Table of Contents

Go Back

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The ASTRA-Italia model for strategic assessment of transport policies and investments

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Abstract

This paper presents the ASTRA-Italia model, a tool to analyse the long-term effect of transport policies and investments. In the ASTRA-Italia System Dynamics strategic transport model mobility prediction is the result of a complex interaction process among four different components: transport, economy, land-use and environment. The tool is then capable to illustrate the reciprocal influences among transport and ecological and socio-economic systems. As an example, the links between passenger and freight mobility and the economic performance are bi-directional, which means that feed-back effects are simulated showing how modifications in the economic performances might reinforce (or alternatively dampen) the transport development and vice-versa.

The spatial representation of the four modules - transport, economy, land-use and environment - is very different and then the common spatial representation in ASTRA-Italia is based on a combination of macro-regions – aggregations of the 20 Italian administrative regions - and functional zones – clusters of the 90 Italian administrative provinces according to different settlement types. The transport system is represented by distance bands (separately for passenger and freight) considering different modal choice alternatives and different driving patterns in dependency of the trip length.

The model simulation period covers thirty years (2000-2030) and a reference scenario was constructed with a projection of past and current trends of key variables. Policy packages can be then tested and compared with such reference case. To explore sustainable paths, the model produces a great variety of quantified indicators including variations in: GDP, employment, private consumption, tax revenues, transport performance (pass*km and tonnes*km), modal shift, vehicle fleet development, traffic emissions, fuel consumption. Monetary values are also estimated for external costs.

This paper illustrates the application of ASTRA-Italia model for the assessment of the impact on Italian transport system of different pricing and taxation policies.

1. INTRODUCTION

The determinants of transport system change over different time scale. Major driving forces can be managed only in the long-term time horizon: 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, like the preference to live in green suburban areas or in city centres, also develop over a long time such that they contribute to the self-image of a generation of people. Other transport determinants have a different pattern, as they vary significantly in the short-medium term: it is the case for transport costs which have a direct impact on modal split (and then a short time effect) as well as on accessibility (both a short and a medium term effect). Furthermore, the transport system is strictly connected with other complex systems like the society, the economy and the environment. Improvements of the transport system were in history often a major source of growing welfare of societies. Also transport forms a part of the social life of society by providing the basis for personal mobility.

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. In 2000 road transport caused 6.410 deaths by traffic accidents in Italy. The World Health Organisation estimates that additionally 15.000 people are killed by hazardous gaseous emissions of transport per year (80.000 in Europe). Also the contributions of transport to global phenomena 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. Particulate matter concentrations had determined road traffic bans in many urban areas at the beginning of the year 2002 putting the environmental consequences of urban car traffic on top of the political agenda.

Transport policy assessment approaches therefore have to be capable of reflecting these highly interrelated systems as well as of measuring long-term changes taking into account the effect for shorter term cycles. The System Dynamics modelling approach seems to be appropriate for these purposes.

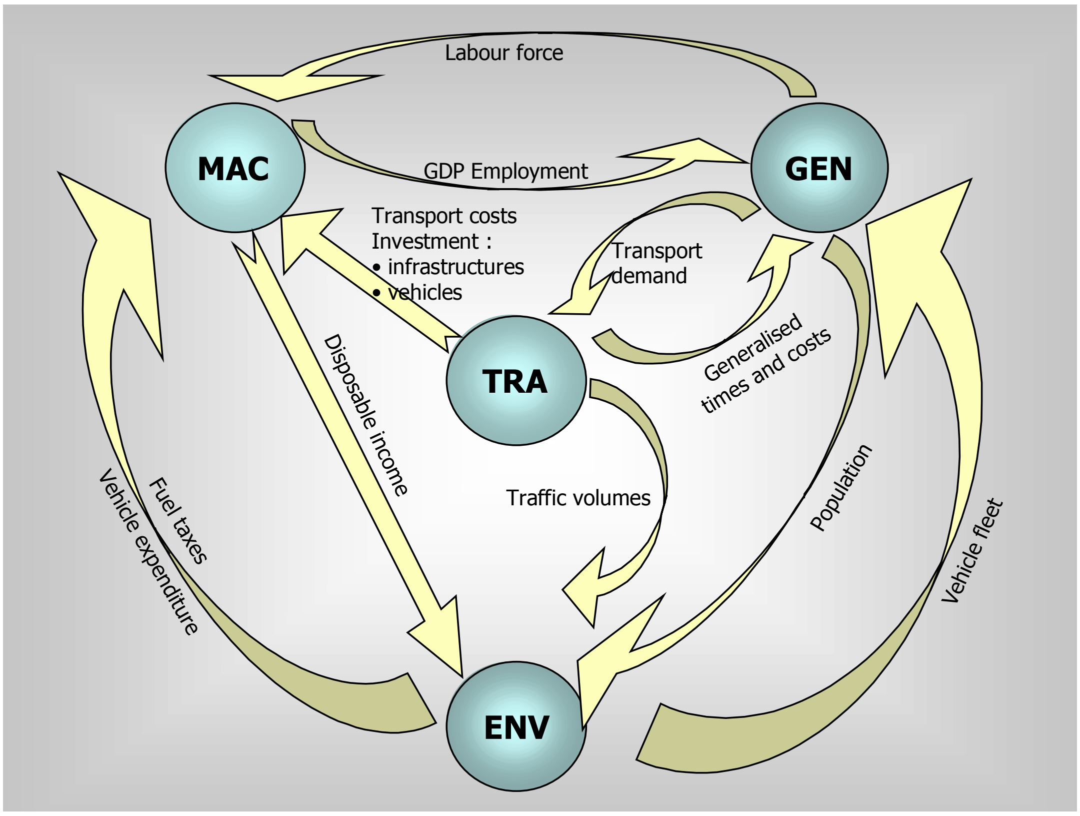
This paper introduces the ASTRA-Italia model, which was developed starting from the Europe-wide ASTRA model[1]. The System Dynamics tool, implemented with Vensim software package, can be used to analyse the long-term effects of transport policies and investments, with particular focus on the economic leverages (tolls, taxes, subsidies), and is based on state-of-the-art components in the four fields of macroeconomics, regional economics and land use, transport and environment.

This content of the paper is the following. In section 2, an overview of the model structure is provided. In section 3, the key elements of the model are described. In section 4 the main feedback effects within the model are presented. In section 5, the results of the application of the model are discussed. Conclusions, acknowledgements and a list references used to build and calibrate the model end the paper., the ASTRA-Italia sub-models are presented in some details in the annex.

2. THE ASTRA-ITALIA SYSTEM DYNAMICS MODEL

The ASTRA-Italia model is a System Dynamics model focused on the study of Italian demand of transport and its links to economy and environment at an aggregate level. Its structure includes four sub-models strictly connected among each other (figure 2.1 gives a broad idea of the main links among the sub-models).

Fig. 2.1 Structure of the ASTRA-Italia model



In brief, the ASTRA-Italia System Dynamics model works as follows. The macroeconomics sub-model (MAC) estimates the economic framework data of the country. The results of the MAC key indicators (e.g. GDP, employment) are transferred to the transport demand generation sub-model (GEN), which forms the input of the first two steps of the classical four-stage transport model: travel demand generation and distribution. The demand is transferred to the transport sub-model (TRA), which includes the final two stages: modal split and assignment. The environmental sub-model (ENV) is mainly fed by data from the TRA (e.g. traffic volumes) and includes the vehicle fleet modules. Environmental indicators (e.g. CO_2 emissions) are calculated and the welfare consequences performed by the environmental impacts are estimated.

The role of each sub-model could be shortly described as follows (more details are provided in the annex):

- The macroeconomics sub-model (MAC) is a Keynesian model with three major elements: *supply side model* (including a Cobb-Douglas production function incorporating the labour supply, capital stocks and natural resources), d*emand side model* (with final demand driven by consumption, investment, government expenditure and exports), and *sector relationship model* (based on an input-output table with twelve economics sectors). The interaction between supply and demand side was adjusted such that the model simulates a supply-demand balanced economy.

- Passenger demand, as modelled in the GEN, is derived through a combination of demographic cohorts based on age and economic position, car ownership and labour force models with feedback with the MAC (employment) and ENV (vehicle fleet), identifying twelve homogenous demand segments (e.g. Employed adults with no car, Unemployed/ inactive adults with a car, etc). Trip rates by purpose (business and commuting, personal and tourism) are then applied. Freight demand is based on industrial production in fifteen economic sectors which are then converted to tonnes lifted using value-to-volume ratios and aggregated into three freight categories (solid and liquid bulk, semi-bulk and unitised freight). Both passenger and freight demand by purpose/category are generated for each of the zones/regions and then distributed across a set of destinations represented by a combination of destination region/zone and distance band to create passenger and freight demand matrices which are fed into the TRA.

- The transport system (TRA) is represented by distance bands, consistent with those used in the GEN, which differ for the consideration of passenger (5 bands) and freight (4 bands) demand. Each of these distance bands consider different modal alternatives: road-based, rail-based, air (for passengers) and sea-based (for freight) modes. After the modal split has been performed for each distance band, the passenger and freight road traffic is assigned to either the urban or non-urban network, each distance band being assigned to one of the networks. The unit monetary costs (freight) and generalised times (passenger) from the traffic assignment feed back into the GEN trip and freight distribution for the next time period and, in this way, the dynamic effects of changes in relative transport accessibility can be monitored.

The geographical scope of the model is Italy, which is split into three macro-regions: North, Centre and South. Each macro-region is defined as an aggregation of Regions - consistent to the definition adopted by ISTAT, Italian bureau of statistics - and is further classified into three functional zones, clusters of Provinces on the basis of urban settlement typologies.

The macroeconomics sub-model works at the macro-region level (i.e. GDP, employment, income are computed for each macro-region) as well as the freight transport modelling and the computation of emissions and external costs, which are further distinguished between urban and non urban. Basically functional zones are used for generation, distribution and modal split of passenger transport demand.

The model simulation period is of 40 years, from 1990 to 2030, where years from 1990 to 2000 are used for calibration. Results are provided year by year.

3. THE KEY ELEMENTS OF THE MODEL

System Dynamics models are not generally used to model transport systems although it is widely recognised that these have a dynamic nature. The main reason why dynamic models are not used is that the level of detail allowed is still lower in comparison with traditional modelling.

Classical four-step transport models can readily manage zoning systems with hundreds of zones and networks with thousands of nodes and links. Their drawback is that they normally take a long time to run (hours), require a detailed calibration of the transport network and still do not cover the impacts of transport polices and investments in the other sectors like environment or economics.

The aim of ASTRA –Italia was to develop an assessment tool capable to take the best of the two methodologies, trying to keep the simplicity of use of system dynamics models (friendly interface, transparent model design, quick simulation runs), while at the same time guaranteeing the application of the quantitative methodology derived from classical modelling in the transport, environmental and economic sectors. Of course the ASTRA-Italia model could not simply be the sum of the detailed models in the concerned sectors: it would have been definitely too complex and not manageable. Then a number of strategies had to be implemented in order to reduce the complexity of the task. Such strategies were essentially directed to simplify the description of the matrix and of the network and are reminded below. Such simplifications have to be considered bearing in mind the aim of the ASTRA-Italia tool, the strategic assessment of transport policies and investments, whose focus is not strictly on the impacts within the transport sector.

3.1 Simplifying the matrix: the functional zones and the distance bands

The first strategy adopted in ASTRA-Italia was to use a non-geographic definition of origins and destinations. A correct representation of the various conditions for the interaction of transport demand and supply (e.g. choice of modal alternatives, choice of path alternatives, etc.) requires a spatial analysis and thus the definition of a set of matrices. In order to keep these as simple as possible, still retaining the maximum of the information required for distinguishing the relevant cases, functional zones and distance bands were defined.

The three Italian macro-regions are further classified into three functional zones, which defined as an aggregation of Provinces[2] according the following criteria:

- **Metropolitan areas (AM)**: Provinces where the large majority of inhabitants live in the capital or in its metropolitan area. The overall population amounts to one million or more.

- **High density areas (AD)**: Provinces where the capital is a town with at least 150.000 inhabitants and/or Provinces where the population density is higher than 250 inhabitants per km^2.
- **Low density areas (AP)**: Provinces where the population density is lower than 250 inhabitants per km^2.

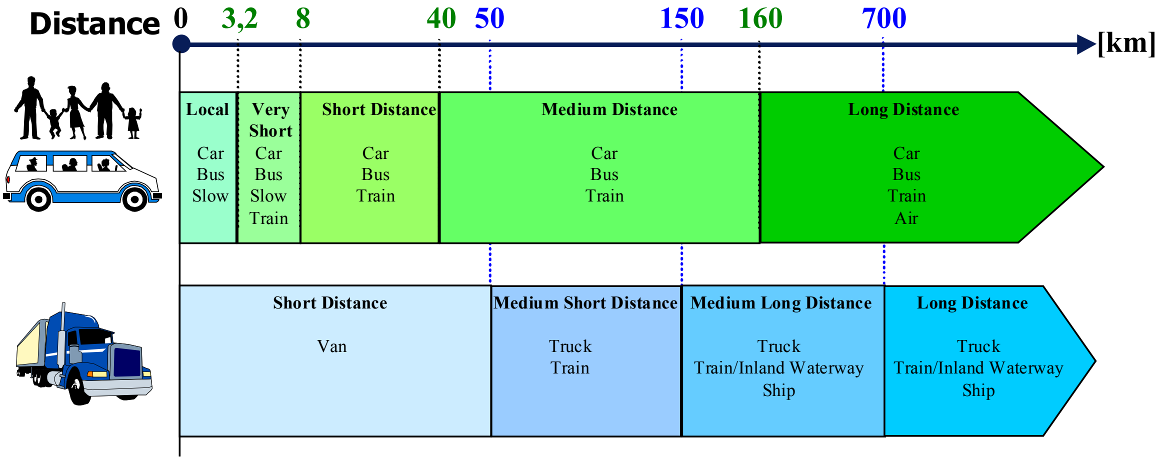
Functional zones associate areas which are far away from each other but which share a common (average) availability of transport supply, a common mobility pattern (average distances, etc.) and so on. Distance bands allow to define a separate set of available modes for each distance class. For instance, slow modes are feasible alternatives if the distance of the trip is limited whereas, on the other side, air is not competitive under a threshold of hundreds kilometres.

Passenger demand was represented in matrix, with functional zones working as origins and destinations. Origin/Destination trips based on functional zones or macro-regions (freight) were further classified according to distance bands. In this way, though the level of transport supply, the availability of modes, etc. of each town-to-town trip could not be represented (like it could have been in a classical model) all trips taking place in similar conditions could be associated to specific parameters.

For instance, a freight consignment from Northern Italy to Central Italy can travel for 100 km or for 500 km. For passenger trips, as functional zones have not an immediate geographical meaning, the information concerning distance is even more important. A trip from metropolitan areas of Southern Italy to metropolitan areas of Southern Italy (i.e. with same origin and destination) could be a short trip within he same town (e.g. Naples) or a long trip from town to another (e.g. from Naples to Palermo).

For these reasons, possible destinations are described also in term of distance bands. In other words, demand generated in a give zone is distributed among the available destinations which are defined crossing functional zones (or macro-regions) and distance bands. Two different distance bands systems are defined for passenger and freight (bands for passenger demand are shifted on shorter distances than freight ones; this reflect the observed pattern of passenger and freight trips). They are represented in figure 3.1.

Fig. 3.1 Distance bands for passengers and freight traffic



3.2 Simplifying the network: the aggregate speed-flow curve

It has been remarked above how the interaction between the assignment and the modal split phases is the core of a transport model. The assignment phase requires a network. Even the most simplified network representing the existing links among the Italian zones would be too complex for the modelling tool however.

Since the demand/supply interaction was of interest, a synthetic representation was adopted by “collapsing” the links of the ideal detailed network in a single variable for each macro-region, where the whole capacity of such links were summed. At the same time, the traffic performed on the links was summed as well in order to have a comparable variable. The interaction between flow and capacity was therefore modelled by means of a single aggregate speed-flow curve for each macro-region.

The speed-flow curves adopted were then fine-tuned during the model calibration phase as their form was necessarily different from those of curves used on single links. As the overall traffic of a region was involved, the average level of congestion was simulated. This means that the average speed was derived. Such an average speed is increased gradually with respect of the base speed by the speed-flow curve calibrated. Even when the flow/capacity ratio exceeds 1, the decrement of speed is not significant as it usually happens when a single link is considered. This for the understandable reason that one link can easily subjected to congestion phenomena when traffic is almost stopped whereas a whole network cannot. Furthermore, it was verified that if a dramatic increment of time was coded when flow exceeds capacity, the model was subjected to large oscillations caused by the effect of trip time on modal shares.

4. THE FEEDBACK EFFECTS

In this section the main feedback effects modelled in ASTRA-Italia are reminded in order to emphasise that the model can handle the typical interactions *within* the transport sector simulated in a classical transport model and enlarge the scope of the analysis to cover the interactions *between* transport and other sectors.

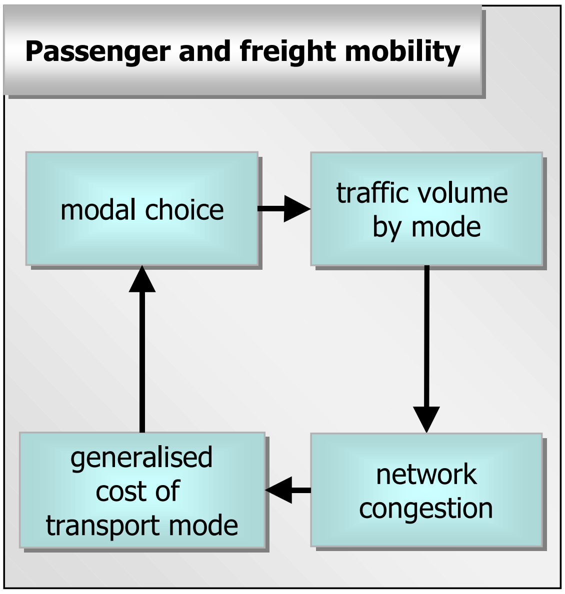
4.1 Modal split and assignment

The classical feedback effect usually implemented in most transport models involves the modal split and the assignment phases. One the one hand the travel time, which plays a significant role in modal choice, is influenced by the congestion level on the network, which is the outcome of the assignment phase; on the other hand is the modal choice which determines the number of vehicles by modes of transport and then influences the level of congestion and thus the assignment phase.

The resulting circle is depicted in figure 4.1. As explained above, the ASTRA-Italia model is able to represent such an interaction for all transport modes. A relevant difference with respect to a classical static model is that the reciprocal effects are read through the time: while a static model does many iterations towards an equilibrium at a given time reference, the ASTRA-Italia model adjusts the variables at each time span and the situation evolves continuously without any balance to reach.

In principle the dynamic simulation is more realistic than the static one as actual transport systems are not in equilibrium. However, when a non-marginal shock occurs and modal split changes considerably leading to a high level of congestion, the dynamic model can require some years to flat possible oscillations, which might propagate their effects through the transport model. The optimal solution would be then a combination of the traditional approach (at static equilibrium) and the dynamic process: this is a research field still to be explored.

Fig. 4.1 Modal split – assignment feedback



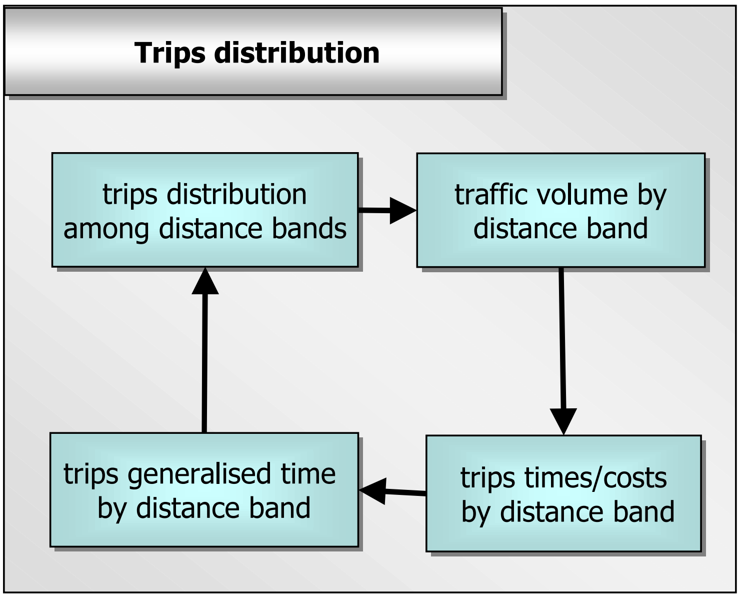
4.2 Generalised transport time and trip distribution

In ASTRA-Italia the matrix of trips is affected by the pattern of generalised times. When travelling becomes less expansive, trips on longer distances become more frequent. This increases the congestion and thus travelling becomes more expansive. So trips on longer distances becomes less frequent. Therefore, the transport sector has a feedback on the distribution module which simulate how activities interacts spatially (figure 4.2).

The trip distribution – transport generalised time feedback effect is simulated by transport models according to different methodological approaches. In land-use and transport integrated models dealing with location choicestravel matrices are produced endogenously with transport disutilities as one input. Such models usually read the generalised costs or times at a given time and use them to affect distribution at a later stage; . this because the decisions related to location require some time to be put into practice.

The approach described for the ASTRA-Italia model is simpler as it does not include any measures of location costs and makes reference to synthetic indicators like average trip distances. Furthermore the current version of the model still does not include the time lag for the distribution impact and any variation of the generalised times affects distribution in the subsequent model time span.

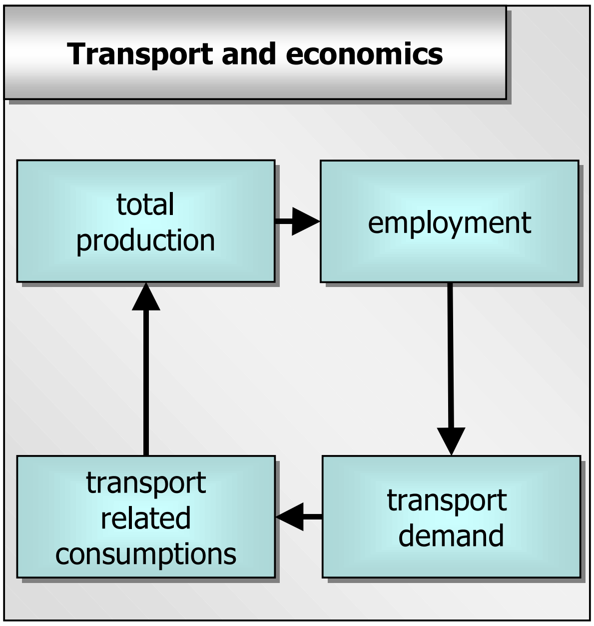
Fig. 4.2 Trip distribution – transport generalised time feedback



4.3 Transport demand and domestic product

The third relevant feedback is between the transport demand and the level of production. When transport demand grows, higher consumption of fuel, vehicles, etc. is simulated. In turn, this stimulates the production and therefore the employment. As the trip rates of employed are higher than those of unemployed, this yields an increment of transport demand (fig. 4.3). This feedback effect connects the transport sector to the rest of economy, which is usually not considered in classical models.

Fig. 4.3 Transport – Economy feedback



5. THE MODEL IMPLEMENTATION

The simplified representation of zones and network involves that the model is suitable to represent the transport system in its general features: overall volume of traffic performed, total fuel consumption, total amount of emissions and so on. For the same reasons the model is useful to test the effect of policies which are thought to have a global impact on the transport system.

In this section a brief review of the main results of the model are presented, with reference to the base scenario and the policies tested.

5.1 The base scenario

The ASTRA-Italia model was used to forecast the level of traffic until 2030 in a base scenario where exogenous assumptions about the demographic and economic trends were adopted and all the main transport variables (e.g. unitary costs of transport) were assumed as constant in real terms. The base scenario was not intended as the most likely evolution of the system, but just as a neutral scenario against which the other scenarios could be compared to highlight the effects of the policies.

The demographic trend is in line with the official forecasts of ISTAT. A slightly growth of population is forecast until about 2015, afterwards the total number of inhabitants should decrease. Within this trend, the class of population over 65 will be steadily increasing.

A moderate economic growth is forecast. GDP average growth is about 1.4% per year. It is worth noticing that this trend is not pre-determined but it is an endogenous product of the model given the parameters calibrated on the first ten years data.

One of the main determinants of mobility is car ownership. In spite of the population decrement, the fleet of cars will be increasing and so the rate will rise from 0.51 car/inhabitant in 2000 to 0.54 car/inhabitant in 2030.

The result of a more intensive economical activity, a higher average income and a higher number of cars per households is an increment of mobility. Figure 5.1 shows the trend of passengers*km and tonnes*km in comparison to the GDP trend.

Passenger*km increase of 24% from 2000 to 2030 while the growth of tonnes*km is 36%. The average growth rate of both passenger and freight traffic is lower than the GDP's (0.7% per year and 1.0% per year respectively), while in observed past traffic has been increasing at the same average rate of the economic activity.

Despite the increment of the traffic volume, the renewal of the road vehicles fleet (cars, buses and duty vehicles) leads to a significant shrinking of the emissions from road transport (fig. 5.2).

Fig. 5.1 Trend of GDP, pass*km and tonnes*km (year 2000 = 100)

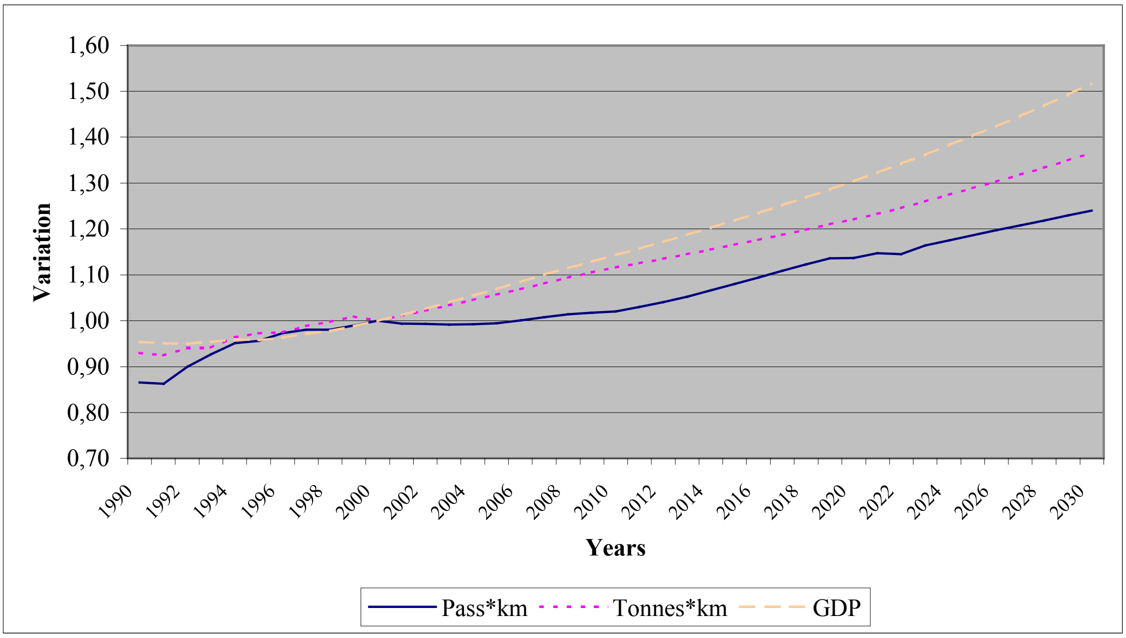
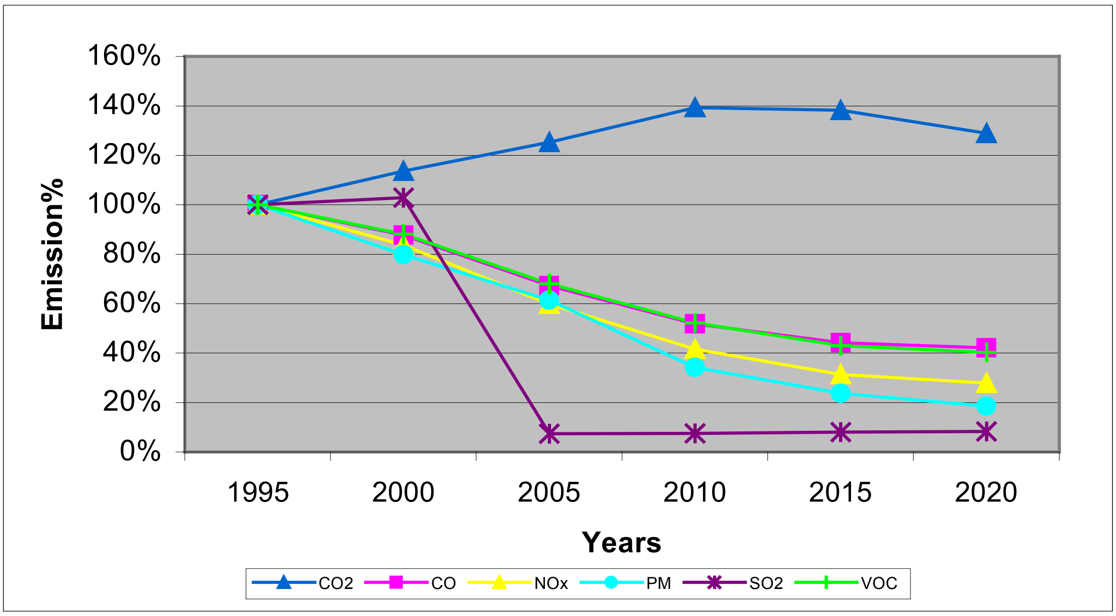


Fig. 5.2 Forecast percentage of emissions from road modes with respect to year 1995



5.2 The policy scenarios

Three policy scenarios were tested. All policies shared the same principle, that is taxing the modes proportionally to their net contribution to external costs (net of taxes and subsidies) and using the resources collected to subsidise measures aiming at reducing the external costs.

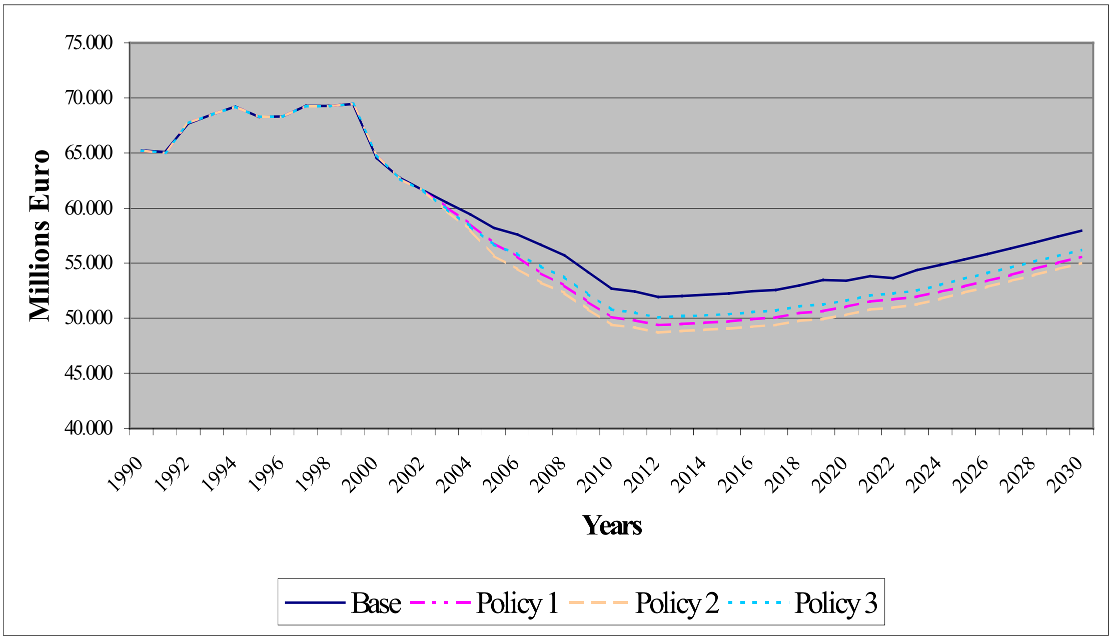
The method of collecting the resources was common to all the policies, that is increasing tolls on motorways, levying a toll on main roads and a price to enter in metropolitan areas. The use of the resources was different in each policy. In the first policy, non-road modes were subsidised in order to favouring the modal shift. In the second policy, an increment of the efficiency of freight transport was simulated, in the third policy the renewal of fleets was considered.

The objective was to evaluate the potential of each policy in terms of reduction of external costs. The main interest was on the comparison among the three ways of tackling the problem: favouring modal shift, increasing transport efficiency and accelerating the renewal of the fleet. In order to compare these three approaches without other effects which could bias the results, the volume of traffic forecast in the base scenario was considered as constant.

Figure 5.3 shows the effect of the three policies on external costs (according to the “low values” estimation provided by the model) in comparison of the base scenario. It can be readily seen that the policy produces a reduction of costs with respect to the base case.

However, if the trend 2000-2030 is considered, the largest part of the change of external costs takes place in the base scenario. The policy adds a relatively small contribution.

Fig. 5.3 Trend of external costs in base and policy scenarios



6. CONCLUSIONS

In this paper, an application of System Dynamics to the analysis of transport and related systems has been presented. The structure of the model, its key elements and some results of its application have been discussed.

The ASTRA-Italia model presents and innovative approach to the analysis of the impact of transport polices and investments as it includes the transport system together with the economic and environment systems and then it is capable to deal with primary and secondary effects of transport policies. As can be seen by the presented results, the model offers a wide range of indicators which are not limited to the transport sector (vehicles*km, passenger*km, modal shares, etc.) covering as well the impact on the economic sector (GDP growth, transport taxes, etc.), on the environment (green house gases and pollutant emissions, noise, etc.), on mobility patterns (average distances, etc.) on the welfare (external costs of transport).

In doing so, the modelling staff has translated in System Dynamics the key relations and functions extracted from state-of-the-art sector models like transport and land use integrated models or econometric models. The ASTRA-family models (Astra-Italia and the other applications at European level) could then be seen as a breakthrough in system dynamics and transportation modelling.

At this stage the model should be still considered under development. Though in its current fashion it can be used to analyse the impact of various policies, several improvements can be considered to enhance the modelling power of the tool. The development of ASTRA-Italia will be continuing in next years, with special reference to the simulation of localisation choices, the representation of network capacity, the dynamics of generation and behavioural parameters.

7. ACKNOWLEDGEMENTS

The ASTRA-Italia model was developed within a research project co-founded by Federtrasporto, the Italian association of transport enterprises.

The authors would also like to thank Wolfgang Schade from IWW Karlsruhe for his precious contribution to model design and development and Gerardo Marletto from Federtrasporto for his stimulus to the model enhancement with reference to policy sensitivity.

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[1] The ASTRA project was carried out by IWW Universität Karlsruhe (Germany), co-ordinator, TRT Trasporti e Territorio, ME&P Marcial Echenique and Partners, Cambridge (UK) e CEBR, Centre of Economic and Business Research, London (UK). The project was partially founded by the DGVII of European Commission. See ASTRA (2000) for details.

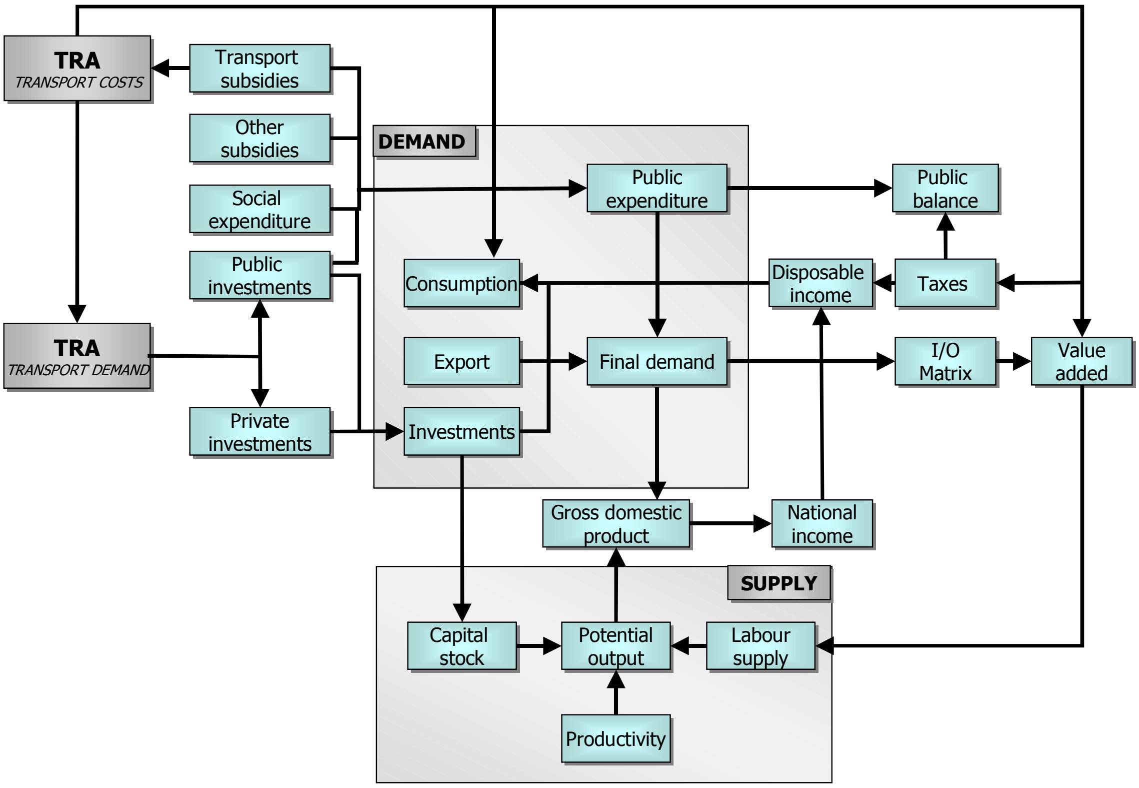
[2] It is worth to note that Provinces are aggregated into the functional zones even if they are not geographically contiguous. For instance, in the macro-region Northern Italy, the Provinces of Milan and Turin are both part of the same functional zone.

ANNEX: THE ASTRA-ITALIA SUB-MODELS IN DETAILS

A.1 The macroeconomic sub-model (MAC)

The role of the macroeconomic sub-model (MAC) is to provide the overall economic trend in term of GDP, Employment, income, etc. and to model in explicit terms the links between economy, demographic variables (e.g. population) and transport variables (e.g. cost of transport modes). Thus, the economy is a major determinant of transport demand and, at the same time, changes on the transport side can affect the level of the economic activity.

Fig. A.1 Structure of the MAC sub-model



MAC is not as sophisticated as an econometric model. The equilibrium between demand and supply, the trend of production, consumption, employment and so on are modelled without claiming of producing macroeconomic forecasts. Instead, MAC allows to read marginal changes of macroeconomic variables induced by changes in the transport sector and to make sure that trend of transport demand is consistent with the trend of the economy.

In figure A.1 the main elements of the MAC and their reciprocal links are depicted. In brief, the MAC consists of two main modules, one dealing with demand and the other one concerning supply. The interaction of the two modules produce the estimation of GDP.

The supply module uses a classical Cobb-Douglas function to estimate potential output. The demand module simulates the evolution of the four components of demand: private consumption, investments, public expenditure and export. Part of the private consumption and of investments are driven by the level of transport demand. Namely, the expenditure for transport services, for fuels, for means of transport is estimated explicitly from the transport demand supplied by TRA and added to non-transport items. As final demand is also part of an Input-Output matrix where also intermediate use of output is simulated, any change affecting one sector is transmitted to all other sectors. Thus, an increment of demand of means of transport does not affect only sector “transport equipment” but also sectors which provide input to it and, in turn, sectors which are suppliers of these and so on.

The MAC model was calibrated by using Italian statistics by ISTAT for the years 1990 – 2000[3]. Indeed, the last year available of published statistics was often 1997. Figures for the three subsequent years (1998-2000) were estimated by TRT. All variables were expressed in constant 2000 EUROs.

A.2 The generation sub-model (GEN)

The role of the Generation sub-model (GEN) is to provide an operating framework to model the generation of the transport demand and its distribution among the possible destinations. This phase is managed in quite a different way for passengers and freight so it is examined separately in the following.

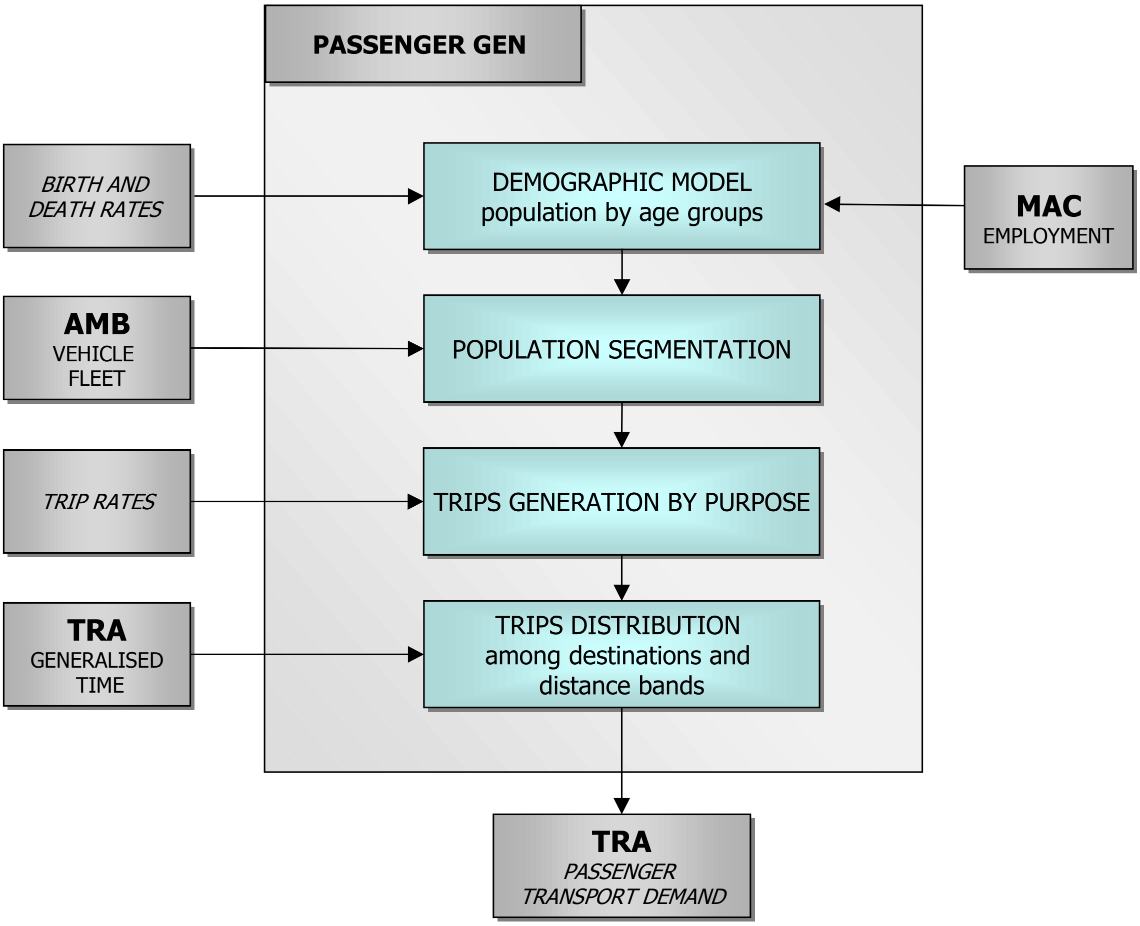
Figure A.2 represents the mechanism of generation of passenger trips. The generation is based on the application of trip rates to population segments. Three variables are used to segment the population – age, employment status and car ownership – which are major determinant of trip generation. A demographic module simulates the population trend and produces the amount of population by age for each macro-region. The information supplied by MAC allows to split population between employed and non-employed. The results of the car fleet module included in ENV allow a further classification according the ownership of vehicles. 12 population segments are obtained.

A.2.1 The generation of passenger demand

Each of the 12 segments can be associated a specific propensity to mobility. For instance, employed people with full car availability produce, on average, more trips than elderly people without a car. This different propensity is reflected in different trip rates, which are expressed in average number of trips per day. A set of trip rates by purpose is coded in the model. Such rates are an adaptation of those estimated for the European

ASTRA model, which in turn were derived from the analysis of the outcome of the National Travel Surveys carried out in UK in last years[4].

Fig. A.2 Structure of the GEN sub-model (passengers demand)



The number of passenger trips generated are therefore obtained as follows:

$$T_{i;r;p} = P_{i;r} * TR_{i;p} \qquad [1]$$

where:

$T_{i;r;p}$ = Number of trips of population segment “i” generated from zone “r” for trip purpose “p”

$P_{i;r}$ = Population of segment “i” in zone “r”

$TR_{i;p}$ = Trip rate of population segment “i”, for trip purpose “p”

The trip rates do not depend on the macro-region. The assumption is that people belonging to a given segment have the same average trip rate whatever their residence is

(North or South, metropolitan area or low dense area, etc.). This assumption is not only adopted for sake of simplicity: the analysis of National Travel Surveys data suggests that the stability of trip rates is significant. This is true also with regard to time: population of a given segment shows a stable mobility through years even though destinations, modes and so on can change[5]. Indeed, a total stability is not justified by data, but the assumption works well enough for modelling purpose at this scale.

Three trip purposes are considered in the model: business (including commuting and other work), tourism (including day trips) and other purposes (including shopping, visits and so on).

A.2.2 The generation of freight demand

The generation of freight demand is mainly driven by the production of physical goods. As the result of industrial activity is generally consumed far from the production location, the larger the amount of products the higher the freight traffic.

Thus, as shown in figure A.3 the starting input is represented by the value of production of physical goods provided, for each sector, by MAC. These monetary aggregates are put into volumes of generated freight demand by dividing them by the average unitary values of production in each sector:

$$V_{j;r} = \frac{O_{j;r}}{UV_j} \qquad [2]$$

where:

$V_{j;r}$ = Volume of goods generated by sector “j” in zone “r”

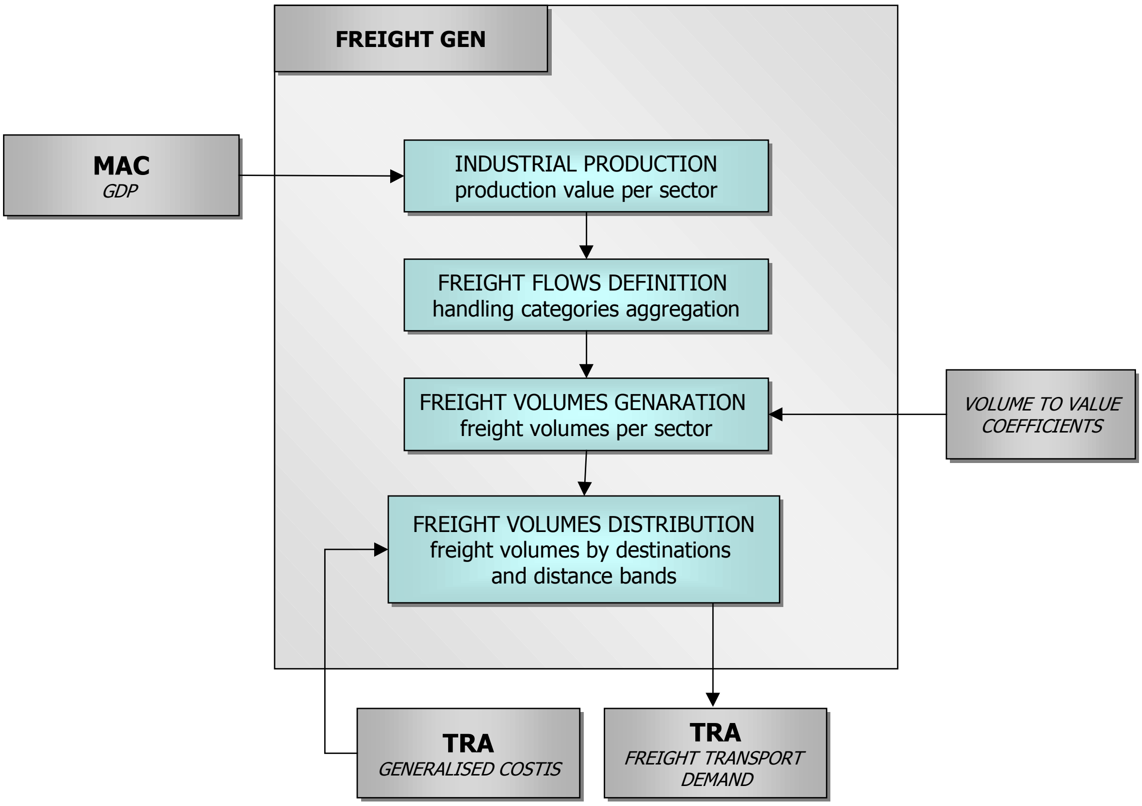
$O_{j;r}$ = Value of production of sector “j” in zone “r”

UV_j = Unitary value of production of sector “j”

The unitary values of production, expressed in EURO/ton were estimated from the available statistics. Such values are hold constant through time, so that the trend of the volume of goods depends only on the trend of the value of production. This is a simplifying assumption as unitary value of goods is not constant over time. However, forecasting unitary values is a very difficult exercise, especially with a not very detailed classification of products, and also an analysis of previous trends does not offer a clear insight. Therefore, the assumption of no variations is assumed as the simplest.

As for passengers, where three trip purposes are considered, three different handling categories are defined: bulk (e.g. oil, sand, cereals), general cargo (e.g. machinery, building materials) and unitised (containers, swap bodies). Each of the 15 sectors gives is associated to one of the three handling categories on an a-priori basis.

Fig. A.3 Structure of the GEN sub-model (freight demand)



A.2.3 The distribution of trips

The distribution phase consists in the allocation of the generated trips among the possible destinations. Given the definition of spatial contexts used in ASTRA-Italia, for passengers both origins and destinations are functional zones whereas for freight both origin and destination are macro-regions.

The distribution among the available destinations is performed according to a Logit algorithm:

$$p_{od} = \frac{e^{-\lambda * u_{od}}}{\sum_d e^{-\lambda * u_{od}}} \qquad [3]$$

and:

$$u_{od} = GT_{od} + SD_{od} \qquad [4]$$

where:

λ = spread parameter

p_{od} = probability that demand generated in origin "o" choose destination "d"

u_{od} = disutility of the trip from origin "o" to destination "d"

GT_{od} = generalised time from origin "o" to destination "d"

SD_{od} = specific disutility of the trip from origin "o" to destination "d"

The distribution of demand among destinations depends on generalised time of trips from the origin and the available destinations. Generalised time is computed as travel time plus the equivalent, in time terms, of the cost of the trip. The translation of cost into time is based on values of time different by trip purpose and by handling category:

$$GT_{od;f} = T_{od} + \frac{C_{od;f}}{VOT_f} \qquad [5]$$

where:

T_{od} = Travel time from origin "o" to destination "d"

$C_{od;f}$ = Monetary cost from origin "o" to destination "d" for flow "f"

VOT_f = Value of time for flow "f".

The value of time is the monetary value assigned to a unit of time and it depends on the type of flow. For instance, business trips are generally associated to higher values of time than leisure trips. Also for freight, finished goods have[6] a higher value of time than bulk goods.

There are a number of studies concerned with the estimation of value of time in different contexts. Values used in ASTRA-Italia were drawn from different stated preference[7] surveys carried out by TRT in previous years.

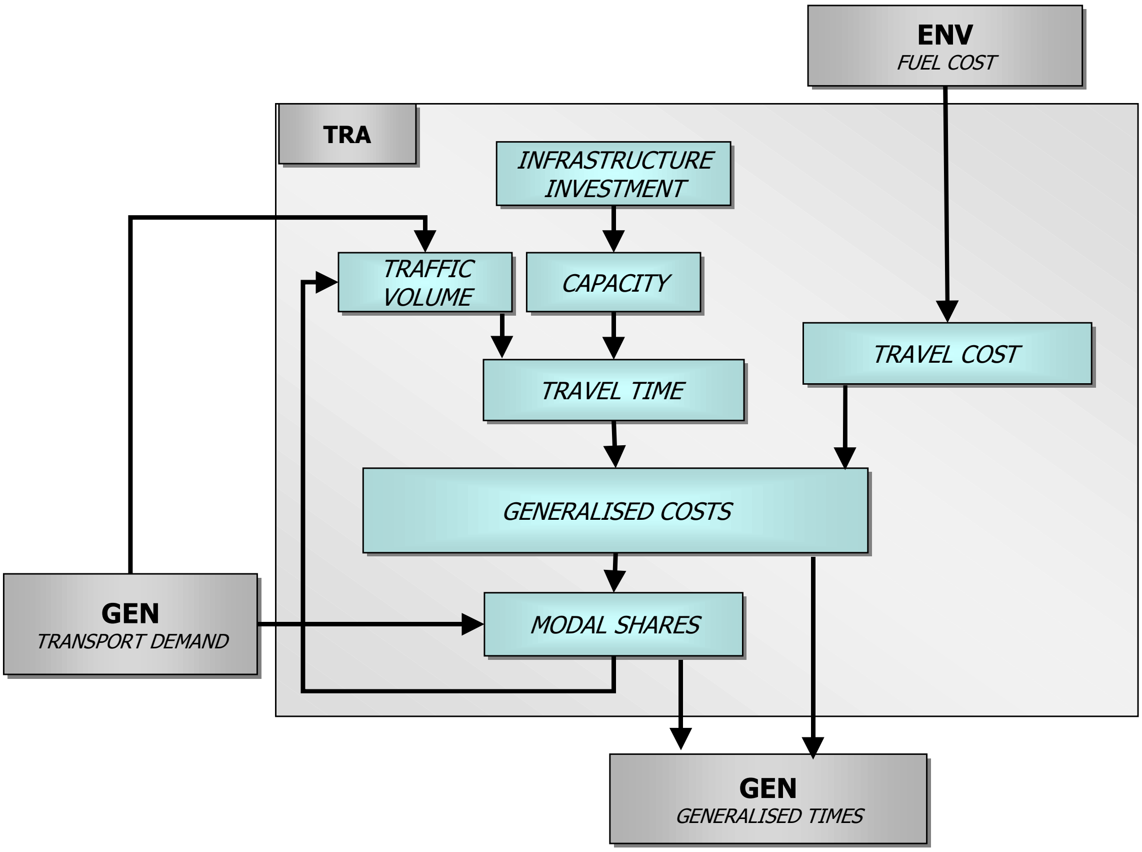
The SD_{od} term which appear in the [4] is an additional term which explain part of the disutility of travelling from two zones. As a matter of fact, the size of flows between pairs of areas depends on specific circumstances which link or separate the areas themselves in addition to the generalised time. This additional term is therefore used to calibrate the overall value of disutilities in order to match the observed distribution.

The most common function of travel cost and time used in transport models is generalised *cost*, where time is translated in monetary unit (still using values of time). In the ASTRA-Italia model generalised *time* was preferred because it can capture the observed phenomenon of increasing trip distances and increasing of value of time. Though the matter is still controversial, it is generally accepted that value of time is growing through time. In ASTRA-Italia this assumption is accepted and value of time grows (less than) GDP. When VOT increases, the generalised time computed by the [5] decreases. Therefore, travelling becomes easier and average distances grow. This effect is actually observed as past trend and generalised time simulate it correctly[8].

A.3 The transport sub-model (TRA)

The Transport Sub-model (TRA) deals with the modal split of demand by Origin/Destination pair and with computation of generalised times used by GEN as input for the distribution of generated trips. Figure A.4 shows the mechanism of the TRA sub-model, which is the same for as passengers as for freight traffic.

Fig. A.4 Structure of the TRA sub-model



The ingredients used to compute the modal split are, like for distribution, travel cost and travel time, summarised by the generalised cost:

$$GC_{od,m} = C_{od,m} + T_{od,m} * \text{VOT} \qquad [6]$$

Costs and times are different for each mode whereas the value of time is the same[9]. The share of each mode is computed by a logit model of the form:

$$p_{od;m} = \frac{e^{-\eta^* u_{od;m}}}{\sum_m e^{-\eta^* u_{od;m}}} \qquad [7]$$

and:

$$u_{od;m} = GC_{od;m} + K_{od;m} \qquad [8]$$

where:

η = spread parameter

$p_{od;m}$ = probability of using mode “m” for the trip from origin “o” to destination “d”

$u_{od;m}$ = disutility of using mode “m” for the trip from origin “o” to destination “d”

$GC_{od;m}$ = generalised cost of using mode “m” for the trip from origin “o” to destination “d”

$K_{od;m}$ = modal constant specific of mode “m”

The term $K_{od;m}$ is a specific disutility attached to the use of mode “m”. This is a common term used in modal split models to represent all the relevant attributes different from time and cost which rule the modal choice (e.g. reliability, comfort, flexibility and so on). Such parameters are used to calibrate the modal split modules in order to match the observed modal split.

Although this is the basic mechanism used in the model, the specification of the algorithm is different from case to case according to the type of demand, passenger or freight.

The set of modes available in the model for the passenger trips includes walking, motorcycle, car, bus/coach, train/metro, air. The modal split for passenger traffic is performed separately for each trip purpose and for each distance band (see above) as the set of available modes is different according to those two variables.

The modes available for freight traffic are Light Duty Vehicles, Heavy Duty Vehicles, rail and ship. For all the three flows (bulk, general cargo, unitised) the same structure of distance band and modes available applies.

A.3.3 The network module

Further of the modal split stage, the TRA sub-model manages a second significant task, that is the computation of travel times.

Given the level of detail, the ASTRA-Italia does not include a classical network made of nodes, links and so on. Nevertheless, the model simulates the available amount of transport capacity and use a speed-flow function to change the base time per km when the congestion rises.

The function used is of the form:

$$Time = BaseTime * \left(1 + ParA * r^{ParB}\right) \qquad \text{If } r \leq 1$$

$$Time = BaseTime * \left(1 + ParA + ParC * \left[1 - \frac{1}{r^{ParD}}\right]\right) \qquad \text{Else} \tag{9}$$

where:

$Time$ = Time per km

$BaseTime$ = Free flow time per km

r = Traffic volume/Capacity ratio

$ParA, ParB, ParC, ParD$ = Parameters

The computation is repeated separately for each macro-region and for different networks: local road network, long distance road network, railways, shipping ports, airports.

The capacity of the different infrastructures is expressed in million of vehicle*km per year and it is updated at each year of simulation on the basis of the investment. A simple relation between money invested and additional capacity was calibrated.

The computation of times is dynamically linked to the modal split phase. At the initial step, base times are used to compute generalised cost and, consequently, modal split. The amount of traffic for each mode is used at the same step to update the travel time according to the speed-flow curve [9]. The times computed are used to calculate the generalised costs at the subsequent step and so on.

Therefore, modal split and assignment are interdependent, like in a classical transport model. However, conversely from the latter, the feedback is managed dynamically step by step and not by means of several iterations at a fixed time.

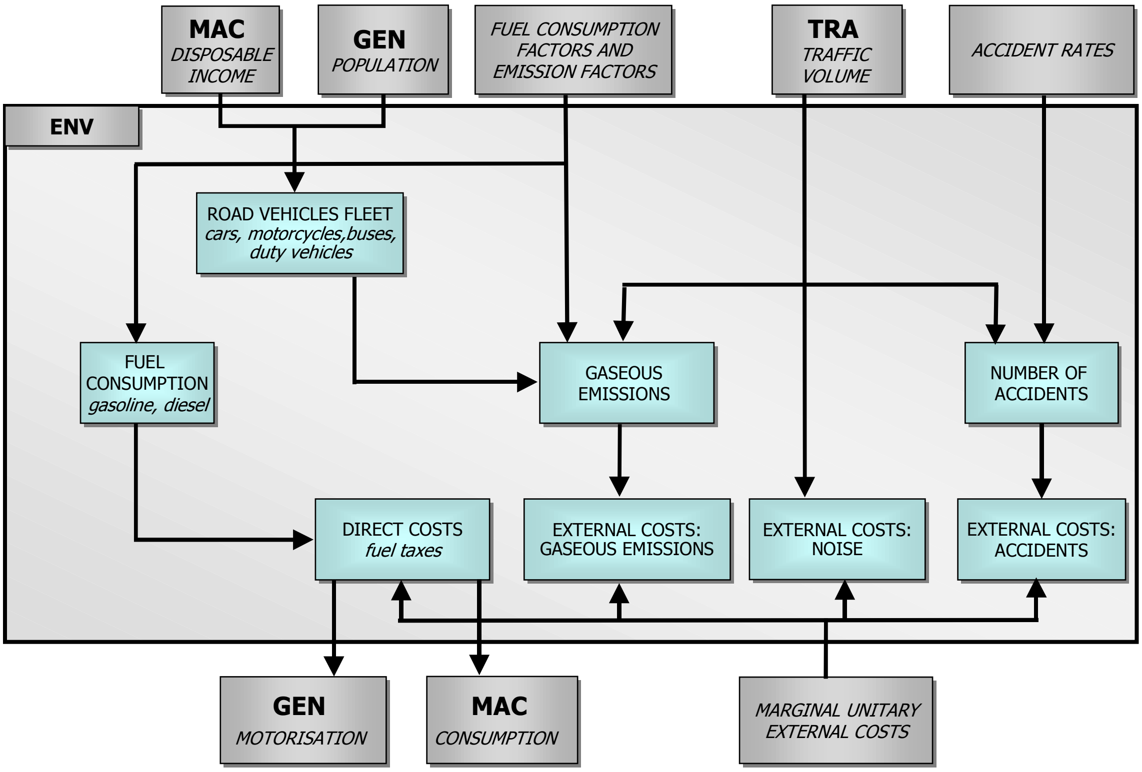
A.4 The environmental sub-model (ENV)

The environmental sub-model (ENV) computes the main impacts of traffic in environmental terms: emissions, noise, accidents. As most of such effects are dependent on the vehicle fleet, a specific module of ENV is devoted to this element. Finally, ENV also computes fuel consumption and feed MAC with this information.

The functioning of ENV is illustrated in the following figure A.5. The main input for the computation of all environmental effects is the volume of traffic provided by TRA. Since this kind of effects are very different in urban areas rather than in non-urban contexts, the amount of traffic is first separated in the urban and extra-urban share according to *a-priori* heuristic rules.

Specific emission factors expressed in g/vehicle*km are therefore applied to the traffic volume by mode in order to compute the total emissions of the following pollutants and greenhouse gas: CO_2, NOx, CO, SOx, VOC e PM.

Fig. A.5 Structure of the ENV sub-model



Emission factors are differentiated by vehicle type: fuel type, cubic capacity and EURO standard. The split of traffic volume according to the share of each vehicle type is obtained from the fleet module (see below).

Accident rates per million vehicle*km are considered to compute the total number of accidents.

Marginal costs are therefore used to appraise the value of the external costs associated to emissions, accidents and also noise. As the definition of marginal external costs is a very controversial issue, two estimates are produced: a “low values” one and a “high values” one. The set of marginal costs was provided by a team of economists involved in the project.

A.4.1 The fleet module

The fleet module simulates the composition of the various fleets (cars, motorcycles, Light Duty Vehicles, Heavy Duty Vehicles, buses). Vehicles are classified according to various elements: fuel type, cubic capacity, EURO standard.

Other than in various groups, vehicles are divided by age. The model simulates a sort of conveyor where vehicles are transferred year by year from to an age class to the subsequent one and, after a maximum period of 20 years, are dropped out. Not all vehicles are used for the whole period of 20 years and a share of vehicles of is scrapped each year from each age class.

In the car fleet module, which is the most sophisticated one, both the purchase rates and the scrapping rates are dependent on various elements: property tax, fuel price, income, etc.

The split of new vehicles among fuel type and cubic capacity classes is managed by means of fixed proportion calibrated on observed data. All vehicles purchased are assigned to the EURO standard in force, for instance, all cars purchased from 2001 to 2005 are assigned to EURO III, from 2006 on all vehicles are assigned to EURO IV.

The share of each type of vehicle is supplied to the module which compute emissions in order to define the amount of traffic to which each specific emission factor is to be applied.

Notes:

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[3] ISTAT data, as well as many other information, were kindly provided by Federtrasporto especially thanks to the collaborative work of Flavia di Castro.

[4] The analysis was performed for the STREAMS project. STREAMS was one of the research studies awarded by EC Directorate General VII - Transport - in the IV Framework Research Programme launched by the Commission on achieving the objectives of the Common Transport Policies. The central objective of the STREAMS project was the creation of a strategic, yet comprehensive, network based multi-modal transport model of the whole EU15 area covering passengers and freight and to produce initial reference forecasts of transport in the EU. See Me&P et al. 1999.

[5] Therefore the growth of mobility, much higher than the growth of population would mainly be due to the changing structure of population: more elder people with full car availability and less young people without car.

[6] Since the value of transport time is mainly a behavioural concept entering in an utility function, goods do not have a value of time but shippers do have it.

[7] Stated preference methodology is based on surveys where hypothetical scenarios are presented to a sample of interviewed individuals in order to elicit their preferences and estimate the relative importance of various parameters entering in a random utility function. See D.A. Hensher, K.J. Button (edited by), 200, Handbook of Transport Modelling, Pergamon

[8] Instead, generalised cost (where VOT is computed at the numerator) increases when VOT grows and the effect would be to simulate a reduction of average distances.

[9] However, it varies among flows as explained above.

Back to the Top