Global Scale System Dynamic Simulation Model for Transport Emissions (GLADYSTE)

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Abstract

GLADYSTE (Global Scale System Dynamic Simulation Model for Transport Emissions) is a research project within the framework of European Commission's policy to develop reliable, useful and well-tested analytical tools to address the policy problems related to transport and climate change. The objective of the project is to develop a model prototype capable of estimating transport demand and emissions, as well as simulating the impacts of policy and technological measures in transport-related sectors, covering all transport modes from the different regions in the world up to 2050.

GLADYSTE model prototype is based on TREMOVE model and a set of transport models developed and used by European Commission's (EC) Joint Research Centre - Institute for Prospective Technological Studies§ (JRC-IPTS), plus a demand module especially commissioned for this project. The model splits the world into 57 regions, and covers all transportation modes. It consists of four interrelated modules: Demand, Fleet, Energy Use – Emissions, and Welfare.

The project consists of three major steps: i) converting the current TREMOVE code from GAMS© to Vensim©, ii) harmonizing modelling assumptions and data from both models, and iii) calibrating the model based on the most up-to-date available reference data provided by IPTS.

At this stage, we have completed the first step of the modelling works. We are currently at the final phase of the second step while at the same time starting the calibration process. In this paper, we present the concept behind the GLADYSTE model and provide example of its potential applications.

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1 Introduction

Transportation models play a crucial role in assessing the implementation schemes of carbon abatement measures. The TREMOVE model was developed and is maintained and improved within this scope[1]. More precisely it is a policy assessment model, designed to study the effects of different transport and environment policies on the emissions of the transport sector in Europe. The unquestionable importance of energy-intensive sectors like the transportation industries, the prominent effect that the Kyoto Protocol could have on them, and the need of having reliable tools to support policy making, motivates the development of GLADYSTE.

The interest in having good sector-wise details is also justified (amongst other reasons) by the necessity of estimating with accuracy sector-wise marginal abatement curves at global level. Introducing technology characterization on a sector basis helps in the creating alternative scenarios assuming accelerate technology substitution and analyzing the impact of these changes over a baseline technological projection, not only within the European markets, but also at global level.

GLADYSTE (Global Scale System Dynamic Simulation Model for Transport Emissions) is a research project funded by the European Commission (EC), Joint Research Centre - Institute for Prospective Technological Studies (JRC-IPTS). This research and development contract is framed within the policy of the EC of developing reliable, useful and well-tested analytical tools to address the policy problems related to transport and climate change, and, in particular, to transform TREMOVE model into a global model able to address the impact of transport sector policies at global scale.

During the last years, some POLES-compatible stand-alone transportation models of the air, maritime, road freight, and rail transport sectors have been directly developed or commissioned by the JRC-IPTS[2]. Those prototypes were developed with Vensim© software, to guarantee full compatibility with the POLES model, which is one of reference modelling tools in use at the European Commission to create and analyse global mid- and long-term energy and GHG emission scenarios. The present JRC-IPTS transport models split the world into 57 markets and each market is formed by either one country or a group of countries. These models estimate transport demand, fleet development, transport performance (in tons-kilometres and passengers-kilometres), energy consumption, and emissions (mainly CO_2) for each market. International trips are modelled indirectly in the transport demand part, i.e. two or more markets are grouped into one macro-market (or macro region) to estimate transport demand including international and domestic trips. This demand is further split into market level where no distinction is made between domestic and international demand.

Therefore GLADYSTE will be based on TREMOVE for Europe and the JRC-IPTS transport models for the rest of the world. The model will adopt exactly the same world zoning system of 57 market regions as used in the JRC-IPTS transport models. All

[1] More information on TREMOVE model: http://ec.europa.eu/environment/air/pollutants/models/tremove.htm

[2] There are several references, not cited elsewhere, available at the IPTS site in which the readers can find more information about these models

transportation modes will be considered, interacting through four interrelated modules: Demand, Fleet, Energy Use – Emission, and Welfare.

The GLADYSTE project consists of three major steps: i) converting the current TREMOVE code from GAMS© to Vensim© so it can be perfectly coupled with the JRC-IPTS transport models, ii) harmonizing modelling assumptions and data from both models, and iii) calibrating the model based on the most up-to-date European Commission's available reference data provided by IPTS. At this stage, we have completed the first step of the modelling works. We are currently at the final phase of the second step while at the same time starting the calibration process.

In this paper, we present the concept behind the GLADYSTE model and provide example of its potential applications. First, we present the model scheme, short definition of the different modules as well as the relation between those. Second, we describe each of the modules in more detailed way: demand, fleet dynamic, emissions, and welfare modules and finally we explain the potential of the model applications.

It is important to remark that since this paper concerns an on-going model development work, information given in this paper might subject to changes in the close future due to any modifications and/or improvements considered necessary to be incorporated.

2 Why System Dynamic?

Apart from the necessity to be fully compatible with the JRC-IPTS transport models and POLES, which are all coded with Vensim©, System Dynamic itself offers certain advantages. First, the transport system is composed by three highly interrelated subsystems: demand generation, dynamic of vehicle fleets, and emissions. Connectivity of the three subsystems takes places in the form of feedback loops between them: first, total transport activity estimated in the demand generation subsystem, is one of the inputs influencing the evolution of vehicle fleet as well as the motorization rate in the vehicle dynamic subsystem which is used again in the demand generation to estimate passenger demand trend. Second, the fleet composition resulted from the fleet dynamic subsystem influences the average cost by vehicle, which is a major component of the (dis)utility used within the demand generation subsystem for demand segmentation and mode split and finally, the cost per vehicle provided by the fleet dynamic sub-system is also influenced by the fuel efficiency of vehicles. These loops as shown give rise to feedback effects in the model, which can be treated accurately, intuitively and in an understandable way thanks to the SD structure of the model prototype. In SD methodology, two key elements in modelling are combined and made explicit for the user of such kind of model i.e. the structure of the modelled system (qualitative part) and the parameter of the modelled system (quantitative part).

3 Basic structure of the model

GLADYSTE is a translation and at the same time an improvement of the current TREMOVE model in the SD environment, combined with the IPTS transport models. In this modelling environment, the prototype is developed following the same approach as the JRC-IPTS transport models: a recursive simulation approach following system analytic concepts, where a number of interacting feedback loops are implemented.

Like the original TREMOVE structure, the prototype model is made of four main modules:

- The transport demand module (DEMAND),
- The vehicle fleet module (FLEET),
- The environmental module (ENVIRONMENTAL),
- The welfare module (WELFARE).

Each module leads to different activities, as described in the following Table 1.

Table 1 Main activity in each module

Name	Module	Activities
DEMAND	Transport demand	Demand generation Mode/network split Demand/supply interaction
FLEET	Cars[3] Duty vehicles Bus Train Airplane Ship[5]	Conversion of demand (passengers-kilometres, tons-kilometres, vehicles-kilometres) into fleet size Further split of vehicle types into vehicle technologies (age) or vehicle emission standards[4]
ENVIRONMENTAL	Fuel consumption Emissions WTW emissions	Calculating fuel consumption and emissions based on demand, speed, and fleet structure
WELFARE	Welfare	Calculating consumer surplus, external costs, taxes and subsidy

The four modules are linked together, i.e. they exchange information in order to provide a consistent picture of the different aspects modelled. Figure 1 shows the main relationships between the modules. Within the DEMAND module, motorised transport demand is endogenously generated and segmented according to several dimensions (e.g. national/international, long or short distances, etc.). In addition, the choice of mode and road type for each specific context is carried out taking account demand-supply interaction. Transport demand by mode is then the input for calculating vehicles-kilometres by type and technology according to the fleet structure estimated in the FLEET module. In the ENVIRONMENTAL module, fuel consumption and emissions are calculated on the basis of vehicles-kilometres (from the FLEET module) as well as average speed of each transport mode (from the DEMAND module). Finally, the WELFARE module takes its input from both the transport module and the environmental module in terms of consumer utility and, respectively, external costs.

[3] including mopeds and motorcycles
[4] emission standards will at minimum exist for the European regions
[5] with inland water ways (IWW)

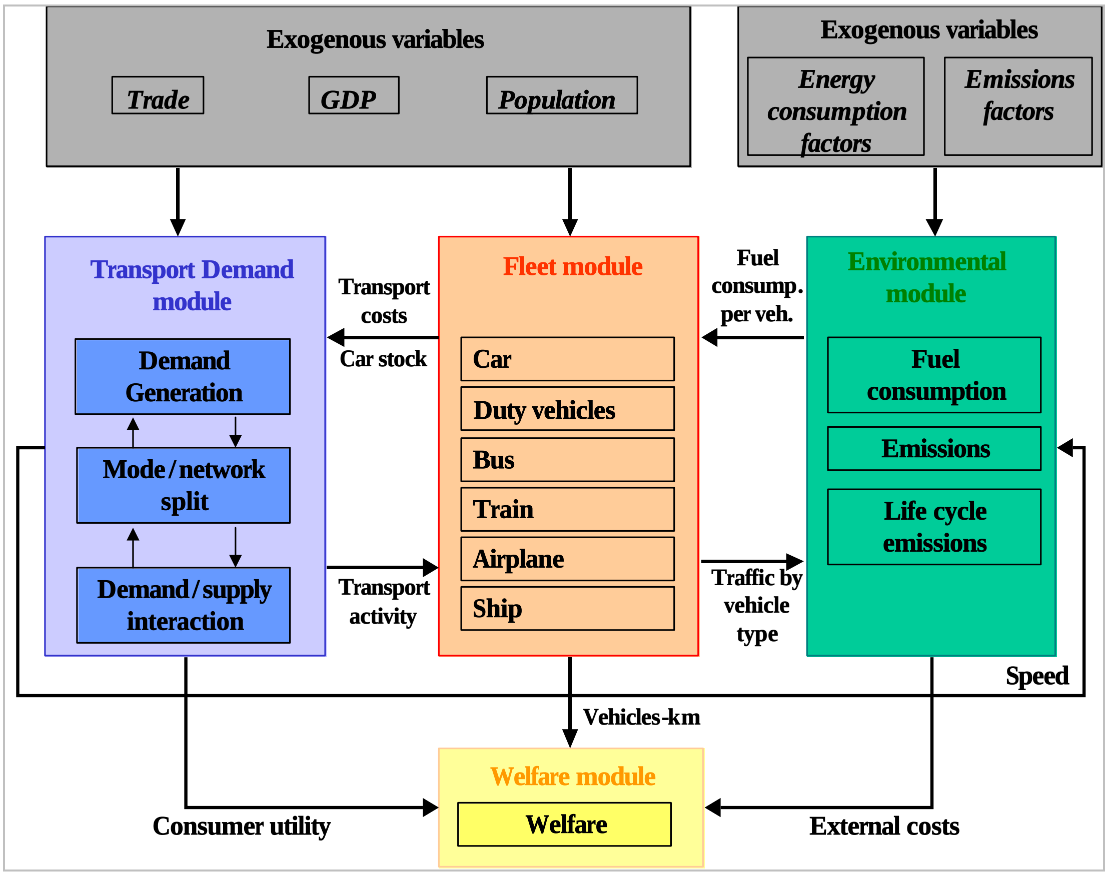

Figure 1 Modular structure of GLADYSTE

Two loops are created between the DEMAND and FLEET modules. First of all, the total transport activity estimated in the DEMAND module is one of the inputs for simulating the evolution of vehicle fleet in the FLEET module. In turn, the motorization rate is one of the inputs for estimating passenger demand trend.

Secondly, the fleet composition estimated in the FLEET module is an input for calculating the average cost by vehicle, which is a major component of the (dis)utility used within the DEMAND module for demand segmentation and mode split.

The cost per vehicle provided by the FLEET module is also influenced by the average fuel consumption per vehicle calculated in the ENVIRONMENTAL module, introducing a feedback also between this module and the DEMAND module.

3.1 Geographical scope and zoning system

The zoning system of the model prototype covers 57 zones divided into 33 zones in Europe and 24 zones of the rest of the world, as in the JRC-IPTS transport models.

Table 2 Geographical scope and zoning system in GLADYSTE

33 European regions	24 zones of the rest of the world
Austria	Canada
Estonia	United States
Latvia	Japan
Lithuania	Australia, New Zealand and the rest of South Pacific countries
Belgium	Russia
Luxembourg	Ukraine
Denmark	The rest of former Soviet Union countries
Spain	Mexico
Finland	The rest of Central American countries
France	Brazil
United Kingdom	The rest of South American countries
Greece	India
Hungary	The rest of South Asian countries
Ireland	South Korea
Italy	Indonesia
Netherlands	The rest of South East Asian countries
Poland	China, Hong-Kong, and Macau
Portugal	Egypt
Czech Republic	Oil producer North African countries: Algeria and Libya
Germany	Non oil producer North African countries: Western Sahara, Morocco, Tunisia
Slovak Republic	Israel, Jordan, Lebanon and Syria
Cyprus	Gulf countries:
Malta	South Africa
Slovenia	The rest of African countries
Sweden	
Bulgaria	
Croatia	
The rest of Balkan countries	
Romania	
Iceland	
Norway	
Switzerland	
Turkey	

3.2 Data base

The data-base used to feed the model prototype comes from three main sources: a) socio-economic and demographic data, which are the main exogenous inputs used to generate demand (they are based on the most up-to-date available reference data provided by IPTS), b) data from the TREMOVE model database, which will be used as the backbone of the European regions modelling, and c) data from JRC-IPTS transport models which will be used as the main modelling base of the rest of the world.

Socio-economic and demographic data i.e. reference scenario projections of GDP, population, and fuel prices are provided by the European Commission (JRC-IPTS). These projections are in line with the assumptions used in the modelling framework supporting the forthcoming White Paper on transport to be issued by the European Commission by the end of 2010.

Data used in the TREMOVE model come from various sources. A detailed description of the data sources used in the TREMOVE model can be found in De Ceuster et al., 2007. Some of most important data sources can be mentioned here: road vehicle stock data come from the TRENDS database[6], Eurostat[7], as well as national sources. Road costs data come from the ASSESS[8] project, UNITE[9], and ACEA[10] while Emission and fuel consumption coefficients for road vehicles are calculated according to the COPERT IV[11] methodology.

Data sources of JRC-IPTS transport models also come from various data. Christidis P., et al., 2003, and Hidalgo, I., et al., 2006, are two open-to-public reports related to these models where complete data references can be found. Some of the most important sources are given in the paragraphs below.

Regarding the IPTS air transport model, the bulk of information in relation to aircraft fleets comes from IATA[12] while energy use and emission estimation methodologies and inventories have been obtained from Kalidova and Kurdna, 1997 and Sutkus et al., 2001, 2003.

For the maritime transport model, data have been obtained from publicly available statistics such as United Nations' Review of maritime transport (UNCTAD, 2006), studies, and scientific and technical literature (Coto-Millán et al., 2005; Dikos et al., 2006; Engelen et al., 2006; Frías and Guisan, 2002; Stopford, 2006).

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[6] TRENDS: TRansport and ENvironment Database System. The road transport module developed in the framework of the TRENDS project produces both analytical and aggregated results for the EU15 countries and for a time-span of 50 years (1970-2020).

[7] Eurostat is the Statistic Bureau of the European Commission (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/)

[8] Assessment of the contribution of the TEN and other transport policy measures to the mid-term implementation of the White Paper on the European Transport Policy for 2010

[9] UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Project Funded by 5th Framework RTD Programme.

[10] European Automobile Manufacturers' Association

[11] COPERT IV is an MS Windows software program aiming at the calculation of air pollutant emissions from road transport (http://lat.eng.auth.gr/copert/)

[12] http://www.iatagabi.com

For the rail transport model, most data have been obtained from publicly available statistics (UIC-International Union of Railways), studies (DAMF Consultants Inc. et al., 2007; Directorate-General for Energy and Transport, 2006), and scientific and technical literature (Friedrich et al., 2003; Wohlgemuth, 1997) while for the road freight transport model, the sources used were publicly available statistics (Cropper and Kopits, 2003; Davis and Diegel, 2007; Directorate-General for Energy and Transport, 2006), studies (Borken et al., 2007; De Ceuster et al., 2007) and scientific and technical literature (Friedrich et al., 2003; Wohlgemuth, 1997).

Finally, for the road passenger transport model, various sources of data have been used: EUROSTAT (Transport and Communications Yearbook), OECD (Statistical Trends in Transport, CO2 Emissions from Transport), US Department of Energy (Transportation Energy Data Book, Transportation Energy Efficiency Trends), International Road Federation (World Road Statistics), IEA (Energy Prices and Taxes) and the POLES model database. The cost data used for EV, HEV and FCV come from studies made by the Institute of Transportation Studies, University of California, and Energy and Environmental Analysis, Inc (Ogden, J.M., 1999).

3.3 Policy simulations

The purpose of the prototype developed in GLADYSTE is to simulate policy measures. The approach used in the model will keep the different policy levers available in TREMOVE and the JRC-IPTS transport models. However, some changes made in GLADYSTE in relation to TREMOVE will extend those features to cover more policy levers. Of course, policies measures can be implemented at the European as well as the national level. In particular the following types of policy measures will be simulated with the prototype:

- Policies related to vehicle technologies: introduction of new emission standards, penetration of new (alternative) technologies, implementation of supplementary measures to increase fuel efficiency, and accelerated vehicle fleet renewal. The fleet module is sensitive to variables that can be changed when specific policy measures are put into practice. The main impact of such policies will concern fleet composition, emissions, and energy consumption, but as far as these measures affect transport costs, also demand can be changed.
- Policies related to the fuel quality: regulatory aspects of fuel quality in terms of costs and the environmental benefits obtained. For instance, different fuel standards developed by CEN since 1993 up to 2009 related principally to the maximum sulphur limits are incorporated in the model prototype.
- Policies related to fiscal instruments in the transportation sector: freight taxation, vehicle taxation, incentives for low emission cars, internalization of external costs via Pigouvian taxes, etc. Since transport costs are a major factor in the demand module of the prototype, fiscal instruments like internalisation or fuel taxes can be readily simulated and have an impact on demand (mode split, demand generation). Vehicle taxation is modelled in the fleet module but can also have an indirect impact on demand.

- Policies related to traffic management (logistics in passenger and freight transport, induction of changes in the speed-flow curves, etc). Parameters like average occupancy factors and load factors or the aggregated speed-flow curves envisaged in the prototype can be used to indirectly simulate measures related to transport supply and infrastructures and read impacts on demand. It should be considered, however, that the scale of the model makes it not the most suitable tool for simulating these kinds of measures that could be implemented only very roughly and provide very coarse responses.
- Policies related to maritime and air transport, where modal substitution is more limited and the international traffics are relatively more important. The two modes modelling require a representation of the rest of the world zones and for this reason; the modelling of these modes is based mainly on the JRC-IPTS transport models.

3.4 Technical specification

Vensim© allows modellers to develop their model starting from a causal loop diagram (CLD) which represent the relationships between the different elements in the model. Figure 2 below shows an example of CLD used in the FLEET module of passenger cars. This conceptual CLD is furthermore converted into more technical view in Vensim© which allows translating elements into more detailed variables (Figure 3). The view shown in the figure represents connectivity between variables in an explicit way. Equations as well as qualitative information (variable definition and other information) is given in each variable and can be shown and edited by only clicking the corresponding variable.

Database and coefficients are written and editable in MS Excel which is further converted into a data format readable by VENSIM (*.vdf*). At this moment the whole model size, included the database, is only around 80 MB. The size of the complete output of the model (in *.vdf* format) is around 2.5 GB, and currently the model needs only around 10 minutes to finish one scenario run with time horizon starting in 2000 and ending at 2050 for the whole 57 world regions.

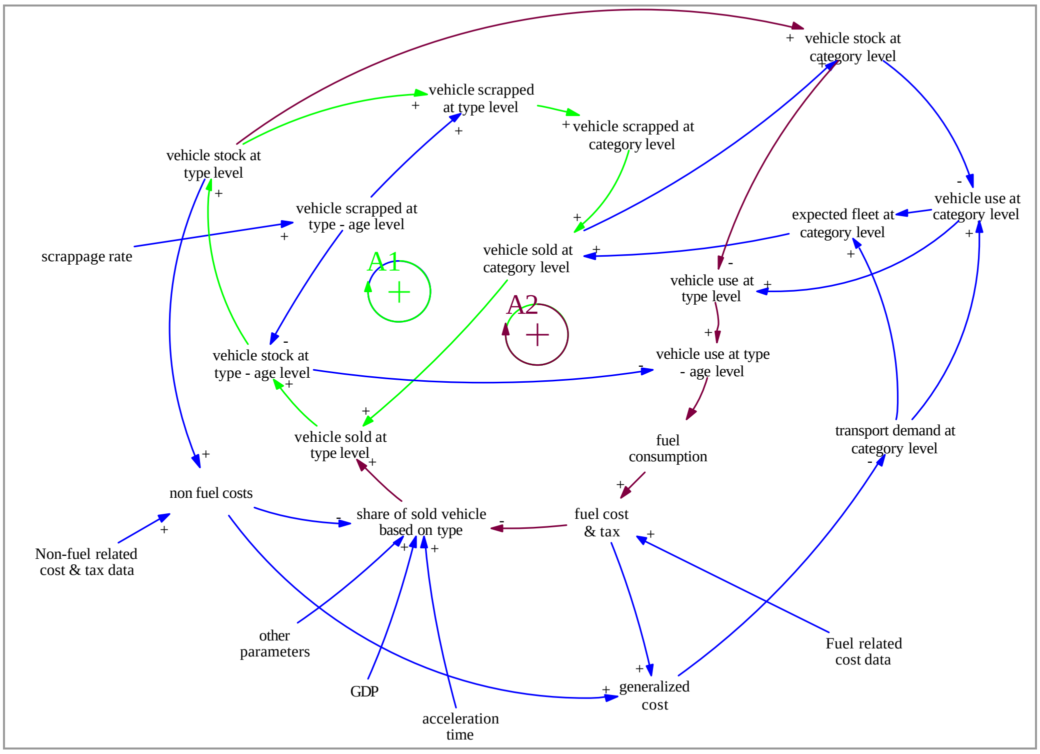

Figure 2 Example of CLD from the FLEET module

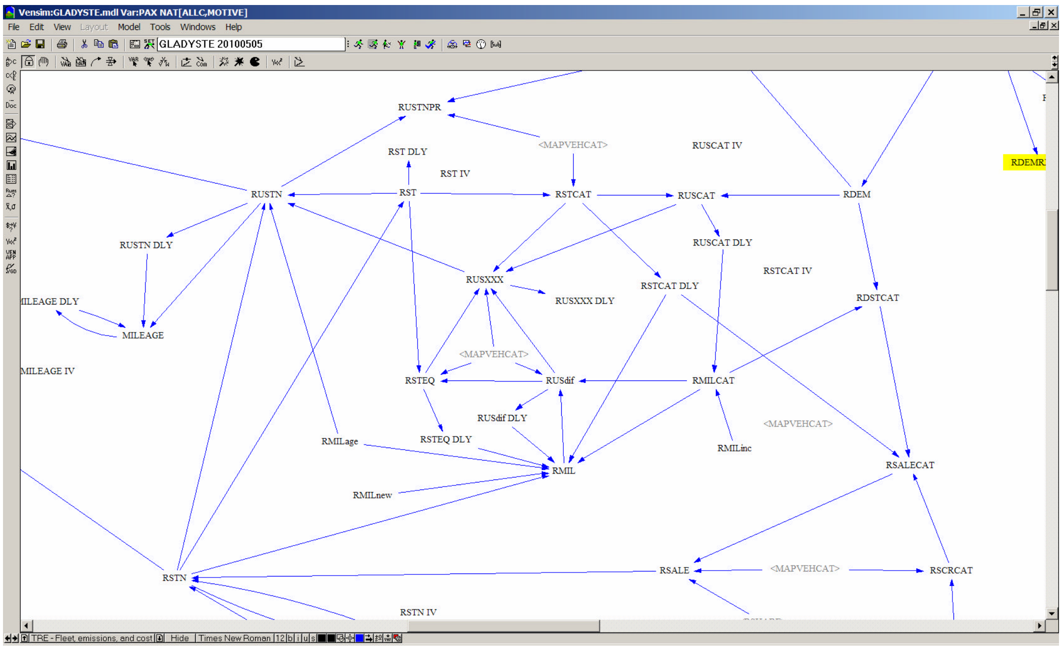

Figure 3 Example of view from the FLEET module of GLADYSTE

4 DEMAND module

4.1 Generation of intra-continental demand

The role of an endogenous demand generation algorithm in the prototype is to avoid the dependency of the prototype on an external source for demand forecasting, and to introduce a loop between demand calculation and the rest of the model. The demand generation algorithm should provide reliable forecasts of the size of future transport demand under a set of exogenous assumptions concerning key variables at the aggregated level (like population and GDP). Thus, it is important that the demand generation algorithm is sufficiently general to represent both Europe and non-European regions with a different level of economic development. However, given the aggregated level of the analysis and given the above considerations, the algorithm should demonstrate itself capable to simulate the overall long-term trend, rather than to reproduce observed short-term fluctuations of demand in specific countries or years.

In the end, the general approach is to generate transport demand at the aggregate level (passenger-km, tonnes-km) and then into the required detail (distance, period of time, mode of transport, etc.). In general, to address the problem of computing how demand is broken down into several segments, two conditions are considered:

a) Segmentation of demand mainly due to “macro” circumstances;

b) Segmentation of demand mainly due to “micro” decisions.

Condition a) includes the segmentation of demand according to the geographical dimensions (national vs. international; long distance vs. short distance; urban vs. non-urban) as well as the segmentation according to trip purposes and period of time (peak vs. off-peak). All these dimensions depend on the macroscopic context rather than on individual choices. Of course, the macroscopic context can change over time (and the module allows to simulate changes) also because of individual decisions, but such decisions belong mainly to domains outside the scope of the prototype (e.g. moving house, change regions where to produce, change job, etc.) and therefore only the additional impact of the model variables (e.g. travel cost) on these elements is considered in the model in aggregate terms.

Condition b) includes the segmentation of demand which can be considered as individual choice, for example choice between transport modes or road types. These two elements can be reasonably interpreted in terms of choices between alternatives.

Then, the segmentation task should be addressed in different ways according to the specific conditions. In the prototype, dimensions falling under condition a) are modelled by means of a mathematical equation depending on policy-sensitive variables whereas dimensions under condition b) are modelled by means of a discrete choice algorithm (nested logit model). In any case, both the generation phase and the further steps to split up demand into segments are directly or indirectly sensitive to parameters whose value can change according to specific policy measures implemented. As well, the different steps (including the generation phase) can be affected by the result of other steps, so giving rise to feed-back effects.

In the demand module, transport activity is modelled with the following level of details:

- Region where the trip is originated (see zoning system, Table 2),
- Region of destination: intra-regional or inter-regional trip,
- Distance travelled: short distance or long distance (for intra-regional trips only),
- Urban level: urban or non-urban (for intra-regional trips only),
- (For passenger demand) Purpose: business, commuting or personal,
- (For freight demand) Cargo type: general cargo, unitised, bulk,
- Passenger mode: car, motorbike, bus, train, tram and metro, airplane,
- Freight mode: truck, train, inland navigation, maritime, airplane,
- Road network type: motorway, rural, urban (for intra-regional trips only),
- Time period of the day: peak or off-peak (for intra-regional trips only).

In terms of regions, each trip is either intra-regional or inter-regional assuming as a reference the zoning system in Table 2.

For Europe in general "inter-regional" is equivalent to "international" (e.g. a trip from Austria to Finland is inter-regional), while for the rest of the world it's related to the specific zone definition.

The intra-regional trips are then split into long or short distance, assuming a distance threshold that will have to be defined. The intra-regional short distance trips will be further distinguished into urban and non-urban. For passengers, trip purpose is distinguished into "personal", "commuting" and "business" while for freight transport demand is split by cargo type thus distinguishing: "general cargo", "unitised" and "bulk".

Various modes are available for passenger and freight transport, depending on the specific demand segment. The following table show the available modes for each transport context for passenger and freight.

Table 3 Passenger modes available in each transport context

	Car	Moped and Motorcycle	Bus	Tram/ metro	Train	Airplane
Intercontinental						X
Inter-regional	X		X		X	X
Intra-regional long distance	X		X		X	X
Intra-regional short distance non urban	X	X	X		X	
Intra-regional short distance urban	X	X	X	X		

Table 4 Freight modes available in each transport context

	Truck	Train	Inland Navigation	Maritime	Airplane
Intercontinental				X	X
Inter-regional	X	X	X	X	X
Intra-regional long distance	X	X	X	X	X
Intra-regional short distance non urban	X	X	X		
Intra-regional short distance urban	X				

In case road modes are used for an intra-regional trip, users can chose the type of road network for travelling: motorway, rural or urban roads.

In addition, it should be noted that in case the air mode is used, the demand will then be split into five distance bands designated to produce detailed results for the environmental module.

The process of demand generation itself can be interpreted as a sequence of splits: first aggregated demand is generated, then it is separated into trip purposes, afterwards it is further split into intra-regional and inter-regional, etc. At each step, a specific set of variables and parameters are used for compute the shares. Basically, two groups of variables and parameters can be distinguished: exogenous, i.e. GDP, population, trade, base share, etc., and endogenous, i.e. variables consisting of input from other modules.

After demand has been generated according to the 'macro' circumstances, those aspects that can be interpreted as the result of individual decisions, i.e. the choice of mode and of network type, are modelled. The approach chosen is random utility theory.

According to this theory, the probability that a consumer chooses a given alternative depends on the utility of the alternative as well as the utility of all the others on the market. This utility of alternative *j* as obtained by decision maker *n* consists of a deterministic and a random term. It is assumed that the consumer prefers the alternative with the highest utility over the others (utility maximization).

In the prototype generalised cost of transport for each alternative (mode or network type) is the main deterministic factor of utility. For generalised cost we mean a function of at least transport cost and travel time expressed in monetary terms.

The random term accounts for additional elements that make it impossible to observe the choice as a fully deterministic process. Depending on assumptions with respect to the statistical distribution of the random term and to the correlation between random terms concerning the alternatives, different models are defined.

The above demand generation and segmentation sequences will avoid the risk of "spurious" changes of demand (e.g. air demand for business is modified because a change of bus cost for commuting in urban areas has occurred). In the demand model of the prototype, the overall generalised cost of transport affects demand generation before it is split into distance, mode, etc. So, in some way there is the possibility of indirect effects. However, mode split will be more sensitive to cost changes than demand generation and therefore, if only the cost of one mode is increasing/decreasing, the reduction/growth of overall demand (and therefore of competing modes demand) will be tiny in comparison to the reduction/growth of the mode whose cost has changed.

All in all, transport demand generation will be based on both exogenous and endogenous factors, of which generalised cost is one of the most important. The influence of endogenous elements will make the demand generation phase sensitive to several policy measures.

4.2 Generation of intercontinental demand

The modelling structure presented above does not apply to intercontinental demand. Intercontinental demand is defined as transport activity between non-neighbour continents, where inland modes cannot physically be used or are unrealistic alternatives. In fact, as far as demand between e.g. EU and Ukraine or Russia and Ukraine or Egypt and Algeria is concerned, inland transport is definitely part of the demand modelling structure presented above. Instead, demand between e.g. Egypt and Japan is considered intercontinental demand.

Three relevant components of intercontinental demand can be identified: air passenger and freight demand and maritime freight demand.

The modelling of such components in the GLADYSTE prototype is separated and performed at a higher level of aggregation, i.e. by macro-regions instead of countries. The aggregated regions used in the JRC-IPTS transport models are used. In the end, for EU, intercontinental demand is detailed at the country level to/from macro-regions (e.g. from France to North America).

Table 5 Macro regions and the corresponding countries or regions

Macro-region	Countries or Regions
North America (NOA)	CAN, USA
Central America (CEA)	MEX, RCAM
South America (SOA)	BRA, RSAM
Europe (EUR)	Europe (first column in Table 2)
Commonwealth of Independent States (CIS)	RUS, UKR, and RFSU
Africa (AFR)	NOAN, NOAP, SSAF
Middle East (MEA)	EGY, MEME, GOLF
China (CHI)	CHN
North East Asia (NEA)	COR, JPN
South East Asia (SEA)	RSEA
Oceania (OCE)	RJAN
South West Asia (SWA)	NDE, RSAS,

The algorithm is basically a two step procedure, where overall inter-continental demand is firstly generated in each macro-region by means of a regression function mainly based on GDP per capita (i.e. the same approach used for generating intra-regional demand) and then destinations are chosen with some attraction measure. The "gravitational" function used in the JRC-IPTS transport models is a starting point. The algorithm is sensitive to the (generalised) cost also in the generation phase (e.g. to capture impact of air emission trading schemes on intercontinental air demand). In terms of "distance band" related to air emissions, the "intercontinental" air passenger demand is supposed to be entirely assigned to the distance band ">2000 km".

5 FLEET module

The vehicle stock (FLEET) module receives the following inputs from the DEMAND module: passengers-kilometres distinguished by zone, purpose, region, distance, urban level, time period, mode and network (where air passengers-kilometres is distinguished further to distance band), tons-kilometres distinguished by zone, car type, region, distance, urban level, time period, mode and network (where air tons-kilometres distinguished further also to distance band), and average load factor by demand segment

In return, this module sends back the following information to the DEMAND module: total amount of fleet per mode and zone, total vehicles-kilometres by demand segment, vehicle-kilometres per vehicle type and demand segment, operating cost per vehicle type, feeds the ENVIRONMENTAL module with: vehicles-kilometres by vehicle type and demand segment, fleet structure by vehicle type and technology (emission standard), usage by vehicle type and technology, and the WELFARE module with: vehicles-kilometres by vehicle type and demand segment, taxes and subsidies.

The main goal of the FLEET module is to convert the aggregate estimation of transport demand, in terms of passengers-kilometres (passengers-kilometres), tons-kilometres (tons-kilometres) and/or vehicle-kilometres (vehicles-kilometres), into a more detailed vehicle classification and generation (cohort) which directly relates to technology in terms of vehicle performance and characteristics, fuel use and emission. The detailed demand, i.e. the transport demand detailed into vehicle technology, will be used to calculate transport fuel and emission use in the emission module.

For European countries the transport vehicle stock module which consists of road, rail, inland waterways (IWW), and air passenger, will replicate the approach of TREMOVE model with some improvements. Maritime and air freight of European countries will be based on JRC-IPTS transport models since those modes are not modelled in TREMOVE.

The rest of the world modelling is not covered by TREMOVE. For these reason, the rest of the world is based on JRC-IPTS transport models.

5.1 European countries

The DEMAND module produces aggregate transport quantities by vehicle categories. FLEET module disaggregates this aggregate demand into detailed vehicles-kilometres by vehicle type, vehicle technology and vehicle age. This requires a detailed modelling and forecasting of the vehicle fleet structures for each mode.

Fleet evolution is modelled using a classic scrap-and-sales approach. Each year scrap rates are applied to estimate the number of scrapped vehicles. Total vehicle sales by mode then can be derived by comparing remaining vehicle stock to the stock needed to fulfil transport demands. Table 6 shows vehicle categories and types of road transport modes: categories of car, motorcycle and bus need to be split into vehicle types.

Table 6 Road vehicle categories and types

Vehicle category	Vehicle type
car	small petrol car -1.4l
	medium petrol car 1.4-2.0 l
	big petrol car +2.0 l
	small CNG car -1.4 l
	medium CNG car 1.4 - 2.0 l
	big CNG car +2.0 l
	medium and big LPG car +1.4 l
	small diesel car -1.4 l
	medium diesel car 1.4-2.0l
	big diesel car +2.0l
	Small electric car
	Medium fuel cell powered car
	Small ICE hybrid electric gasoline car
	Small ICE hybrid electric diesel car
	Small ICE hybrid H2 powered car
petrol moped	moped
petrol motorcycle	MC1 2-stroke > 50cc
	MC2 motorcycle 50-250cc
	MC3 motorcycle 250-750cc
	MC4 motorcycle +750cc
petrol light duty truck	light duty truck petrol
diesel light duty truck	light duty truck diesel
petrol vans	
diesel vans	
HTD1 heavy duty truck 3.5-7.5 ton	
HTD2 heavy duty truck 7.5-16 ton	
HTD3 heavy duty truck 16-32 ton	
HTD4 heavy duty truck +32 ton	
bus	Diesel bus
	CNG bus

For rail transport, demand in the level of vehicle categories is not split into vehicle types. Passenger and freight rail transport are classified into ten vehicle types:

- Passenger locomotive diesel
- Freight locomotive diesel
- Passenger railcar diesel
- Freight railcar diesel
- Passenger locomotive electric

- Freight locomotive electric
- Passenger railcar electric
- Freight railcar electric
- Metro/tram
- Passenger high speed train (HST)

The train sales segmentation in the baseline is based upon exogenous inputs. Sale shares for trains have been determined such that the evolution of the train fleet is consistent with the long-term trends in the TRENDS database.

GLADYSTE distinguishes 3 inland waterway vessel types: cargo, pusher and tankers and 3 freight categories: unitised, bulk, and cargo-container. The baseline fleet composition forecast for those vessel classification used in TREMOVE model is based upon detailed Dutch statistics (CBS) and predictions (AVV) on domestic and international movements.

Finally, fleet model of passenger/freight air and freight maritime transport in Europe is based on the JRC-IPTS transport models as the fleet part of these modes are not modelled in TREMOVE. Vehicle classification of these modes is given in the Table 7 below.

Table 7 Air and maritime modes classification

Modes	Vehicle categories	Vehicle types	Description
AIR	Passenger	PJJ	Passenger jumbo jet
		PJN	Passenger narrow body jet
		PJW	Passenger wide body jet
		RJ	Regional jet
		SJ	Supersonic jet
		TP	Regional turbo propeller
		TS	Small turbo propeller
	Freight	FJJ	Freighter jumbo jet
		FJN	Freighter narrow body jet
		FJW	Freighter wide body jet
MARITIME	Gas bulk	TK GCAR	LNG and LPG carrier
	Liquid bulk	TK ULCC	Ultra large crude carrier
		TK VLCC	Very large crude carrier
		TK SUEZ	Suezmax
		TK AFRA	Aframax
		TK PANA	Panamax
		TK HAND	Handy
	Dry bulk	BC CAPE	Capesize
		BC PANA	Panamax
		BC HANM	Handymax
		BC HAND	Handy
		BC COMB LN MULT	Combo Multipurpose liner
		LN OTGC	Other general cargo

Modes	Vehicle categories	Vehicle types	Description
		LN RORO	Roll-on Roll-off
	Containerized cargo	CS PPAN	Post-panamax
		CS PANA	Panamax
		CS SPAN	Subpanamax
		CS HAND	Handy
		CS FEEM	Feedermax
		CS FEED	Feeder
	Others	NON CARGO	Other vessels

5.2 Rest of the world (RoW)

Vehicle fleets in non-European regions are also estimated based on classic scrap-and-sales approach. The only difference is found in the fleet dynamics modelling of passenger cars that uses a car ownership model instead of taking demand estimated by the DEMAND module. This car ownership model estimate the number of cars per thousand vehicles based on Gompertz function that uses GDP per capita as the main driver of car ownership level (Dargay and Gately, 1997; Dargay et al., 2007). This rate allows determinate the number of car fleets necessary in the future which in turn is used to estimate the number of new cars needed to enter the market taking into account the number of scrapped cars every year.

While the stock modelling approach is relatively similar to the approach used in the European regions, the main issue for the rest of the world modelling lays in the level of detail of vehicle classification.

In road and rail transport modes, vehicle classification in the RoW regions differs to that of Europe due to the two different models based on which the prototype is built i.e. TREMOVE and JRC-IPTS transport models. Table 8 shows modes classification of road and rail transport in the RoW region which is based on the JRC-IPTS transport models' classification which is different to the classifications used in European regions (section 5.1).

These two different classifications will be used in GLADYSTE. However, a mapping between the two classifications has also been made which allows user to choose one of other classification system to visualise modelling results.

Finally, some modes and vehicle types, currently not modelled in the JRC-IPTS transport models are being included in GLADYSTE. These are bus, motorcycle and mopeds, and inland waterways. Albeit, as a mere prototype, the modelling of those modes will be conducted in a simplified way and will take place only in regions where the presence of such modes is considered significant (for example: inland waterway in China, motorcycle and mopeds in South East Asia, etc.).

Table 8 Modes classification on the RoW

Model	Vehicle category	Vehicle type	Description
ROAD	Passenger car	LPETROL	ICEV, gasoline, small size
		HPETROL	ICEV, gasoline, large size
		NATGAS	ICEV, natural gas, large size
		LDIESEL	ICEV, diesel, small size
		HDIESEL	ICEV, diesel, large size
		ELECTRIC	Battery-powered small size
		FUELCELL	Fuel cell powered big size
		HYBRID	Hybrid, gasoline, small size
		HYBDIS	Hybrid, diesel, small size
		HYBH2	Hybrid, H2-powered, small size
	Freight V.	LDTG	Gasoline light duty truck <3.5 t
		LDTD	Diesel light duty truck <3.5 t
		VANG	Gasoline van <3.5 t
		VAND	Diesel van <3.5t
		HDT1	Diesel HDT 3.5-7.5 t
		HDT2	Diesel HDT 7.5-16 t
		HDT3	Diesel HDT 16-32 t
		HDT4	Diesel HDT > 32 t
RAIL	Locomotive	LD	Diesel locomotive
	Railcar	RD	Diesel railcar
	Locomotive	LE	Electric locomotive
	Railcar	RE	Electric railcar
	Locomotive	HE	High-speed electric locomotive
	Locomotive	LS	Steam locomotive

6 ENVIRONMENTAL module

In the ENVIRONMENTAL module fuel consumption and emissions are calculated for all modes. In general, both are calculated by multiplying disaggregated vehicle kilometres, calculated in the demand module, by an appropriate factor for the pollutant or fuel of interest.

For road vehicles in the European countries, emission factors are based upon the COPERT IV emission calculation methodology with several improvements made and included in the current TREMOVE model.

Fuel consumption and emission factors for diesel trains and aircrafts (by distance class) have been derived from the TRENDS database. For electric trains, trams and metros only total energy consumption (in kilowatt-hours) is calculated in this module.

The fuel consumption and emission factors for inland waterway vessels in Europe have been calculated following the first version of the approach developed within the

ARTEMIS project[13]. Factors have been estimated using data on vessel characteristics for the 21 types included in TREMOVE and using estimates on waterway characteristics.

In TREMOVE, a restricted life cycle assessment module is implemented which focuses on the fuel cycle only. Concentrating on fuel implies that not only operational emissions of vehicles, but also emissions due to production and distribution of the fuel (or electricity) are taken into account, i.e. well-to-tank and tank-to-wheel emissions are calculated. This is based on the Ecoinvent Database (Ecoinvent Centre, 2004).

The pollutants considered in the air transport module are CO_2, H_2O, SO_2, NO_X, CO and HC. Emissions of NO_X, CO and HC depend not only on the fuel consumption but also on flight altitude and other operation conditions. For these substances two different emission indexes are considered, according to the available sources (Sutkus et al., 2001, and 2003), each one corresponding to a specific altitude band (climb and descent phases, which takes place between ground level and 9 km during 10% of the flight time, and cruise phase, between 9 km and 13 km of altitude). The corresponding emissions of each pollutant are obtained by multiplying the emission indexes by the jet fuel consumption. Jet fuel consumption is the aggregation of the products of each vintage fleet by its corresponding fuel consumption and the average use.

For maritime transport, average daily consumption of bunker fuels per vessel is calculated by taking into account all changes in average sailing speed, with respect to the design speed and the design fuel consumption driven by changes in the freight rates. The design fuel consumption is corrected in order to take into account the variations in fuel consumption due to the average time spent laden at sea, in ballast and in port, which also depend on the changes in freight rates. The total yearly demand of bunker fuels by vessel class is obtained by multiplying the average bunker consumption by the ratio between the active fleet divided and the average ship tonnage (a proxy of the number of ships). CO_2 emissions by vessel class are the result of multiplying marine bunker consumption by the carbon content of the fuel.

For the rest of the world ENVIRONMENTAL module of the road and rail modes, at the minimum, the emission calculation method used in the JRC-IPTS transport models will be used. Some emissions, such as CO_2, H_2O, SO_2, are assumed to be proportional to the fuel consumption. For those kinds of emissions, the IPTS models calculate simply the fuel consumption with the corresponding fuel pollutant content, for example for CO_2 it is the carbon content of the corresponding fuel.

[13] Assessment and Reliability of Transport Emission Models and Inventory Systems (http://www.trl.co.uk/artemis/)

7 WELFARE module

In GLADYSTE the welfare module is based on nested logit (NL) tree structure used in the DEMAND module. In this structure, the module will calculate the absolute value of each element: consumer surplus, external effects, distortion effect due to taxes and subsidies.

The nested logit tree structure in the demand module of GLASDYSTE consists of two to three levels of choices. Consumer surplus is calculated using Logsum approach (De Jong et al, 2005) based on Ben-Akiva and Lerman, 1979.

Apart from consumer surplus, the model prototype considers also externalities linked to pollution, accident, noise, and wear and tear, as calculated in the ENVIRONMENTAL module. Still in term of external effects, the welfare module takes generalized prices (resource cost + time cost) calculated in the DEMAND module. The private time cost for each vehicle kilometre is incorporated. The total time costs for all vehicle kilometres (congestion cost) have thus already been taken into account in the calculation of the consumer surplus above, through the utility function in demand split model. Thus, no further correction for congestion needs to be made for the welfare calculation.

Finally, to estimate the effect of distortion, all taxes and VAT are calculated and summed up for all lowest nodes of the nested logit tree. Apart from taxes and VAT, the cost of public funds is calculated taking into account the regime of tax redistribution.

Total welfare is finally calculated as the sum of the consumer surplus and tax and subsidy deduced by the total external costs.

8 Calibration of the model prototype

The calibration GLADYSTE model prototype is a stepwise, iterative process since the dimension of model prototype does not allow the calibration of the whole model within one calibration step. The very first step in the calibration is the use of some important exogenous variables like GDP, population, and fuel prices for the whole simulation period (2000-2050). Secondly, whenever possible, endogenous variables of transport demand and fleet are replaced by exogenous variables coming from statistical data for a calibration period between years 2000 and 2005. Finally, endogenous transport demand projections of the years beyond 2005 are replaced by official reference scenario projections from the European Commission (JRC-IPTS). The second and third steps performed principally in the DEMAND and FLEET modules allow calibrating model parameters, coefficients and in some cases equations.

9 Example of potential application

The use of TREMOVE ensures that GLADYSTE can be used for transport, environmental, and economic analysis of different policies and measures to reduce atmospheric emissions from all modes of transport with high level of detail in the enlarged European Union. Some of the most important policies scenarios have been analysed by TREMOVE include: Euro 5 and Euro 6 emission standards application for cars, Euro 6 emission standards for heavy duty vehicles, fuel efficiency improvements beyond the 2008/2009 voluntary objectives of the car industry, infrastructure charging, fiscal measures for road transport vehicles, speed limits for trucks on motorways, CO2 target curves for cars (up to 95 grams of CO_2/vehicles-kilometres at 2020) and light duty vehicle (up to 150 grams of CO_2/vehicles-kilometres at 2020).

The use of the JRC-IPTS transport models ensures the capacity of GLADYTE to cover the whole world in an appropriate level of detail. The JRC-IPTS transport models are used to support various internal works in the European Commissions related to world scale transport-energy-environmental studies for example in the analysis of green-house gas emissions from international maritime and air transport.

10 Summary

The GLADYSTE model, capable of estimating transport demand and emissions, as well as simulating the impacts of policy and technological measures in transport-related sectors, covering all transport modes from the different regions in the world up to 2050 is being developed. The model prototype is based on the TREMOVE model and a set of transport models developed and used by European Commission's JRC-IPTS, plus a demand module especially commissioned for this project to ensure that the model prototype will be able to generate transport demand endogenously. GLADYSTE is designed and currently developed to be able to address issues of policies related to vehicle technologies, fuel quality, fiscal instruments, traffic management, and policies related to maritime and air transport where modal substitution is more limited and the international traffics are relatively more important.

The model prototype, developed in a System Dynamic environment, splits the world into 57 regions and covers all transportation modes, i.e. road, air, rail, maritime, and inland waterways transport. Those modes are modelled based on interaction between four interrelated modules: Demand, Fleet, Energy Use – Emission, and Welfare.

Finally, the use of the two existing models ensures that GLADYSTE can be used for transport, environmental, and economic analysis of different policies and measures to reduce atmospheric emissions from all modes of transport with high level of detail in the enlarged European Union and with appropriate level of detail for the rest of the world regions.

11 References

Ben-Akiva, M. and Lerman, S. R., 1979, Disaggregate travel and mobility choice models and measures of accessibility, in Hensher, D. A. and Stopher, P. R. (eds.) Behavioural Travel Modelling, Croom Helm.

Borken, J., Steller, H., Meretei, T., Vanhove, F., 2007. Global and country inventory of road passenger and freight transportation, their fuel consumption and their emissions of air pollutants in the year 2000, 86th Annual Meeting Transportation Research Board, Washington.

Christidies, P., Hidalgo, I., Soria, A., 2003, Dynamics of the introduction of new passenger car technologies. The IPTS Transport technologies model. European Comisión Joint Research Centre. EUR 20762.

Coto-Millán, P., Baños-Pino, J., Villaverde Castro, J., 2005. Determinants of the demand for maritime imports and exports. Transportation Research Part E 41, 357-372.

DAMF Consultants Inc., Joseph Schulman Consulting, CANARAIL Consultants Inc., 2007. Estimation of unit costs of rail transportation in Canada. Transport Canada.

De Ceuster, G., van Herbruggen, B., Ivanova, O., Carlier, K., Martino, A., Fiorello, D., 2007. TREMOVE: service contract for the further development and application of the transport and environmental TREMOVE model. Transport and Mobility Leuven.

Dikos, G., Marcus, H.S., Papadatos, M.P., Papakonstantinou, V., 2006. Niver Lines: a system-dynamics approach to tanker freight modeling. Interfaces 36, 326-341.

Ecoinvent Centre, 2004, Ecoinvent Data v1.1. Swiss Centre for Life Cycle Inventories, Dübendorf.

Engelen, S., Meersman, H., van de Voorde, E., 2006. Using system dynamics in maritime economics: an endogenous decision model for shipowners in the dry bulk sector. Maritime policy and management 33, 141-158.

Frías, I., Guisan, M.C., 2002. Modelización del transporte marítimo internacional, Working Paper Series Economic Development. University of Santiago de Compostela.

Friedrich, M., Haupt, T., Noekel, K., 2003. Freight modelling: data issues, survey methods, demand and network models, 10th International Conference on Travel Behaviour Research, Lucerne.

Hickman, A.J., Hassel, D., Joumard, R., Samaras, Z., Sorenson, S., 1999. Methodology for calculating transport emissions and energy consumption. European Commission, Brussels.

Hidalgo, I., Ciscar, J.C., Soria, A., 2006, A Dynamic, Technology-based Air Transportation Model: Description and Some Applications. European Commission Directorate-General Joint Research Centre. EUR 22617 EN.

De Jong, G., Pieters, M., Daly, A., Graafland, I., Kroes, E., Koopmans, C., Using the Logsum as an Evaluation Measure: Literature and Case Study. Working Paper (WR-275-1VV). RAND Europe.

Kalidova, M.T., Kurdna, M., 1997. Methodologies for estimating emissions from air traffic. Psia-Consult, Perchtoldsdorf, Vienna.

Ogden, J.M., 1999, Developing an infrastructure for hydrogen vehicles: a Southern California case study. International Journal of Hydrogen Energy 24 (1999) 709)-730

Stopford, M., 2006. Maritime economics, 2nd ed. Routledge, London.

Sutkus, D.J., Baughcum, S.L., DuBois, D.P., 2001. Scheduled civil aircraft emission inventories for 1999: database development and analysis. NASA-Glenn Research Center, Seattle.

Sutkus, D.J., Baughcum, S.L., DuBois, D.P., 2003. Commercial aircraft emission scenario for 2020: database development and analysis. NASA-Glenn Research Center, Seattle.

UNCTAD, 2006. Review of maritime transport. United Nations Conference on Trade and Development, Geneva.

Wohlgemuth, N., 1997. World transport energy demand modelling: Methodology and elasticities. Energy Policy 25, 1109-1119.