has been split into 4 macro regions. These have been chosen to provide regions of approximately the same size and containing economies with roughly similar characteristics (see also figure 9).

- Macro region 1: Germany and Austria.
- Macro region 2: France, Belgium, the Netherlands and Luxembourg.

[14] SCHADE B. ET AL. (1999), SCHADE B. ET AL. (2000)

- Macro region 3; Italy, Spain, Portugal and Greece.
- Macro region 4: UK, Ireland, Sweden, Denmark and Finland.

Each of the four regions is modelled using the same macroeconomic framework. All monetary values are calculated in real values of 1995 EUROs. Most variables are calculated net of all taxes as taxes are treated separately. The MAC works on a yearly time basis.

The interaction between supply and demand side can be adjusted such that the model can simulate supply-demand balanced economies but also either a supply side driven or a demand side driven economy. In the base run both sides are treated as their influence is of the same importance.

6.1.2.1 Supply side model

Basic element of the supply side is a production function of Cobb-Douglas type that incorporates the three major production factors labour supply, capital stock and natural resources as well as an exogenous technological progress given as a productivity influence. Labour supply and capital stock are calculated endogenously based on variables like labour force, investments and capital depreciation respectively scrappage. The influence of natural resources is considered exogenously but one could think of opportunities to endogenize the resource use in future versions at least by using one or more proxies like use of fresh water for production.

It should be mentioned at this point that technical progress is only included on the supply side, such that if the supply-demand balance is moved strongly towards the demand side the technical progress has only a very minor influence on the economic development. However in the long run especially technical progress drives the economic growth, such that a balanced or a supply side driven version of the supply-demand model should be applied.

Future expectations on the supply side are in line with the forecasts of the SCENES project. That means production potential will grow with rates around two percent a year, which is due to an increase in capital stock and technological improvements, while labour supply is stable or even decreases in the last two decades of the simulation.

6.1.2.2 Demand side model

The aggregated variable on the demand side is the final demand, which is driven by consumption, investments, government expenditures and export. Consumption and investment are split into a share that is independent from transport and a share that is dependent on the development of the transport markets given by the TRA and the ENV. Government expenditures develop according to GDP development, while export is driven by the aggregated demand for the three other variables.

Future expectations on the demand side indicate further growth of national income respectively personal income, which will lead to growing consumption. In the base run a reduction of the share of government expenditures on GDP is not expected though it could be a reasonable and probable policy in the future.

6.1.2.3 Sectoral interchange model

The basic element of the sectoral interchange model is an aggregated input-output table with twelve economic sectors. The sectoral disaggregation is also applied for other economic variables like consumption to be able to consider the direct effects of transport developments within their corresponding sectors as well as the indirect effects in the sectors supplying intermediate products.

The data for the I-O-table is taken from the EUROSTAT R25 projection tables for 1995.[15] The structure of the tables is not kept constant over time, instead the change of final demand alters the third quadrant of the I-O-table. Updating the inverse input coefficients and recalculating the I-O-table leads to a change of the sectoral relationships within the economic sectors of the MAC.

Two major outputs from the sectoral input-output-model are the sectoral gross-value-added that is used for the calculation of employment and the GDP share for goods production that forms an input for the transport generation model within the REM.

In the future it is expected that the service sectors will increase stronger than the agricultural sector and the industrial sectors. In other words, the share on GDP of the service sectors will increase, while the goods sector´s share will decrease.

6.1.3 Implementation of the macroeconomics sub-module (MAC)

The following figure 11 presents the major models of the MAC and the structure of their main relationships, which is already explained in brief above.

[15] The EUROSTAT Input-Output-Tables can be ordered from the EUROSTAT datashop in Luxembourg in electronic format (EUROSTAT 1995)

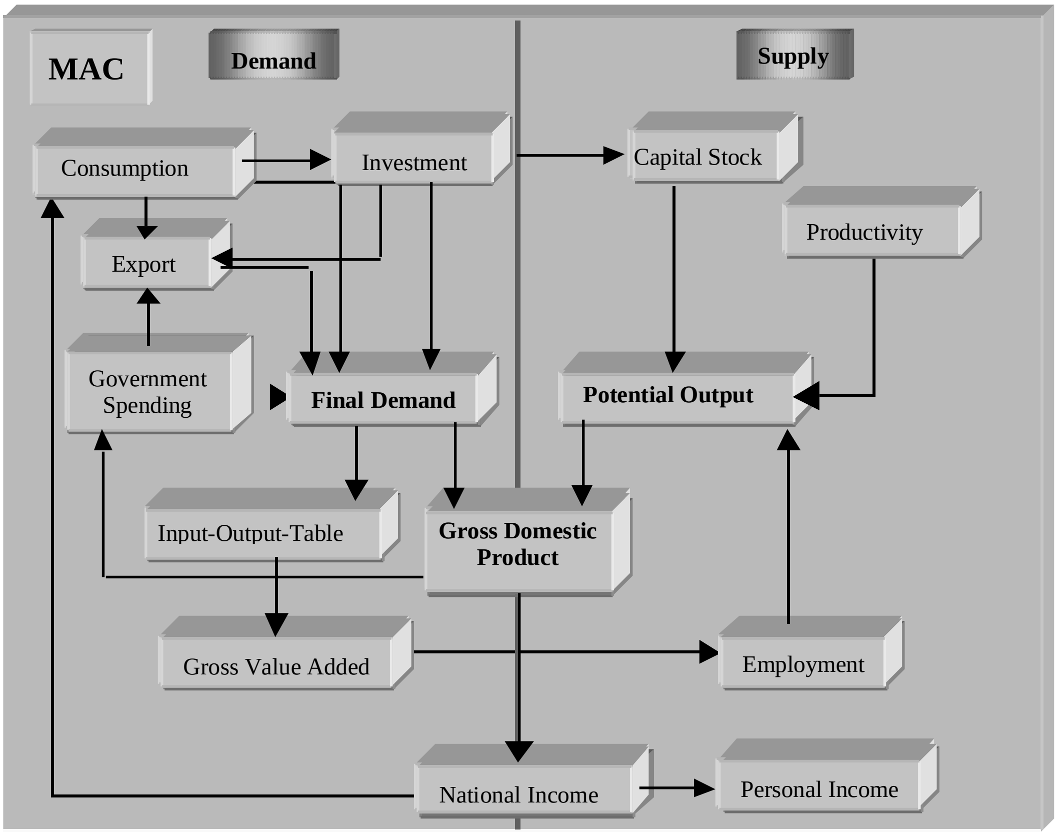

Figure 11: Relationships between the Models of the MAC

6.1.3.1 Potential Output Model

For the calculation of potential output an extended Cobb-Douglas function is used including labour, capital, natural resources and productivity as inputs:

$$PO = bPO + cPO * e^{(PROD * t)} * LS(t)^{\alpha} * CS(t)^{\beta} * NR(t)^{\gamma} \qquad \text{(eq. 1)}$$

where: PO = Potential Output [Bio*EURO]

bPO = Base level variable for potential output

cPO = Constant factor for potential output development

PROD = Productivity development

LS = Labour supply in working hours

CS = Capital Stock

NR = Natural resources

α, β, γ = production elasticities

Labour supply stands for the total number of yearly worked hours. As such it is based on total employment calculated within the employment model and the number of average yearly worked hours. The capital stock depends on the initial gross capital stock, the investment (capital goods including transport investments) and the scrappage of the capital stock. The autonomous productivity influence is modelled with a diminishing increase over time. For further improvements of the model the productivity increase could be split into an autonomous increase of productivity and a transport system dependent increase e.g. if time savings in the transport system are realized.

Basic information about production elasticities for labour, capital and resources are taken from existing studies.[16] For labour supply the elasticity is in the range of 0.48 and for capital of 0.62. These values have been adjusted for the different macro regions in the calibration process.

6.1.3.2 Final Demand Model and GDP

Final demand is aggregated from the four major demand variables: consumption, investment, government expenditure and export. As the four drivers of final demand are disaggregated into 12 economic sectors (e.g. mineral oil industry) this is also valid for final demand.

$$\mathbf{FD_s = C_s + I_s + GE_s + EX_s} \qquad \textbf{(eq. 2)}$$

where: FD = final demand [Mio*EURO]

C = private consumption

I = investments

GE = government expenditures

EX = exports

s = index for 12 economic sectors

Aggregating final demand over all 12 sectors leads to the total final demand in each macro region. Total final demand and potential output are used to calculate the supply-demand balanced gross domestic product (GDP). The balance between demand and supply side can be adjusted in the model. For ASTRA both sides are treated with an equal weight.

6.1.3.3 Input-Output-Model

The objective of the input-output-model is to consider also the indirect effects of the varying sectoral developments in the ASP. For this purpose an aggregated input-output-table with 12 economic sectors[17] is implemented:

1. Agriculture, forestry and fishery.

2. Energy, water-, mining products, crude oil.

3. Chemical-, mineral-, plastic- and petroleum products.

4. Ferrous and non-ferrous ores and metals.

5. Steel products, machinery, transport equipment.

[16] MÜLLER/ROTHENGATTER (1988)

[17] The concept of an aggregated input-output-table is established in the German system of national accounts, where a detailed I-O-table with 58 economic sectors and an aggregated I-O-table with 12 sectors is used (e.g. STATISTISCHES BUNDESAMT 1997a).

6. Electrical-, optical goods, office and data processing, toys.
7. Textiles, clothing, paper, wooden goods.
8. Food, beverages, tobacco.
9. Building and construction.
10. Services for repair, wholesale and retail, transport, communication.
11. Other market services like lodging, catering, credits, insurances.
12. Non-market services.

The sectoral split enables to consider effects of changes in the transport system directly in the economic sectors, in which they have an effect e.g. road vehicle production in sector 5 "Steel products, Machinery, Transport Equipment". But also via the update of the input-output-table with the use of endogenously calculated inverse coefficients (see figure 12) the indirect effects of changes within one sector provided by another sector are covered. E.g. changes in vehicle production in sector 5 will have an effect on sector 4 on the production of ferrous and non-ferrous metals.

The changes in the input-output-table are driven by the changes in sectoral final demand e.g. consumption of transport services (e.g. passenger rail transport) that have an effect on sector 10 " Services for Repair, Wholesale and Retail, Transport, Communication". With the use of the input-output-table several important economic indicators can be calculated and used for further purposes e.g. input of intermediate products per sector, production value, gross value added. An overview of the structure is shown in figure 12:

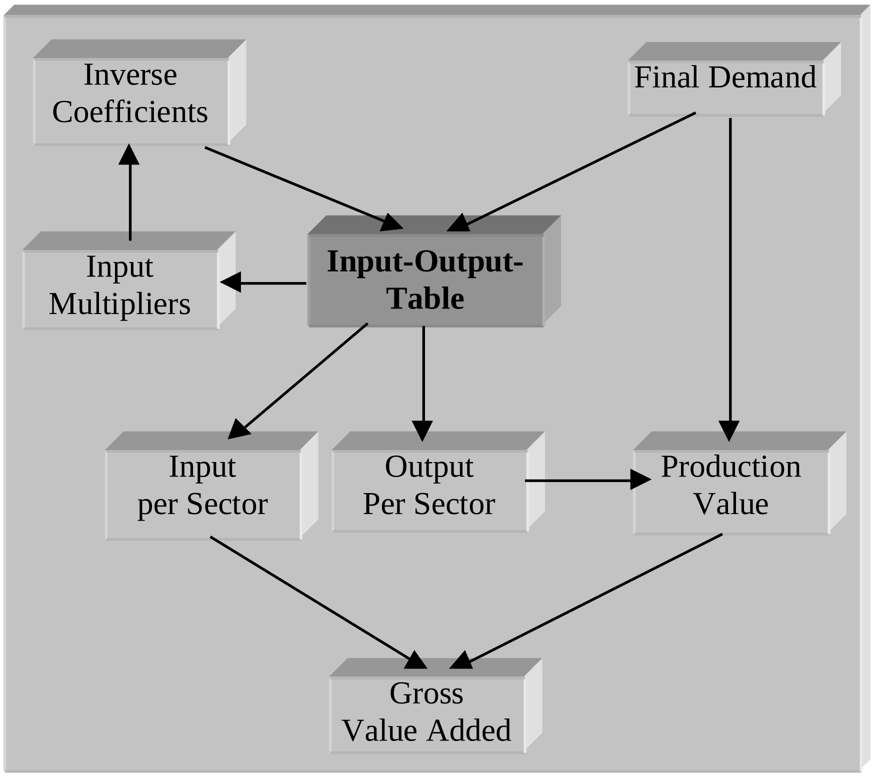

Figure 12:Structure of the Input-Output-Model

6.1.3.4 Consumption Model

The consumption model calculates the consumption of private households. The baseline for the consumption model is given by national income that is derived from GDP subtracting depreciation, indirect taxes and subsidies. The former two influences are calculated endogenously while subsidies are taken exogenously.

Considering savings national income is used to calculate the possible consumption of households. Then consumption is disaggregated twofold: first the sectoral split into 12 economic sectors is performed and second a split into consumption for non-transport purposes and consumption for transport purposes is introduced. The latter split actually only effects sectors that are **directly** influenced by transport, which are the sector 3 including petroleum products, sector 5 including car manufacturing and sector 10 including passenger transport services (bus, rail, air).

With this approach substitution effects between transport and non-transport consumption are considered in a way that e.g. a decrease of consumption in transport sectors leads to a non-negligible increase of consumption in non-transport sectors. This does not mean that there will be a complete compensation because of complementarities between transport and other activities and incentive effects.

As all variables in the consumption model are representing net values without any taxes it has to be taken into account that most transport related consumption is taxed different than non-transport consumption. That means without considering any secondary effects a decrease in transport fuel consumption (net!) would increase overall consumption (net!) as transport taxes are higher than average taxes on consumption. Figure 13 gives an overview on the consumption model.

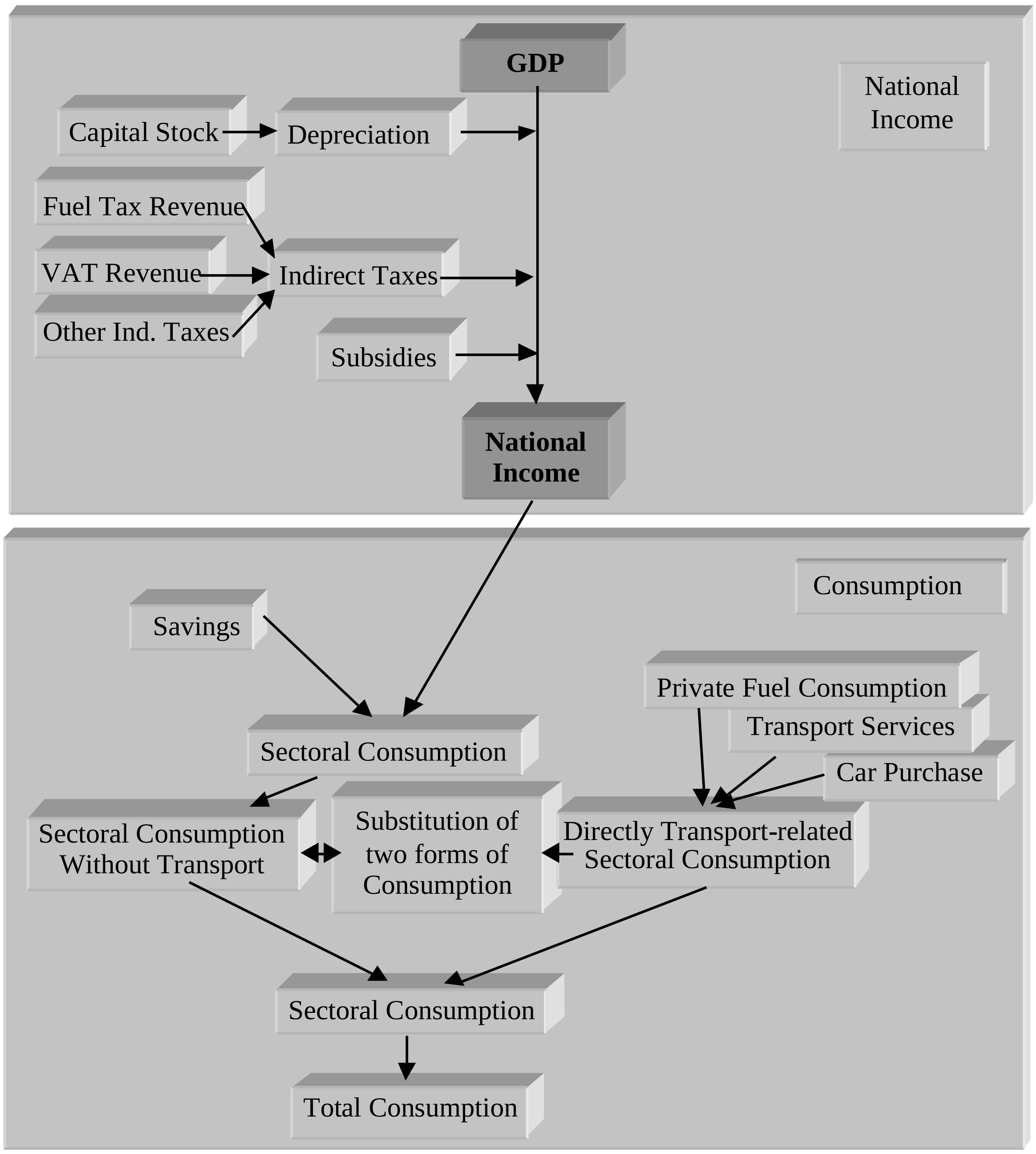

Figure 13: Structure of National Income and Consumption Model

6.1.3.5 Investment Model

The investment model calculates the investment of enterprises and government. Basically there is a similar disaggregation of investments as for consumption. That means, first a sectoral disaggregation into 12 economic sectors is applied and second investments are separated into the transport related and the non-transport investments. For the non-transport investments the development of investment in one sector depends on the development of consumption in the same sector.

Transport related investments describe the investments in vehicles for passenger transport (e.g. buses, planes) and in freight vehicles (e.g. LDV, HDV). Values for these investments are provided by the vehicle fleet models or in dependency of transport demand. These investments are included within sector 5 as transport equipment belongs to this sector. Investments in transport infrastructure belong to sector 9 building and construction. These investments can be private (e.g. for loading- and unloading facilities) or public (e.g. for most of the transport infrastructure network). Values for facility investments depend on transport demand, while network investments depend on GDP development and transport policy measures.

6.1.3.6 Employment Model

The employment model is also disaggregated into 12 economic sectors of which sector 5 with transport equipment and sector 10 with transport services include employment in the transport system while the other sectors represent only employment in non-transport sectors.

The basic calculation of employment depends on the sectoral gross value added (GVA) calculated by the input-output model and an inverse labour productivity expressed as emplyoment over GVA. The productivity variable is changing over time because of higher labour productivity. Also there is a feedback implemented from unemployment to an enforced increase of labour productivity if unemployment rates reach very low levels.

Employment in the transport related sectors 5 and 10 depend on the transport expenditures paid either for transport services, for purchase of domestically produced vehicles or for vehicle export. These values that are provided by TRA and ENV can be assigned to the four modes road, rail, air and ship. For each mode a specific employment productivity is used to calculate the employment produced in the different modes. This enables to capture employment shifts e.g. caused by changes in modal split. The structure of the employment model is shown in figure 14:

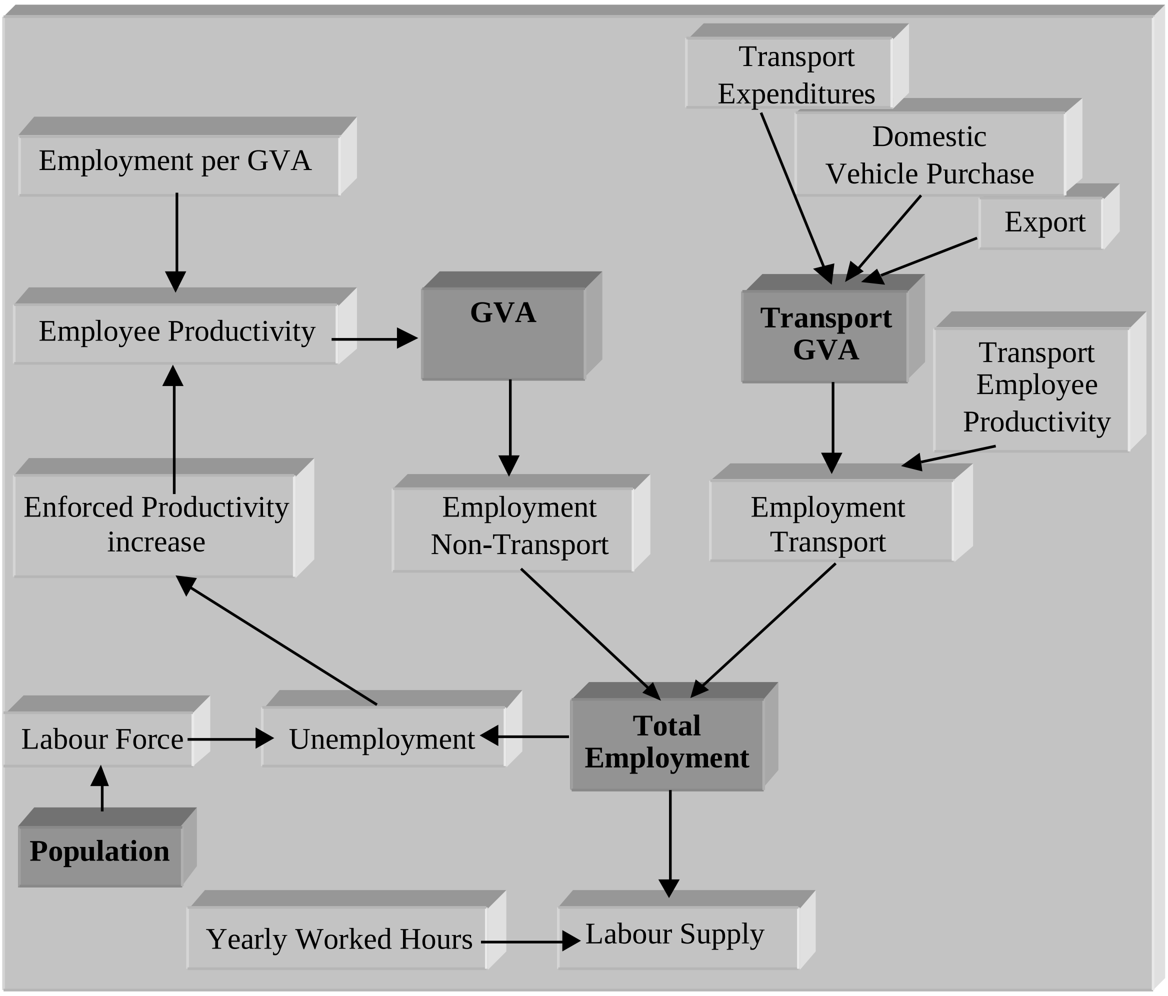

Figure 14: Structure of the Employment Model

Finally, based on the employment figure and the yearly worked hours the labour supply for each of the regions is derived. This forms an input to the calculation of the production potential.

6.1.3.7 Model of the Capital Stock

The capital stock is modelled from two viewpoints. The first view represents the gross fixed capital stock in each macro region, which is the relevant input variable for capital within the calculation of production potential. The second view stands for the net capital stock that forms the baseline for the calculation of depreciation in the macro regions. Gross and net capital stock are divided into public and private capital. The capital stock for both is increased by investments of which a defined share is private investment and the network infrastructure investment are treated as public investment. The decrease of gross capital stock is driven by scrappage depending on the average lifetime of capital while the decrease of net capital stock by depreciation depends on the average depreciation period for private and public capital.

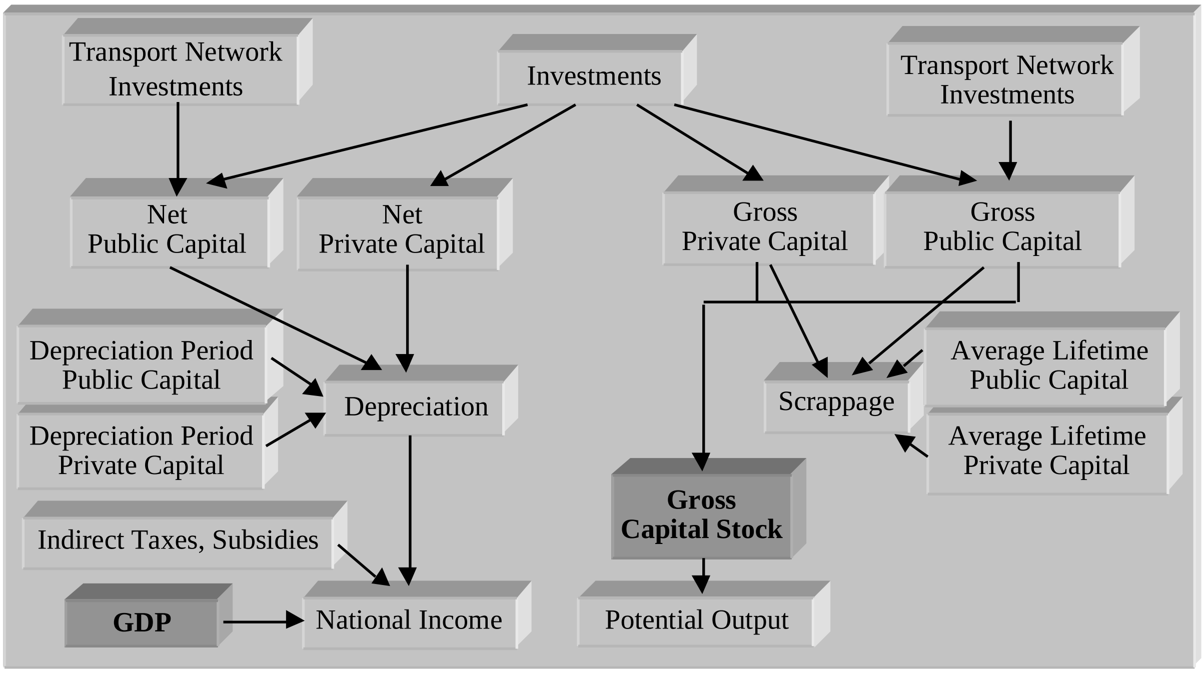

Figure 15: Structure of the Model of the Capital Stock

6.1.3.8 Model of National Income and Personal Income

The baseline for the calculation of national income is given by GDP. Considering the payments balance between foreigners employed in a country and nationals employed abroad the gross national product is derived. The payments balance is taken exogenously. It might even be omitted as it represents only a small number. In the following step depreciation, which is calculated in the capital stock model, is subtracted and one receives the net national product. Subtracting the indirect taxes (including VAT, fuel tax and other taxes) and adding subsidies the national income is calculated. This leads to equation 3:

$$\mathbf{NI = GDP - EBP - D - IndT + SUB} \qquad \textbf{(eq. 3)}$$

where: NI = national income

GDP = gross domestic product

EBP = employment balance payments

D = depreciation

IndT = indirect taxes

SUB = subsidies

In subsequent steps disposable income is calculated based on the national income. First direct taxes and social protection payments both given as shares of GDP are subtracted and second transfer payments to households (exogenously) are added:

$$\mathbf{DI = NI - DirT - SPP + THH} \qquad \textbf{(eq. 4)}$$

where: DI = disposable income

NI = national income

DirT = direct taxes

SPP = social protection payments

THH = transfer payments to households

Finally based on disposable income and the employment figures an average personal income per employee is calculated, which for instance is used as an influence for the calculation of the vehicle fleet.

6.1.3.9 Tax Model

With the tax model direct and indirect taxes are calculated. The calculation of direct taxes follows a simplified approach that uses trend shares of direct taxes on GDP. Indirect taxes are treated more sophisticated as their influence on transport is stronger. Indirect taxes in the model consist of:

- fuel tax revenues,
- value added tax revenues from
  - fuel
  - other transport consumption
  - non-transport consumption
- other indirect tax revenues.

The total fuel price for gasoline, diesel and kerosene is calculated in the ENV. The fuel prices consist of a pure fuel price, a fuel tax for each type of fuel (in case of kerosene in the base run the tax is zero) and the value added tax. Based on this structure the fuel tax revenues are calculated using the fuel consumption by the different modes and combining it with the tax rates for the specific fuel.

$$\mathbf{FT_i} = \sum_m (FC_{m,i} * TR_{m,i}) \qquad \textbf{(eq. 5)}$$

where: FT= fuel tax revenues

FC = fuel consumption for transport

TR = tax rate

i = fuel types (gasoline, diesel, kerosene)

m = transport modes (private car, business car, bus, LDV, HDV, diesel rail, air).

Until 1996 fuel prices and tax rates are taken from statistics. Afterwards increasing trends are applied (see annex A).

The revenues from the value added tax on fuel can be calculated similar to fuel tax considering not only the fuel consumption and the tax rates but also the pure fuel price for different fuel types. The VAT revenues from transport consumption stem from two sources: first private car purchase are used to calculate VAT from transport production and second the demand for transport services (bus, rail air) is used to calculate VAT from transport services. The calculation of VAT revenues from non-transport consumption is based on the consumption without-transport variable in the consumption model.

Finally other indirect taxes are also considered in the model as an input to VAT revenues. These revenues represent taxes on alcohol, tobacco, etc. The output of the tax model is used in the calculation of national income, personal income and for the shift of consumption between transport and non-transport consumption.

6.1.4 Calibration of the MAC

As major data sources for the MAC and also as sources for calibration data the following three sources are used:

- EUROSTAT harmonised input-output-tables for 1995 with 25 economic sectors (R25) for all EU15 member countries except Greece,[18]
- EUROSTAT statistical yearbook for 1997 including statistics from 1986 to 1996[19] and
- from the German statistical office the statistical yearbook 1997 for foreign countries.[20]

The latter two sources provide data as time series for the years (1986-) 1990 to 1996, while the harmonized I-O-tables are only available for the year 1995. So, basically the calibration period lasts from 1986 to 1995. Considering that within system dynamics models there can occur initial oscillations or other initial irregularities the core period for calibration is 1990 to 1995. Also for some (e.g. sectoral) data only the 1995 values are available such that for this year the strongest anchor to reality is attempted. Major variables used for calibration are:

- GDP
- Employment
- Consumption
- Capital

The objective for calibration is to keep the variables in a range of +/- 3% deviation from real variables for the core period. For variables of minor importance deviations can be in the range of +/- 10%. It has to be mentioned that because of recession tendencies in Europe in the years 1992-1993 e.g. GDP in real terms in some countries was constant or even declined. However

18 EUROSTAT (1995)
19 EUROSTAT (1997c)
20 STATISTISCHES BUNDESAMT (1997b)

it is not aspired to model that short term economic oscillations and therefore also not to calibrate to these oscillations. Instead then the focus of calibration was put on the long term growth rates of GDP.

As the structure of the MAC enables to use the GDP development as a major driver for the future economic development, the calibration of GDP in the core period in the base scenario considers also that the future development of GDP is in the range of what is projected by other studies (e.g.SCENES).

6.1.5 Interfaces to other sub-modules

As one purpose of the MAC sub-module is to provide the other sub-modules with continental level influence it is obvious that macro variables have to be transferred from MAC to the other sub-modules. So, the following three links are established:

- GDP goods is transferred to the REM,
- employment and unemployment per macro region provided to the REM and,
- income per employee transferred to the ENV.

6.1.5.1 Interface MAC => REM

For the freight model the MAC provides data on the GDP produced by good sectors per macro region. This so-called GDP Goods is then used in the REM to drive the freight generation model for the 13 goods sectors within the REM. The GDP Goods value is derived from the agricultural sector and the 8 industrial sectors of the I-O-table.

For the passenger model the MAC transfers information on employment per macro region to the REM. This information influences the size of the economically active population, which performs an impact on the activity patterns.

6.1.5.2 Interface MAC => TRA

The MAC transfers information about GDP and annual GDP growth rates to the TRA, where it is used to calculate a kind of base level investment into road infrastructure. This base level investment drives the development of the road network.

6.1.5.3 Interface MAC => ENV

The ENV receives from the MAC data on the average income per employee within the different macro regions. This data is then used to calculate the changes in car vehicle fleet, which subsequently is transferred to the REM, where it forms an input to the car-ownership model.