THE TRIMODE INTEGRATED MODEL FOR EUROPE

Davide Fiorello
TRT Trasporti e Territorio
Klaus Nökel
PTV AG
Angelo Martino
TRT Trasporti e Territorio

1. INTRODUCTION

The implementation of the European transport policy is subject to a pre-defined process including a thorough impact assessment respecting the European Impact Assessment Guidelines (European Commission, 2009). The most important elements of such an impact assessment are (1) the definition of distinct policy options and (2) the quantification of potential impacts of these policy options. This requires the use of models.

A major component of European transport policy has always been the development of the Trans-European Transport Networks (TEN-T) and the policy initiative in this field was accompanied by the development of the first European transport network models such as STREAMS and SCENES, used for the mid-term assessment of 2000 White Paper on European transport policy (Ying et. al., 2005), and VACLAV, that was applied to perform the Transport Infrastructure Needs Assessment study (TINA Secretariat, 1999) and TEN-STAC project (NEA, 2004). These transport network models remained accessible only for their developers, while the European Commission is interested in developing a model that is more transparent and accessible. Furthermore, the European transport policy has widened over the last decade and requirements for supporting transport modelling tools have changed accordingly.

Against this background the European Commission supported the development of a model that is:

- transparent and feasible to validate,
- sufficiently academic and fully reliable,
- accessible to the European Commission,
- built on existing approved models and software platforms,
- able to be integrated with economy models and energy models.

This paper presents this model that we call TRIMODE (TRansport Integrated MODel of Europe). Within a single software platform, the TRIMODE model includes a full four stage transport model of passenger and freight movements across Europe, an energy model with dynamic vehicle fleets for all transport modes and an economy model representing the complete macroeconomic system of European countries. A web-interface has been developed to ensure that the model can be used easily and effectively for policy testing.

The TRIMODE model is being developed by an international consortium led by TRT Trasporti e Territorio (IT) and including PTV AG (DE), E3MLab (EL), MDS Transmodal (UK), Bauhaus Luftfahrt (DE), M-Five (DE), Fraunhofer-ISI (DE) and INRIX (UK). The model construction is split in two phases: currently a Phase I version of the model exists including six European Countries: UK, NL, DE, AT, IT, SI. Phase II version will cover the whole of Europe and will be completed in 2019.

The rest of this paper is organised in five sections. In section 2 an overview of the structure of TRIMODE model is provided. In section 3 more details are given on the passenger demand model, while section 4 explains the functioning of the assignment model, especially as far as multi-modal chains are concerned. The policy scope of the model is explained in section 5. Section 6 deals with the user interface. Conclusions end the paper.

2. OVERVIEW OF TRIMODE MODEL

TRIMODE is designed to be able to represent a comprehensive range of infrastructure investment, pricing, technology and regulatory policy scenarios. The model integrates fully a comprehensive European transport network model with state-of-the-art energy and economic models. TRIMODE is designed to represent in detail all transport movements on all freight and passenger modes across all of Europe at a NUTS III zonal scale (as well as demand to and from neighbouring countries and overseas modelled as external zones), together with the economic structures that generate this transport demand and the energy and environmental impacts that it creates.

The overall TRIMODE system comprises several components belonging to three main blocks (Figure 1): a transport model, an economy model and an energy model.

The economy model estimates for all zones in a particular year their zonal demographic and economic activities and the change in bilateral trade between all zone pairs. The estimation is made first at the national level and is then regionalised to NUTS III zones. The resulting output from the economy model is used to generate the demand pattern for passenger and freight transport. In parallel, the energy model determines the composition of vehicle fleets and calculates the operating costs of transport modes and their resulting unit user costs of transport. These user costs are a major input to the passenger and the freight demand models that estimate the spatial pattern of passenger and freight transport movements and how these are allocated among modes and to the vehicle types within a mode. The network model assigns these vehicle movements to the paths and links of their respective modal networks. The demand model and assignment are iterated so that any resulting congestion delays or economies of scale in service operations are fed back to influence the choices of route, mode or destination within the freight and passenger demand models. This transport modelling system is iterated until an equilibrium solution is reached for all transport responses for the year.

The equilibrated travel cost and time characteristics for each type of passenger and freight movement are fed back 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. In this way the full transport impacts of 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 to estimate the spatial pattern of energy consumption, pollution emissions and of other external costs based also on developments within the vehicle fleets. In this way the full transport impacts of policy measures on environmental costs and on energy consumption can be measured at a spatially detailed level.

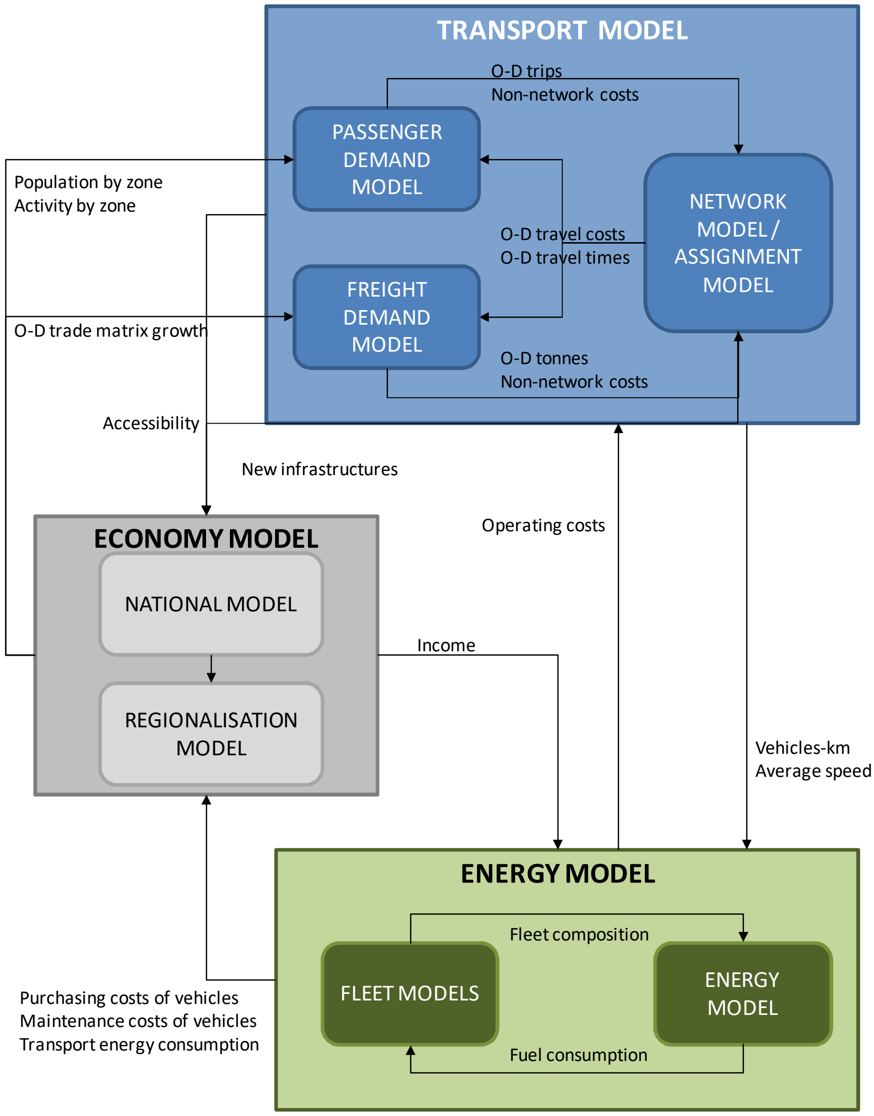

Figure 1: Overview of TRIMODE integrated modelling system

The TRIMODE model is calibrated with reference to year 2010 data and validated against year 2015 data. The model runs until the year 2050 and the integration of its components within a consistent dynamic sequence consider that, on the one hand, the transport demand model and the network model compute a static equilibrium for a few pre-defined points of time, while on the other the economy and the energy models compute dynamic projections for five-year steps.

TRIMODE includes a number of important innovations that ensure that it captures transport behaviour in a consistent and comprehensive manner. All passenger and freight movements are represented as door-to-door movements by a main mode, within which its feeder modes (e.g. car and/or rail feeder legs to or from airports for the main mode air passenger) are explicitly represented on their own modal networks. All goods are transported through a range of distribution channels from the producer to their consumer with each channel explicitly split into the sequence of distinct intermediate logistic legs and distribution centres that it traverses. In the two following sections, more details are provided on the passenger model and the assignment model. The freight model is dealt with in a separate paper (Williams et. al., 2017).

3. TRIMODE PASSENGER DEMAND MODEL

The TRIMODE passenger demand model consists of three classical main stages basically executed in sequence: trip generation is followed by trip distribution and finally by 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 Trip generation

Demand generation is modelled by estimating trip rates for several different population groups and for several trip purposes in each country. Provided that all trips are considered (i.e. including local non-motorised trips) trip rates for a specific person type show a significant stability across time and across different region types (Jahanshahi et al., 2009). At the same time trip rates can vary significantly among individuals with different socioeconomic characteristics. Since trip rates are applied to detailed population segments this approach allows us to estimate the number of trips, to explain differences across regions without the need for estimating region-specific parameters – the differences are the result of different socioeconomic composition of region's population – as well as to forecast future changes without the need for updating parameters – as the changes are the result of modifications of the socioeconomic characteristics of population, e.g. income growth, motorisation. Using this approach, the modelling of generation of passenger transport activity is sensitive to:

- Relocation trend (e.g. urbanisation);

- Population structure trend (e.g. ageing);
- Motorisation trend (e.g. emerging shared mobility paradigm).

We consider 36 population groups based on three segmenting variables: employment status, car availability and income level.

Trip purposes distinguish demand categories with different characteristics: average trip length, value of travel time, etc. In TRIMODE we consider 12 different trip purposes (Table 1).

Demand segments for trip generation are the relevant combinations of all population groups and all trip purposes. Namely, it can be assumed that some groups do not make any trip for some purposes. For instance, it is expected that students do not travel for business.

Table 1: TRIMODE passenger model trip purposes

Trip purpose	Notes
Commuting to work/university	Home to work and home to university.
Commuting to school	Home to school Virtually all these trips are intra-zone
Managerial Business local	Trips in course of work in the local area made by managers, white collars, etc.
Technical business local	Trip in course of work in the local area made by manual workers (e.g. construction, repairs, etc.)
Leisure local	Local holiday without overnight stay
Other non-business local	Trips in the local area to visit friend and relatives and towards specific attractors (shops, offices, cinema, etc.)
Non-home-based personal	
Non-home-based Managerial business	
Non-home-based technical business	
Business long	Trips for working purposes and education outside the local area
Holiday long	National and international holiday trips with at least one overnight stay
Other purposes long	Trips with at least one overnight stay to visit friends and relatives or towards specific attractors (sport events, cultural events, exhibitions, etc.)

3.2 Trip distribution

Trip distribution is modelled by means of a singly-constrained gravitational-type approach based on measures of the attractiveness of each zone as destination for trips of a given trip purpose (and possibly for a certain population segment) and on generalised time (sum of actual travel time plus the equivalent in time units of the travel cost) used as a measure of the impedance between each origin/destination pair. Generalised time between two zones is obtained as logsum of generalised time of the set of modes available to travel on that Origin-Destination pair.

The reason for using generalised travel time rather than generalised travel cost is that, according to the latter, when value of time increases farther destinations become less attractive and, other things being equal, average trip length is reduced. Instead, there is evidence that in past years, growing average income has been associated to growing average trip length (see e.g. Williams, 2012). Using generalised travel time longer trips are generated in response to higher value of time, which is more consistent with the observed trends.

For trip distribution (and mode split) the quite detailed population groups used in the generation phase are aggregated. The reason is that differences in trip distribution and mode choice of some segments are not large. When these segments are merged the loss in terms of accuracy is acceptable in comparison to the significant gain in terms of computational effort.

A specific feature of TRIMODE passenger demand model is that intra-zonal trips are further distributed among different distance bands. This distance band approach to intra-zonal modelling was originally developed for use in the SCENES model (ME&P et. al., 2000) of Europe to ensure that it represented all freight and passenger travel demand on all modes despite being implemented with a NUTS 2 level of zoning. This methodology 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, which has been used intensively for policy assessment by the UK Department for Transport from 2002 through to the present.

In TRIMODE six different zone types, from rural areas to metropolitan areas, are also identified according to population density and share of urban population.

Using distance bands and zone types, intra-zone demand is segmented into homogenous groups and competitiveness of transport modes can be differentiated (with e.g. pedestrian trips feasible only for very local trips).

3.3 Trip mode split

The full set of transport modes considered in TRIMODE Passenger demand model includes:

- Pedestrian
- Bicycle
- 2-Wheelers
- Car
- Bus

- Tram/Metro
- Coach
- Rail (further segmented into conventional rail and High-Speed Rail within the assignment model)
- Airplane

A Nested logit algorithm is used to estimate the mode share of alternative modes available for each Origin-Destination pair (distance band for intra-zone trips) and for each demand segment. Generalised time is used as a measure of disutility for each mode. It is provided by the assignment model for those modes assigned to the network: car, coach, rail and airplane. For other modes, endogenous estimation based on average speeds influenced by zone types are made. User costs are computed building on either exogenous information or on variables modelled in other TRIMODE components (e.g. average fuel costs are received from the energy model). The estimation process is made explicit so that it is easier to introduce corrections and variants for calibration purposes or for simulating scenarios.

The generic transport mode “Car” considered in the mode split algorithm means different things. On the one hand, a growing share of individuals drive vehicles bigger than ordinary cars: Light Duty Vehicles (e.g. vans). On another hand, driving a private vehicle is not the only way to use a car. Alternatives have becoming more and more popular and it is expected that they can become even more popular in the future: car sharing services, the private platforms Uber and Blabla car. For the time being alternatives to driving own private car are market niches and in modelling terms they can hardly be part of the mode split algorithm. Therefore, in mode split “car” is only one mode but a further segmentation of car demand is made in a separate, more aggregated manner.

A fundamental feature of the Passenger Mode split model is that 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).

Multimodal chains are managed in the Assignment model, which computes convenient Origin-Destination routes using, where appropriate, a combination of modes. Travel times and travel costs used in the mode choice algorithm reflect the full chain. For instance, for a specific Origin-Destination pair, mode “Airplane” can actually correspond to a multi-modal combination and its cost and time are those of this combination. More details are provided in the next section.

4. TRIMODE ASSIGNMENT MODEL

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 Origin-Destination pair.

Assignment is made for 6 passenger demand segments (aggregations of those used in the Passenger demand model) and for 13 freight demand segments (based on transport mode and mode of appearance defined in the freight model).

TRIMODE poses a challenge for assignment because of the diversity of transport modes considered. As these modes possess different characteristics (transport costs depend on flow or not, services continuously available or only at discrete times), different assignment methods are appropriate for the various modes. Nevertheless, a single passenger door-to-door journey or freight shipment may combine several of these modes, typically a dominating mode (main mode) with one or several feeder modes. For this reason, the assignment method separates a higher level model of strategic route choice across all modes from mode-specific route choice models (within each modal leg).

The TRIMODE assignment is formulated as a bi-level problem (Figure 2):

- At the upper level (mode sequence choice) the choice is between mode sequences for a given main mode. O-D demand per main mode is received from the mode choice step of the demand model. The choice set for each O-D pair consists of feasible and efficient mode sequences, each specifying the order of modes used on the journey and the mode transfer locations. Generalized costs for each alternative are computed based on single-mode specific costs skimmed from the single mode assignments (lower level). Total demand for the O-D pair is distributed over these alternatives, using a discrete choice model. Finally, for each single mode demand is summed over all O-D pairs and over all mode legs that use this mode. This leg-wise single mode demand is passed to the lower level. The volume-weighted average generalized cost of the mode sequences is passed as main mode generalized cost to the (main) mode choice.
- At the lower level the leg-wise demand is assigned separately for each single mode (single mode assignments). Link volumes and paths are stored for each assignment. Generalized cost components are skimmed off each single mode assignment and passed to the upper level.

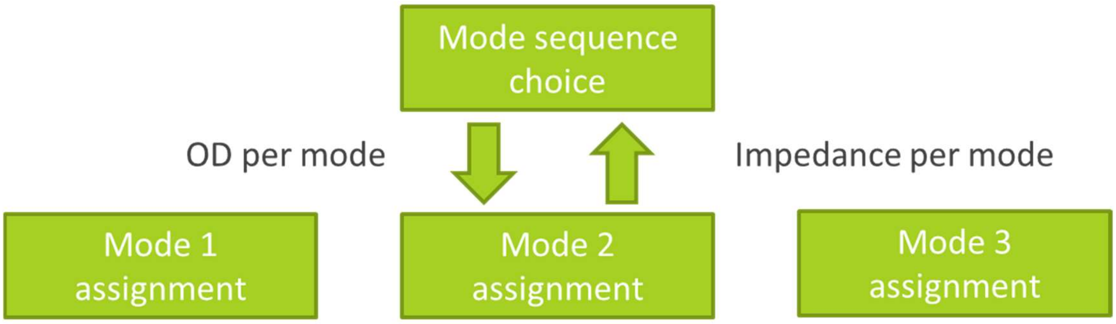

Figure 2: Bi-level formulation of TRIMODE assignment

Since some of the cost components fed back from the lower to the upper level are flow-dependent, the bi-level problem is solved iteratively until a termination condition is met.

4.1 Mode sequence choice

Mode sequence choice is carried out on a "multi-graph" that is simplified from the full network and constructed automatically from the input of mode sequence choice. We make the simplifying assumption that mode transfers are located at zones, just like origins and destinations. During the refinement of the zoning system in Phase II there may be the need to introduce point zones in those cases where a NUTS3 zone contains multiple transfer locations that should be kept distinct.

Figure 3 shows an example of the multi-graph and a feasible path for main mode Air. The path specifies the sequence of modes taken (first car, then air, then rail) as well as the locations at which the mode transfers take place. Paths like this form the choice set in Mode Sequence Choice.

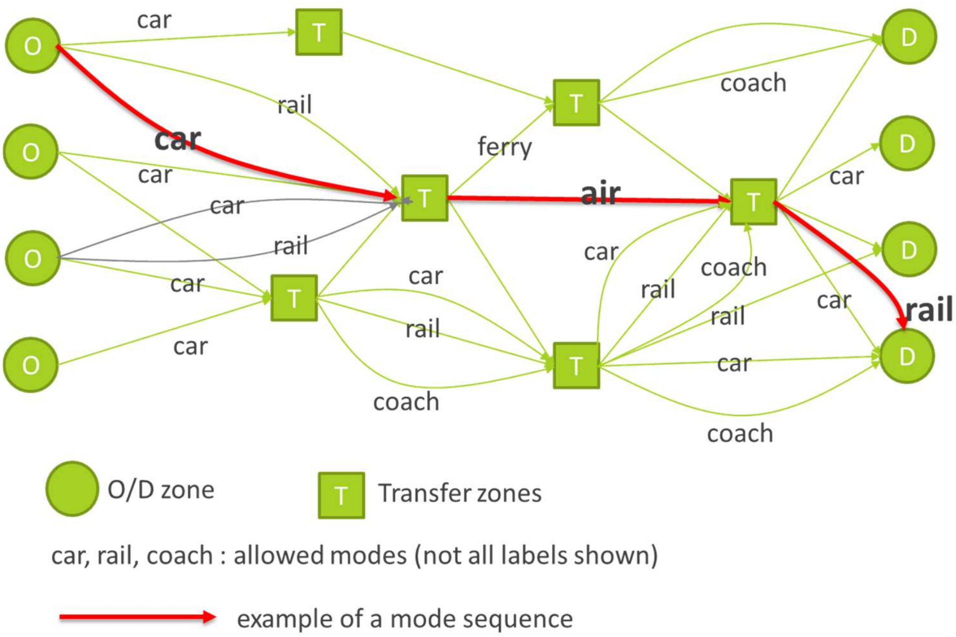

Figure 3: Example of a feasible mode sequence path in the multi-graph

While the graph only needs to be built once for all main modes, the path search is executed separately for each main mode. A branch-and-bound search is run from each origin zone to all destination zones, keeping multiple paths as long as their utility is not worse than the best path by a given threshold. The search proceeds in much the same way as connection search in the timetable based public transport assignment described in (Friedrich and Wekeck 2004) except that here no time dimension is involved.

The utility for each path alternative is computed by summing the utilities of each modal leg. These utilities are found by simple table lookup into the skim matrices obtained from the single-mode assignments. Based on the composite utilities total demand for each demand segment is split across the alternatives using a logit model.

Finally for each mode the demand for all path legs using this mode is cumulated into OD demand matrices by demand segment and passed as input to the single-mode assignments at the lower level.

4.2 Single mode assignment

After mode sequence choice, separate assignments for each single mode are run, all in parallel. The assignment method depends on the characteristics of the mode.

For road assignment a user equilibrium assignment is calculated based on travel costs (e.g. charges) and travel times, which depend on link flows by way of volume-delay functions. Therefore all passenger and freight demand segments need to be assigned simultaneously.

For most discontinuous transport modes some form of public transport assignment is applied. For rail and airplane the schedule-based public transport assignment method in Visum is used, as for long-distance traffic it appears more realistic that the passenger uses a journey planner to look up alternatives and picks the one with highest utility (lowest generalized cost). With a proper timetable and the long headways typical of long-distance traffic, schedule-based assignment gives in addition more realistic results than frequency-based assignment, because transfer waiting times are real values extracted from the timetable, instead of expected values based on frequencies.

For other modes, where insufficient information is available all demand is assigned to the shortest-distance path for the given transport mode. This is the case for coach, since a representation of the actual coach network and timetables is not reasonable because of their dynamics and volatility.

Where no explicit link network exists (e.g. bulk shipping services), only the resulting single-mode demand is stored in matrix form, without assignment to a network.

5. POLICY SCOPE OF TRIMODE

As mentioned in the introduction, the TRIMODE model is being developed to support policy assessment at the European level. Thanks to its modular structure a large variety of policy scenarios can be analysed and a wide set of impacts can be estimated.

As for previous European transport network models, the development of TEN-T infrastructures is a policy field where TRIMODE can provide useful indications. Applications of the model can help to assess:

- Network flows on TEN-T core and comprehensive network
- Network flows on single corridors
- bottlenecks at a European dimension

Network flows on new infrastructures depend on alternative routes becoming available and on mode shift. The TRIMODE model can however provide also wider impacts at the economy level driven by modification of accessibility, level and location of employment and increased efficiency. Therefore the TRIMODE model could be used to support the assessments of large projects (e.g. Brenner, Fehmarn), i.e. infrastructures whose demand is reasonably expected to consist of movements between NUTS3 regions, especially at national and international level.

A second policy field where assessment could be usefully supported by TRIMODE is the usage of economic instruments, such as:

- Transport energy taxation and differentiated vehicle taxation
- Transport user charges (e.g. road charges, track charges, slot charges)
- Internalisation of external cost

Again, the model is able to provide first order impacts on modal split and, in the case of link-based tolls, on route choice as well as wider second order effects on economy but also on energy consumption, fleet development and transport emissions.

The policy scope of TRIMODE includes decarbonisation strategies (mid- and long-term GHG targets). Other than contributions of measures like charging or vehicle taxation, the model can also simulate policy supporting technology development and innovation in the energy and in the automotive sectors, e.g.:

- Increased share of renewables (biofuels, electricity from RES) in the transport energy mix
- Improvements in energy infrastructure supporting the use of CNG, LNG and hydrogen in transport
- Efficiency and GHG emission standards
- Electric mobility and charging networks
- Diffusion of new powertrains

Lower energy consumption or penetration of alternative fuels leading to modifications of transport costs influence transport choices in the model, through the linkages between components, so that potential rebound effects of efficiency on the volume of transport demand and on mode shares can be estimated.

Many other transport policy measures could be analysed indirectly using TRIMODE implementing exogenous modifications of parameters which are expected to be influenced by the content of the measures. For instance, the impact of measures targeted at reducing trucks' empty runs can be simulated by means of exogenous increments to load factors. Simplification of port freight procedures can be translated in lower fixed time at ports in the network model. Revision of market access rules for buses and coaches can be modelled in terms of the expected impacts on user tariffs. In these and other similar cases, TRIMODE would not provide information on the effectiveness of measures in obtaining the first order they are designed for (reduction of empty runs, easier port procedures, better public transport services) but it could be used for "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.

6. THE USER INTERFACE

One key requirement of TRIMODE is that European Commission's users can access the model through a web-interface and can arrange model applications in a reasonably (given the overall complexity of the model) easy fashion.

In order to offer the best user experience for users from different backgrounds and competence, the TRIMODE model platform distinguishes between two types of users. Each user type will be presented with user interfaces tailored to their specific needs:

- Model developers are expert users of the TRIMODE integrated model. They will inspect and edit every aspect of the model and will set up the building blocks from which scenarios are composed. For this they need to make arbitrary changes to the model input data and parameters, e.g. changing attributes of supply or demand or adding new parts to the network. They will also do sophisticated types of analysis of model results and export results for external post-processing. This requires familiarity not only at the conceptual level, but also with the modelling software, its data models and formats, and its user interaction.
- Model analysts are any parties that wish to view and analyse model results. They may want to look at results from previously computed model runs, or request new model runs based on changed scenario assumptions. Model analysts are not assumed to be familiar with the

underlying modelling software. Instead they will be able to access the model through a simplified, custom-built interface that exposes only the necessary operations and ensures that all actions preserve the integrity of the model and its input data.

The software platform and all model data reside on a web server and a model server provided by the European Commission. Model users connect to the model through a web application running inside their browser. Requests from the user are received by web server communicating with the Visum instances on the model server via a web service protocol. The business logic behind the web service translates the requests into transactions and calculations executed by the Visum and GAMS instances.

On the input side, scenarios or variants represent the principal modelling unit in the TRIMODE platform. A variant captures a set of anticipated changes to framework conditions, policies and infrastructure. Each variant spans the entire modelling period from 2010 to 2050. The parameters controlling the model calculation are stored with each variant/scenario. Users define variants and set up their calculation parameters in the web application.

After a variant has been defined, the computation of the model for this variant can be launched. Users can inspect the progress of their model runs at any time.

At the end of a model run, the results of the computation are stored into a PostGIS database and can be analysed through the web user interface or exported to common file formats for analysis in external tools. Most TRIMODE results are geo-referenced to either zones, countries or network links or nodes. Some network-wide totals are given as tabular output. All result datasets can be further filtered and compared to the results of other variants through the web user interface.

7. CONCLUSIONS

This paper provided some information on the European strategic model TRIMODE, which is being developed on behalf of the European Commission to serve as a supporting tool for transport policy assessment. The TRIMODE model has a modular structure – covering transport, energy and economy and their linkages. Each module has a sophisticated representation of demand and supply interactions, thus providing a powerful tool for exploring a wide range of policy measures. A sophisticated web-based interface allows users with different levels of knowledge of the model to arrange scenarios and read results in graphical and tabular format. This paper is aimed at providing an overview of model features and, regarding the transport component, it is focused especially on the passenger demand model and the network model, while the freight model is addressed in a separate paper also presented in this Conference. More details on these and other components as well as results will be disseminated in the literature in the future as the model implementation process will develop.

ACKNOWLEDGMENTS

Authors wish to acknowledge the contribution of the partners of the TRIMODE consortium in the design and development of the model.

REFERENCES

European Commission (2009) Impact Assessment Guidelines [SEC(2009) 92], Brussels

Friedrich, M., Wekeck S. (2004). A schedule-based Transit Assignment Model addressing the Passengers' Choice among competing Connections. In Schedule-Based Dynamic Transit Modeling: Theory and Applications, Kluwer Academic Publishers, pp. 159-173.

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

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

NEA, COWI, IWW, NESTEAR, PWC, TINA, IVT, HERRY, MKmetric (2004) Traffic, bottlenecks and environmental analysis on 25 corridors, Deliverable D6 of the TEN-STAC project: Scenarios, traffic forecasts and analysis of corridors on the Trans-European Network

TINA Secretariat (1999) Identification of the network components for a future Trans-European Transport Network in Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia, Draft Final TINA Report.

Ying, J., Deane, G., Zhu, Y., Jakimovska, V., Martino, A., Fiorello, D. (2005) Results from the SCENES model, Annex VI of ASSESS Final Report, DG TREN, European Commission

Williams, I. (2012) a comparative study of commuter patterns and trends in Great Britain, Ireland and the US, Presented to the *European Transport Conference, 2012*.

Williams, I., Garratt, M., Wright, C. (2017) TRIMODE Freight & Logistics Model of Europe, Presented to the *European Transport Conference, 2017*.