Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

TRIMODE: integrated transport model for Europe

Martino, Angelo *[a]; Williams, Ian [a]; Fiorello, Davide [a]; Noekel, Klaus [b]; Capros, Pantelis [c]; Siskos, Pelopidas [c]; Zazias, Georgios [c]; Charalampidis, Ioannis [c]; Karkatsoulis Panagiotis [c]; Schade, Wolfgang [d]

[a]*TRT Trasporti e Territorio, Via Rutilia 10/8, 20144 Milano, Italy*
[b]*PTV Group, Haid-und-Neu-Strasse 15, 76131 Karlsruhe, Germany*
[c]*E3MLab, 9 Iroon Polytechniou Str., 15773 Athens, Greece*
[d]*M-Five, Bahnhofstr. 46, 76137 Karlsruhe, Germany*

Abstract

The TRIMODE integrated model for Europe combines the simulation of transport, economy and energy systems for the assessment of major transport infrastructure projects and policies. Within a single software platform, the model components include a full four stage Transport model of passenger and freight movements, an Energy model with dynamic vehicle fleets for all transport modes and an Economy model representing the complete macroeconomic system of European countries with a two-layer General Equilibrium model that works at both a regional and a national level. Covering the whole European Union and it neighbouring countries, the model has a very detailed spatial resolution of the transport system, with a NUTS III level multimodal network, coupled with detailed disaggregation of transport demand by socio-economic groups, purposes, etc. for passengers and by NST and handling categories, etc. for freight. The model considers all types of energy sources and technologies for all modes of transport.

Keywords: Impact Assessment of Policies; TEN-T network; Transport Modeling & Simulation; Decarbonisation; intermodality; Socio-Economics.

1 Introduction

The transport sector is a key component of modern society and it has multiple correlations with other sectors of the European economic system. The TRIMODE project has the ambitious objective to develop a new integrated model covering transport, economy and energy components at European scale. The new tool is designed to provide the European Commission with a usable and reliable transport network model within which transport infrastructures of European importance and genuine transport policies can be assessed looking also at their impact on the energy and economy systems. The TRIMODE model is being developed by an international consortium led by TRT Trasporti e Territorio (IT) and composed by PTV (DE), E3MLab (GR), M-Five (DE), MDS Transmodal (UK), ISI Fraunhofer (DE), BHL (DE) and INRIX (UK). The project started in 2016 and, after a first phase dedicated to the demonstration of the model capability for a subset of countries, is to be completed in the year 2019.

The core of TRIMODE is a network based transport model, simulating passenger and freight transport activity and covering all mobility – urban, regional, national, international and intercontinental – for EU28 and neighbouring countries. This transport core model is fully integrated with the economy and the energy models, i.e. the three components are linked to each other so that changes in one component affect the results of the other components in a consistent two-directional fashion. These links concern, among others: changes of transport activity due to development of economic activity (link from economy to transport); changes of transport activity due to transport-related technology developments (e.g. uptake of new vehicle technologies, link from energy to transport); changes of regional economic activity due to changes of accessibility (link from transport to economy); changes of transport emissions due to changes of transport activity (link from transport to energy).

TRIMODE fills a gap in the European models' toolbox. While the European Commission uses detailed economy models (e.g. QUEST and GEM-E3), energy models (e.g. PRIMES and POLES), strategic models (e.g. ASTRA) for its policy analyses, it lacks a transport network model to conduct detailed impact analysis, also due to the failure of previous attempts in such direction (e.g. TRANSTOOLS). Although previous European-level and national models (such as PRIMES-TREMOVE, ASTRA or SCENES) provide many of the methodological foundations for TRIMODE, this is the first time in literature that a large scale integrated transport, energy and economy model is developed. And even though the individual modules are based on existing methods, the structure of each model component has been designed afresh. This redesign aimed to maximise the consistency in the linkages between the TRIMODE components so as to create an entirely new standalone integrated model, rather than interfacing together a set of existing models. The choice to make effective re-use of existing procedures that have already proved their worth, has minimised development risks and freed up resources to tackle the inevitable new methodological issues that emerge in the course of any ambitious model building project.

Thanks to its modular structure a large variety of policy scenarios can be analysed and a wide set of impacts can be estimated:

- TEN-T infrastructures
- Transport energy taxation and differentiated vehicle taxation
- Transport user charges (e.g. road charges, track charges, slot charges)
- Internalisation of external cost
- Increased share of renewables in the transport energy mix
- Improvements in energy infrastructure supporting the use of alternative fuels in transport
- Efficiency and GHG emission standards
- Electric mobility and charging networks
- Diffusion of new powertrains.

Other transport policy measures could be analysed indirectly using TRIMODE to implement exogenous modifications of parameters and running "what if" scenarios to assess impacts expected under an assumed level of effectiveness of these measures. Last but not least, TRIMODE could be applied also to assess the impact of modifications of background conditions, e.g. energy prices, productivity trend, ageing and population growth.

The paper is organized as follows: section 2 provides an overview of the model and of its policy scope, while the following sections (3 to 7) are devoted to the specific model components: passenger demand, freight demand, transport network and assignment, economy and energy. Conclusions and references end the paper.

2 TRIMODE model structure

2.1. The model components

The TRIMODE integrated modelling system comprises several components belonging to three main blocks: a transport model, an economy model and an energy model (Figure 1). The economy model estimates the zonal demographic, economic activities and change of bilateral trade in a particular year for all zones of the model (see chapter 6). The estimation is made first at the national level and is then regionalised and is used to generate the demand for passenger and freight transport. At the same time, the energy model determines the composition of vehicle fleets and provides the operating costs of transport modes that are then used to estimate user costs.

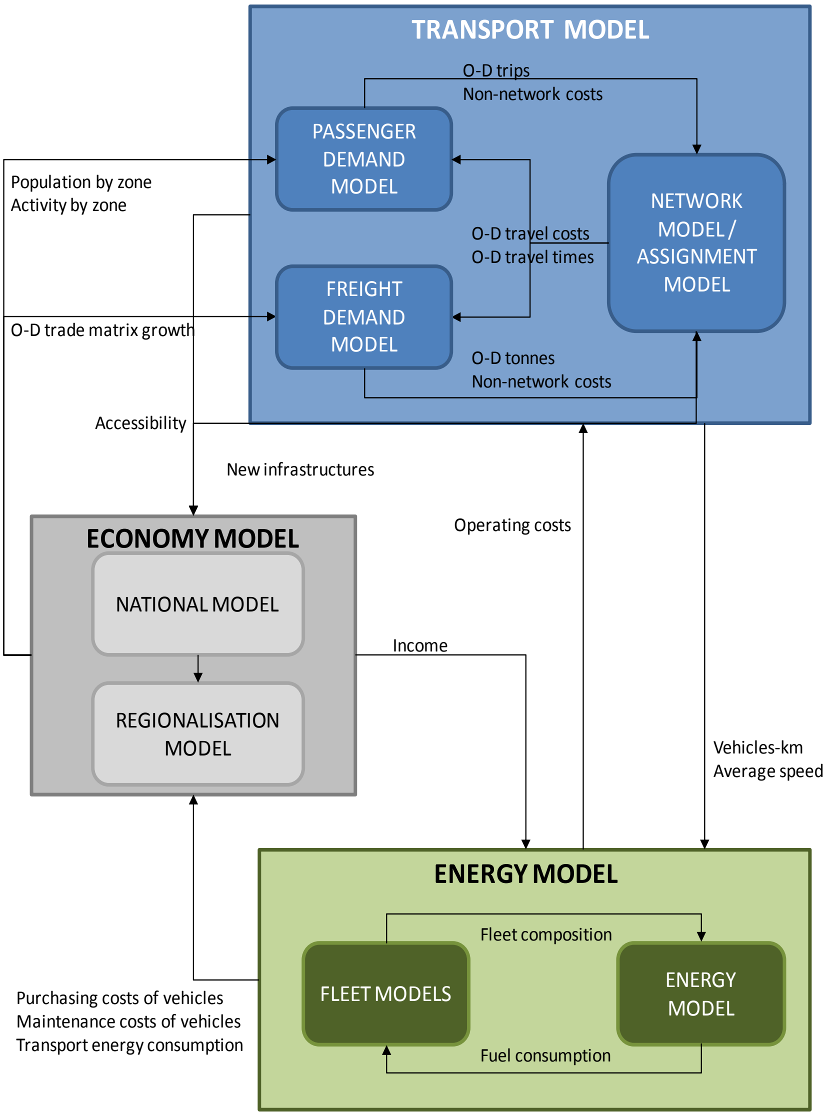

Fig. 1 Overview of TRIMODE integrated modelling system

These user costs are a major input for the passenger demand model and freight demand model to estimate the resulting spatial pattern of passenger and freight transport movements and how these are allocated to modes and to the vehicle types within a mode (see chapters 3 and 4). The network model assigns these vehicle movements to the paths and links of the multimodal network (see chapter 5). The transport demand and the assignment modules are iterated so that any resulting congestion delays or economies of scale in operations are fed back to influence the choices of route, mode or destination within the freight and passenger demand models. In turn, the whole modelling system iterates until an equilibrium solution is reached for all its components on the simulation year.

The equilibrated travel cost and time characteristics for each type of passengers and freight movement are fed back up to the economy model to influence the future attractiveness for economic development of specific sectors in individual zones as well as to provide estimates of transport sector activity for use within the macro-economic modelling (chapter 6). In this way the full impacts of transport policy measures on economic development can be measured at a spatially detailed level. The information on the traffic volumes and speeds, segmented by vehicle type and by driving conditions (e.g. motorways, local roads), is fed back to the energy/environment model (chapter 7) to estimate the spatial pattern of energy consumption, pollution emissions and of other external costs based also on development of vehicle fleets.

2.2. The geographical coverage

The main geographical scope of the model is EU28 and candidate and potential candidate countries: Western Balkans (Serbia, FYROM, Albania, Bosnia and Herzegovina, Kosovo, Montenegro), Turkey, Iceland. Bordering countries are relevant mainly for their impact on mobility and transport within the EU and thus are modelled in a somewhat more simplified way. The Rest of the World countries are treated as external zones so that only their freight and passenger movements to and from the internal countries are modelled, but not those solely within or between these external zones.

2.3. The zoning systems and the zone types

Within EU28 countries, candidate and potential candidate countries, most of the components of the overall modelling system operate at the NUTS III level or below, including also some specialised "point zone types" that represent major passenger or freight facilities, or inter-modal terminals, or further adjustments to some extent reduce existing imbalances of the current NUTS III system in terms of population size. To ensure that the population density, the access to public transport and the supply of transport is homogenous for the majority of the population within a zone, it is important within NUTS III zones to separate out significant dense urban areas in which public transport services are likely to be frequent and to have comprehensive spatial coverage, from the rural surrounds in which car travel will be the main option, except perhaps for rail or bus services to the centres of nearby urban areas. These are the reasons behind the classification of zones into different types based on the information on LAU-2 territorial units provided by the LUISA modelling platform (Kompil et. al, 2013). Building on density indicators, NUTS III zones have been classified into six different categories defined as follows: Metropolitan areas; Dense areas; Mixed areas; Sparse areas; Polarised areas; Rural areas.

2.4. Intra-zonal movements

At the model scale, a significant share of passenger and freight activity is intra-zone and therefore, although the focus of TRIMODE is on mobility at the national and international level, the modelling of intra-zonal trips affects the correct representation of overall passenger activity. Instead of assigning intra-zone trips to the network, as this would require too detailed a network, these trips are split instead among different virtual distance bands. The distance band approach to intra-zone modelling, that was originally developed for use in the SCENES model (ME&P, 2000) of Europe, has since been refined by combining it together with an area type based zoning system to provide the core functionality underpinning the policy model component of the national passenger transport model (NTMUK) of Great Britain. Six distance bands are used to split intra-zone activities: < 1.5 km; 1.5 – 3 km; 3 – 5 km; 5 – 10 km; 10 – 20 km, > 20 km. Depending on zone size, it can be that not all distance bands are available in a given zone.

2.5. The interaction among the model components

The TRIMODE model components' methodologies are different with respect to their dynamics, i.e. their treatment of changes over time. On the one hand, the transport demand models and the network model compute a static equilibrium for a few pre-defined points of time, while the economy and the energy models compute dynamic projections in five year steps. Furthermore, the various components of TRIMODE exchange several variables. From a computational point of view the ideal solution would be to develop a single linear sequence within which each component model is calculated only once and then can provide all of the outputs that are required for input within this model year to any subsequently evaluated component models. This single linear sequence approach is not feasible for TRIMODE because some component models both require inputs and produce outputs for some other individual component models within a run year. The integration of the components within a consistent dynamic sequence needs to consider these aspects. The sequence of steps for running the full suite of model components is defined to reduce the repeated running of models to the minimum necessary, while still achieving a fully converged equilibrium solution in each run year.

2.6. TRIMODE software platform

The software used to develop TRIMODE needs both: to be flexible to ensure that the wide range of functionality required for this complex model is available; and to be efficient in its computation to mitigate the large size of this model resulting from its detailed spatial scale and comprehensive modal and economic coverage. Accordingly, TRIMODE is based on PTV Visum platform and GAMS software. The functionalities of these two proprietary software packages are extended and coupled using the widely distributed open-source programming language Python.

TRIMODE is conceived to enable transparent access for two groups of users: (i) standard users (model analysts), and (ii) expert users (model developers) that will make use of different options to run the model and to adapt it to their specific needs. The standard users will run the model through a web interface that enables them to configure scenarios and to test, analyse and understand their outcomes. The expert users will be in a position to adapt any parameter of the model through the sophisticated user interface of the PTV Visum software package.

3 The Passenger demand model

The main purpose of the passenger demand module is to estimate origin-destination matrices of trips by mode of transport for different demand segments. These matrices provide aggregate results of transport activity (based on origin country principle) and feed the assignment model. The estimation of transport demand is based on exogenous assumptions on demographic trends (size of population and age distribution) as well as on input data estimated endogenously in other components of TRIMODE about distribution of population, jobs and economic activity across zones; income trend; transport costs trend. The passenger demand model consists of three main stages which are executed in sequence: trip generation, trip distribution and mode split. The outcome of mode split is sent to the assignment model whose results (in terms of travel times and costs by O-D pair) are fed back to the trip distribution and mode split stages of the passenger demand model. The process is iterated until equilibrium.

3.1 Trips generation

Passenger demand generation (total number of trips - including local trips - generated in one year in each zone) is modelled by means of trip rates for 36 population groups (based on three segmenting variables: employment status, car availability and income level) and for 12 trip purposes in each country. Given that trip rates are considered constant over time (Jahanshahi et al., 2009), the total number of trips changes according to the modifications in the population size and structure. The exception is for leisure and for long holiday trip rates that are elastic with respect to income level provided by the economy model component. Using this approach, the modelling of generation of passenger transport activity is sensitive to different trends such as urbanisation; ageing and motorization; emerging of shared mobility.

3.2 Trips distribution

Trips distribution between each origin-destination pair (including intra-zonal trips which are further distributed among different distance bands) is estimated for demand segments obtained by crossing - and aggregating in order to reduce the computational effort - trip purposes and population groups used in the generation model. The impedance of the singly-constrained gravitational-type model is measured in terms of generalised travel time (the sum of actual travel time plus the equivalent in time units of the travel cost). The reason for using generalised travel time rather than generalised travel cost is that the former generates longer trips in response to income (and therefore value of time) increases which is consistent with observed evidence. Using this approach, the modelling of distribution of passenger transport activity is sensitive to: differentiated regional growth (through trend of zonal attractors); accessibility changes (through trend of generalised time) and income trend (through the changing value of travel time).

3.3 Modal split

For each segment of the distribution model, and each O-D pair (and each distance band for local trips) demand is split among alternative transport modes by means of a nested logit algorithm. The full set of transport modes (not necessarily available to all demand segments) includes: Pedestrian; Bicycle; 2-Wheelers; Car (later split into car and LDV and car further split among: own car, taxi and car sharing); Bus (public transport); Tram/Metro; Coach; Rail (further segmented into conventional rail and High-Speed Rail within the assignment model); Airplane. The components of the choice sets used in the mode split algorithm (i.e. the transport modes mentioned so far) are the "main modes" of a (potential) multimodal chain. For instance, one component of the choice set is "Airplane". When a plane is used for a trip, almost invariably also other modes are used to complete the door-to-door journey (e.g. a car from home to the departure airport, then the plane trip, then a bus from arrival airport to the final destination) and these are called "feeder modes". Travel times and travel costs used in the mode choice algorithm reflect the full chain.

4 The Freight demand model

The main purpose of the freight demand module is to estimate (i) production to consumption (P-C) zone matrices of freight trade for distinct types of goods and (ii) their associated origin-destination (O-D) logistic legs which are segmented by their stage within the distribution system and by the main mode of transport of the leg. As for passenger demand, the freight demand model simulates the complete set of all urban, interurban and long distance freight movements on all modes throughout the study area, including all import and export movements from/to external zones. Considering the high degree of heterogeneity of freight and the need for specialised equipment for loading, transfer and discharge, a very detailed set of modelling steps coupled with a high degree of segmentation is adopted.

4.1 Trade of goods and physical transport movements

The economic transactions between suppliers and consumers, and the logistics operations that actually deliver the physical goods, are the two main drivers behind the observed pattern of freight movements. A distinction between two separate matrices of movements that are used conceptually in the analysis of the demand for freight transport is used to simulate the relationship between transport and the economy.

- The pattern of economic trade in goods from their initial producer to their ultimate consumer is called the **Production-Consumption (P-C) matrix of trade**. Changes in this matrix are strongly influenced by economic changes outside the transport and distribution sectors. The TRIMODE economy model is where this P-C matrix of trade is forecast.
- The actual set of physical transport movements generated by the logistics structure that distributes and transports these P-C trades in practice is called the **Origin-Destination (O-D) matrix of shipments** and it is forecast within the TRIMODE freight demand model using the distribution channel choice methodology outlined below. Changes in this matrix are strongly influenced by changes within the freight transport and the distribution industry sectors.

The reason for considering a P-C matrix in addition to an O-D matrix for the same good, is that the impact of trends in logistics and of the responsiveness of logistics to policy initiatives can best be understood realistically if these impacts are considered within the context of their underlying P-C matrix. For example, the lengthening of P-C trades does not automatically imply a lengthening of O-D shipment lengths since there may be a succession of separate intermediate logistic legs along the distribution channel between the initial production and the final consumption of a good, with the good being warehoused in distribution centres between these legs.

4.2 Freight tonnage generation

At the outset, the base year matrix of freight P-C tonnes is constructed through making major use of observed modal freight flows to ensure that this synthetic base matrix matches well to the existing observed pattern of freight movements at the O-D level. The categorisation adopted makes reference to the EU's current standard NST 2007 classification of 20 types of goods transported. In future years or scenario tests, the P-C tonnages are calculated by multiplying each base year P-C matrix element by its corresponding growth factor. These trade growth factors are calculated for each element as: the ratio in constant prices of the total value for the future year/scenario relative to the base scenario for each corresponding industry sector, based on the outputs from the economy model. By using growth factors that are dimensionless to scale the tonnages of goods traded between each zone pair in the base year, the spatial variations between zones in their volume to value ratios cancel out, thus avoiding one major source of aggregation error that could arise when forecasting.

4.3 Distribution channel choice

P-C movements can either be transported directly from door-to-door in a single (though perhaps multimodal) movement or else may involve primary, secondary and/or tertiary logistic legs, with intermediate storage activities occurring between each leg at national, regional or local distribution centres, respectively. The primary logistic legs tend to involve large volumes being moved on a regular basis often over long distances and are the legs where the modal alternatives to road tend to compete most effectively. In contrast, the tertiary logistics movements from local distribution centres to individual retail premises are characterised by relatively small consignment sizes; they may face difficulties in vehicle access to the premises and so are captive to road; may often use smaller trucks or LDVs; and will generally be over relatively short distances so that a significant proportion will occur as intra-zonal rather than inter-zonal movements within the model. The modelling of distribution channel options for a P-C trade uses a hierarchical logit discrete choice structure. This sequentially selects the logistic leg type plus the associated distribution centre location, in a distribution channel that stretches from the production to the consumption zone. The probabilistic choice between distribution channel options for a P-C is based on the sum of their transport and warehousing costs. Each resulting individual logistic leg movement stage is then part of the O-D matrix to which the mode choice model is applied.

4.4 Main mode choice

For each individual logistic leg, the estimation of the split between main modes from its origin to its destination zone is calculated using a standard hierarchical logit discrete choice model based on the disutility of transport of each of the competing main modes. For the road main mode there is a further split by vehicle size, again using a logit choice model that is located below the road mode within the choice hierarchy. It splits among the set of relevant vehicle types for the particular type of logistic leg and freight type combination. For the non-road modes, distinct types of vehicles or vessels are used to take account of the differences in operating costs and characteristics between transporting containers and transporting other types of bulk goods.

Six freight modes (road, rail, inland waterway, maritime, air and pipeline) and their 13 component vehicle types are explicitly represented within the freight demand model. Prior to being allocated to feeder modes within the mode sequence choice and then assigned by vehicle type along the routes on the modal networks, the freight types are transformed and aggregated into seven modes of appearance (MoA - also known as type of cargo) classes. These relate to the form in which the goods are either transported or are handled at terminals, rather than unambiguously to the actual type of good itself.

5 The Transport network and assignment model

The estimation of route choice and link/node flows performed in the assignment model is based on exogenous assumptions on supply characteristics. These are mainly the networks for all represented modes, with capacities, free-flow time, and toll in the case of road transport, and the timetable with fare information for public transport. The assignment model uses as well input data estimated endogenously in other components of TRIMODE and these are: O-D demand matrices for persons and freight, between zones, for each main mode, and for each demand segment; mode-specific unit costs for transport that are calculated depending on information from the Economy and Energy models, e.g. fuel price.

The transport network is represented as a single multimodal model including all transport systems that are relevant within TRIMODE and includes links for road, rail, air, and waterways, with appropriate transfer links. For conventional rail, high speed rail and air passenger services exact timetables are coded in the network, whereas for shipping and rai intermodal services only the geographic courses of lines are specified, together with frequency. The complete network consists of about 130.000 nodes and 316.000 links. Scheduled services for passengers and freight are coded as about 78.000 lines serving 31.000 stops. The TRIMODE assignment model minimizes expected user cost according to the equilibrium principle which states that network flows shift until an equilibrium is reached in which the expected generalized costs for all loaded paths are equal for each O-D pair.

5.1 Bi-level formulation of main mode assignment

As already mentioned, TRIMODE mode choice adopts a main mode approach: each member of the choice set (Car, Coach, Rail, Air, Ship, …) represents the choice of the dominant mode (main mode) for the journey and is associated with a set of feeder modes. The assignment for each main mode is formulated as a bi-level problem. At the upper level (mode sequence choice) each choice alternative is a sequence of modes (main mode and feeder modes) and mode transfer locations (e.g. Chester – *Road* – Manchester – *Air* – Frankfurt – *Rail* – Karlsruhe). Total demand is distributed over these alternatives using a discrete choice model based on generalized cost, then the O-D demand for each individual mode is summed over all legs that use this mode, and passed to the lower level. At the lower level for each individual mode the O-D demand from the upper level is assigned in a separate assignment for that mode. Link volumes and path information are stored for each such assignment. For each individual mode generalized cost components are skimmed off each assignment and fed back to the upper level. Since some of the cost components fed back from the lower to the upper level are flowdependent, the bi-level problem is solved iteratively until a termination condition is met. The mode sequence choice concept was specifically designed for TRIMODE, prototyped as a Python script run from within PTV Visum and subsequently re-implemented as built-in functionality in the product.

6 The Economy model

The TRIMODE economy model is a fully fledged macroeconomic and regional model, which follows the computable general equilibrium methodology (CGE), ensuring completeness of all macroeconomic, demographic and industrial mechanisms so as to ensure consistent closed loop interaction between transport, infrastructure, vehicle fleet, energy, emissions and the economy. The model, coded in GAMS, has high resolution in terms of industrial and services sectors. The model receives from the other TRIMODE components information regarding: unit costs of transport services; transport activity split by transport mode; fleet composition, including the expenditures for purchasing transport means; energy mix; expenditure for developing infrastructure (exogenous scenario-specific inputs). Using this information, the model calculates the impacts of transport related policies and developments on the economy in terms of GDP, income, employment, production by sector, bilateral trade etc. both at the country and sub-country (regional) levels. The economy model has two layers, namely the country layer (CL) and the sub-country layer (SCL). The country layer has global coverage and covers all European countries and major neighbours individually. The sub-country layer covers the NUTS III regions and is subordinated to the country layer. Both layers handle the entire economy and the inter-industrial, inter-country, and inter-regional flows as a simultaneous system.

6.1 The Country Layer

The country layer of the economy model is a multi-sectoral, multi-regional, dynamic general equilibrium model formulated as a simultaneous system of mixed-complementarity conditions, derived as Kuhn-Tucker conditions of microeconomic optimisation of the agents (suppliers and consumers) and equilibrium conditions covering simultaneously all markets for commodities and primary production factors (i.e. labour and capital). The dual variables of the equilibrium conditions are the prices of commodities and primary production factors. A global closure of money flows is added, corresponding to the Walras law, implying that one of the prices (or a price index) has to be fixed as a numeraire.

The main agent categories of the model are: households, firms and government, that are specific to each country. Households' demand for commodities derives from utility maximisation under a budget constraint, which includes wage salaries, dividends and social benefits. The population is projected into the future using exogenous demographic parameters. Firms produce distinct commodities by sector and country and use as inputs commodities produced by other sectors/countries and primary production factors. They choose the mix of inputs as derived from production cost minimization depending on relative prices, technological substitution possibilities and input-related productivity factors. Firms consider investing to increase and renew production capacity and for such a purpose they use equipment goods, construction and other commodities to build investment. The model solves at a predictive sequence of static equilibria linked to each other through dynamic stock-flow equations, which involve investment by firms in each sector and the debt-repayment relationships. Investment depends on anticipation of future evolution, which is based on a backward-looking and partial-adjustment mechanism.

6.2 The Sub-Country Layer

The sub-country layer operates at the NUTS III level for the EU countries and its purpose is to downscale the projections of the country layer model to the level of regions. Using a two-calculation step procedure it quantifies by region: the production by sector, investment and capital stock, employment and population, income, final and intermediate consumption of goods and services and finally bilateral trade flows between regions. This two-steps method includes: (i) the change of location of population/labour and production capacities by region; (ii) the determination of production, consumption, income and bilateral trade at the regional level. The modelling of location is based on new economic geography theory (Redding & Esteban, 2017). It aims at calculating agglomeration and dispersion forces, which depend on the relative features (attributes) of the regions (amenities and dis-amenities) as the various agents (people and firms by sector) perceive them as attractiveness. The modelling of location serves to determine the migration of factors (mainly labour and capital) across the regions. The amenities and dis-amenities are multi-dimensional and are considered as enablers of utility (or disutility) for households and productivity (gains or losses) for the firms. Both perceive them through aggregators (attractiveness index) weighted by marginal utilities or marginal productivities. The quantification of each amenity or dis-amenity by region depends on factors expressed as state variables, such as environment, urbanisation, industrialisation, infrastructure, human capital and tourism development. In general, accumulation of state variables has non-constant scale effects on amenities.

Migration of factors that is determined in the first level of the sub-country model influences labour and capital endowment of the region and thus influence the regional allocation of activities and consumption. The modelling of this allocation draws on spatial computable general equilibrium modelling literature. The variables determined at the country level, such as total income, investments, total production by sector, and others, enter as constraints in the sub-country level. Interest rates are those determined at the country level and wage rates by region are linked to the country-wide wage rates. Fiscal and other public policies, the financial balancing and public budget balancing apply only at the country level, but public sector spending, fiscal policy and social benefits can be different by region in the same country, provided that country-level totals are respected. The initial allocation of resources and production factors poses constraints in the economic performance of a region due to limited mobility of production factors. Infrastructure and transport-related policies can influence both attractiveness and competitiveness of a region. Decreasing return to scale assumed for the relationship between the amenities and the state variables, act as a limitation of agglomeration. Dis-amenities act as dispersion factors, inducing regional specialisation for certain activities. Thus, the divergence of regions may persist in scenario projections. Changes that take place from year to year are rather gradual given that factor migration does not fully follow optimum location, due to the different idiosyncrasies of behaviours formulated according to discrete choice theory.

7 The Energy model

The main purpose of the energy model is to estimate the evolution and the operation of the fleet of vehicles throughout the projection period as well as the resulting impact on: the amount of energy consumption in the transport sector by fuel type; the amount of greenhouse gas emissions in the transport sector; the pollutant emissions and the external costs. The Energy model also calculates the operating costs (fuel costs) and the investments in new transport equipment for all transport modes. Hence, the evolution of the fleet over the years yields changes in the average costs related to the purchasing of vehicles (e.g. a shift towards more capital-intensive vehicle technologies depending on the scenario context). The evolution of both cost elements feeds the user costs modules that are associated with the transport models. The Energy model is coded in GAMS and is based on the PRIMES-TREMOVE model.

7.1 The equilibrium between supply and demand

The TRIMODE integrated model solves a market equilibrium problem for the transport sector through the interaction of the individual model components. The passenger and freight transport models determine the demand for the passenger and freight transport activity and the Energy model the available supply of services to fulfil this activity. Equilibrium is established through the iterations of the entire TRIMODE model and the exchange of information between the models.

7.2 The transport supplier problem

The Energy model assumes that two representative suppliers of transport services exist. Part of the supply of transport services is carried out by the same person who is a demander for such services. Hence, supply is split between self-supply and purchasing transport services from transportation companies. The representative agents are assumed to determine the operation and expansion of their transport equipment. Transport supply is calculated at the national level as the mix of vehicle technologies by transport mode, the mix of fuels and the rate of use of equipment so as to meet demand, as calculated by the transport demand component of TRIMODE.

Stock-flow relationships in the energy model are fully captured in tracking evolution of transport means fleet. The model considers stock of equipment inherited from previous time periods, calculates scrapping due to technical lifetime and determines the best choice of new cars which are needed to meet demand. Discrete choice models are employed to determine choices regarding purchasing alternative types of equipment. Environmental targets on car manufacturers apply as documented in Siskos et al. (2015). For the supply of road transport modes to meet the transport demand, the energy model solves an optimisation non-linear programming problem with constraints.

The aim of the modelling approach is to be able to simulate endogenously (as derived by economic decisions of actors – shippers) technology transformation towards alternative fuels, higher energy efficiency and low-carbon mobility. The basic decision making refers to suppliers' behaviour. The decision has three simultaneous components: (a) how much to invest in new equipment, decommission older ones or extend their lifetimes; (b) select vehicle technology and size for new investment, where technology refers to powertrain, energy efficiency and fuel type; (c) allocation of the use of the fleet of vehicles over the various trip types to meet demand for passenger and freight transport (as coming from the detailed transport models). The objective of the transport supplier is to minimize total transport cost of the supplied services.

For the non-road transport modes - aviation, railways, inland navigation and maritime - the energy model determines the mix of the alternative transport equipment, the evolution and the operation of the fleet to meet passenger and freight transport demand, coming from the transport models. The energy model assumes a representative transport supplier (e.g. a transportation company) who offers transportation services towards passengers. The representative transport suppliers choose the optimum way of using the existing fleet, determining the need for investments for new transport equipment. The evolution of the fleet depends on its utilisation (i.e. the available activity that the equipment can provide each time period) and the evolution of passenger and freight transport activity. Using stock-flow relationships and retirement functions to capture evolution of the non-road transport equipment, the energy model determines the volume of new investments necessary for each time period, without solving an optimisation problem.

8 Conclusions

This paper presents an overview of the TRIMODE model and of its components. The TRIMODE model is being developed to provide the European Commission with an integrated tool based on a European wide transport network model usable for strategic assessment of transport policies and transport infrastructures at the European level. The TRIMODE model has a modular structure, allowing it to simulate a wide range of policy leverages and to estimate a large number of indicators regarding not only the size and patterns of transport activity down to the link level, but also impacts on energy consumption, emissions as well as effects on the economy.

TRIMODE is founded on previous modelling applications at European and national level, but its components have been specifically designed and implemented and include innovative elements such as regionalisation of economic variables or bi-level assignment.

When the TRIMODE model is completed, in 2019, the suite of modelling tools available at the European Commission will be enriched by a new model which will be usable not only by expert model users but also by policy analysts who will be able to run the model through a web interface that enables them to configure scenarios and to test, analyse and understand their outcomes.

9 References

Jahanshahi, K., Williams, I., Hao, X. (2009) Understanding Travel Behaviour and Factors Affecting Trip Rates, Presented to the European Transport Conference, 2009.

Kompil M. et al., 2013, European cities: territorial analysis of characteristics and trends - An application of the LUISA Modelling Platform (EU Reference Scenario 2013 - Updated Configuration 2014), EUR 27709, Luxembourg, Publications office of the European Union, JRC100001

ME&P, TRT (2000) SCENES European Transport Forecasting and Appended Module: Technical Description, Deliverable D4 of the SCENES project funded by the European Commission under the transport RTD programme of the 4th Framework Programme.

Redding, Stephen J., and Esteban Rossi-Hansberg. 2017. Quantitative spatial economics. Annual Review of Economics, vol. 9, pp. 1-47.

Siskos, P., Capros, P., & De Vita, A. (2015). CO2 and energy efficiency car standards in the EU in the context of a decarbonisation strategy: a model-based policy assessment. Energy Policy, 84, 22-34.