TRIMODE FREIGHT & LOGISTICS MODEL OF EUROPE

Ian N Williams

TRT Trasporti e Territorio

Mike Garratt

Chris Wright

MDS Transmodal

1. INTRODUCTION

TRIMODE (TRansport Integrated MODel of Europe) is a strategic transport network model that simulates passenger and freight transport activity and covers all mobility – urban, regional, national, international and intercontinental – for the European Union and its neighbouring countries. The tool is being developed to provide the European Commission with a usable and reliable tool to support the assessment of transport policies and infrastructure investments.

This paper focuses specifically on the freight demand model component of TRIMODE and on how it integrates with the various other components of this modelling system. 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) to estimate 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. These modal origin-destination matrices feed into the assignment model, while their spatial pattern of movement and of mode choice is influenced in turn by the modal transport costs that are output from the network paths determined by this assignment model.

The freight demand model simulates the complete set of movements on all modes throughout the study area of Europe, including all import and export movements from/to external zones. It is designed to reproduce the observed freight transport activity in the base year (2010) and in the validation year (2015), and then to provide forecasts at 5-yearly intervals in future scenarios of freight demand that can provide reliable freight transport demand responses when specific policy measures are simulated.

The TRIMODE model is being developed as part of a European Commission service contract by an international consortium led by TRT Trasporti e Territorio (IT) and composed of PTV AG (DE), E3MLab (EL), MDS Transmodal (UK), Bauhaus Luftfahrt (DE), M-Five (DE), Fraunhofer-ISI (DE) and INRIX (UK).

2. OVERVIEW OF THE TRIMODE MODELLING SYSTEM

The overall TRIMODE integrated modelling system comprises several components organised within three main blocks: the transport model, economy model and energy model (Figure 1).

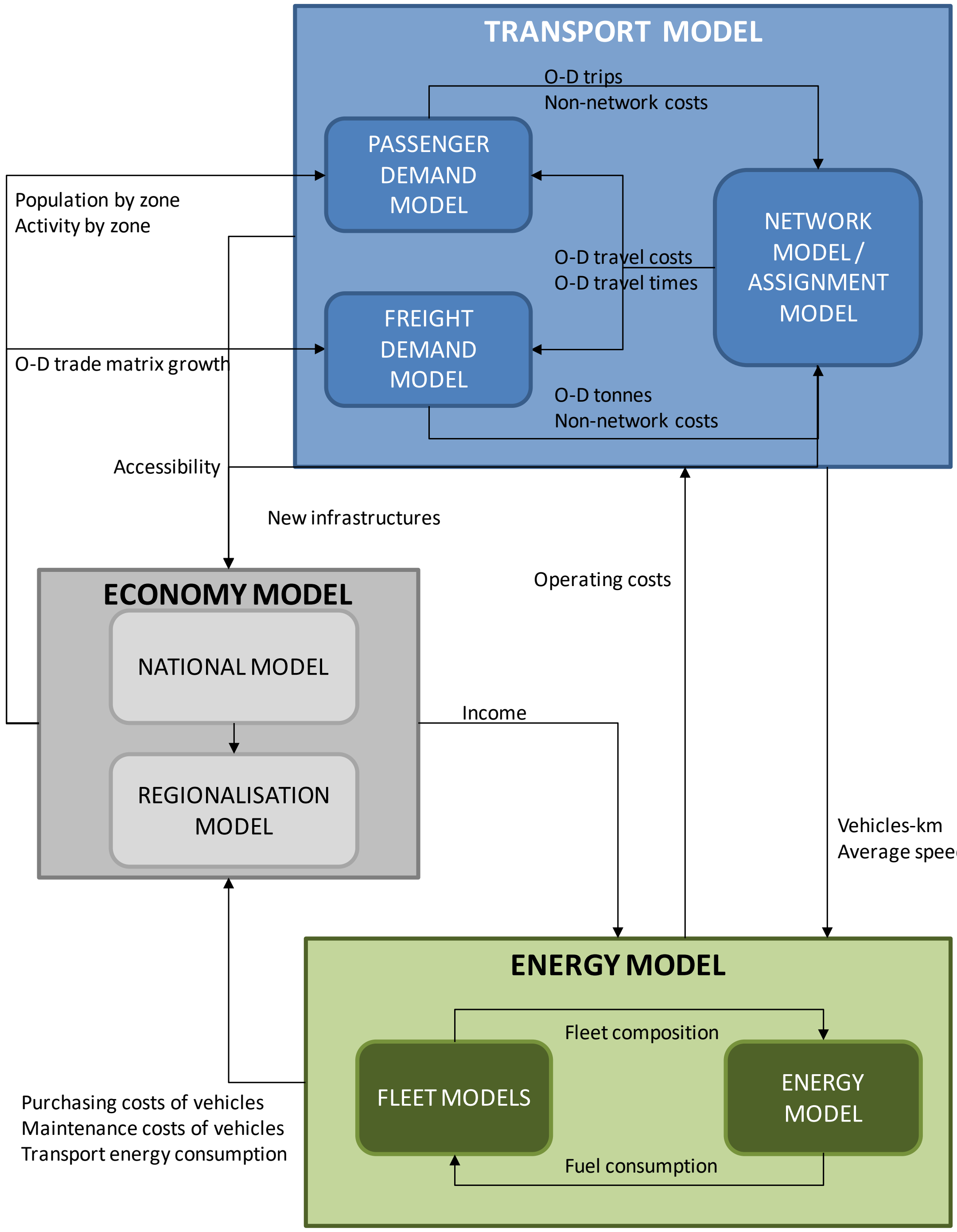

Figure 1: Overview of TRIMODE integrated modelling system

The economy model estimates the zonal demographic and economic activities and the change in bilateral trade in a particular year for all zones of the model. The estimation is made first at the national level and is then regionalised. The resulting output from the economy model is used in turn to generate the demand for passenger and freight transport. In parallel, the energy model determines the composition of vehicle fleets and provides the operating costs that are used to estimate user costs for transport modes. These user costs are a major input to the passenger demand model and freight demand model that 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. The network model assigns these vehicle movements to the paths and links of their respective modal networks. The assignment is 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. 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 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. 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 to estimate the spatial pattern of energy consumption, pollution emissions and of other external costs based also on development of vehicle fleets. In this way the full impacts of transport policy measures on environmental costs and on energy consumption can be measured at a spatially detailed level.

The overall TRIMODE model and the policy measures that it can test are described in more detail in the companion ETC 2017 paper (Fiorello et al., 2017).

3. OVERVIEW OF THE FREIGHT DEMAND MODEL AND SEGMENTATION

The rest of this paper focuses just on the freight demand model component of TRIMODE. This consists of three main stages implemented either within the PTV VISUM software or within the scripting language Python, plus several appended modules developed as additional functions (Figure 2).

The freight tonnage generation stage is followed by the distribution channel choice between logistic leg and intermediate distribution centre combinations; and finally by the main mode choice within each logistic leg. These first two stages are coded in Python, while the main mode choice stage is implemented directly within PTV VISUM. The freight flow output from the mode choice model is sent to the assignment model whose results (in terms of travel times and costs by O-D pair) are fed back to the mode choice and logistic leg distribution stages of the freight demand model, iterating until a converged equilibrium solution is achieved.

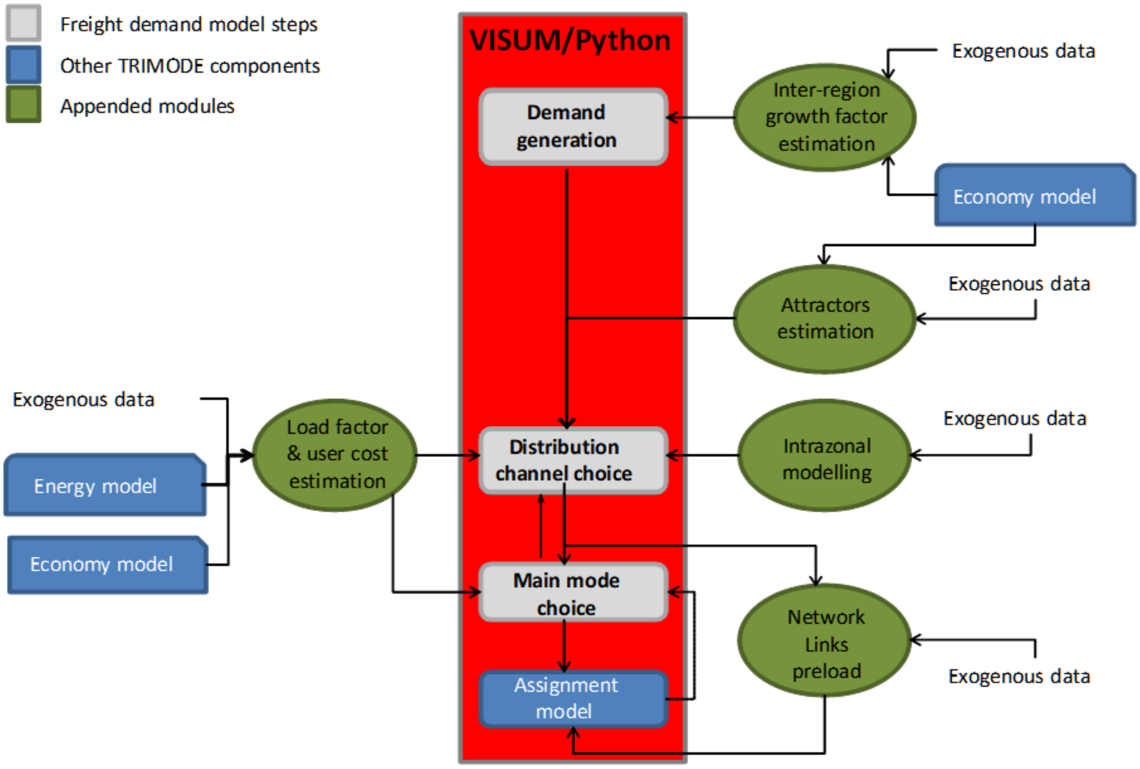

Figure 2: Structure of the freight demand model

The freight demand model formulation combines three main past methodological developments that are central to being able to represent the complexities and heterogeneity of freight transport demand systems within a realistic and computationally feasible model structure:

- The Spatial Input-Output (SIO) modelling framework;
- Residual Disutility based constraint representation for incremental modelling; and
- Distribution Chains represented as hierarchical discrete choice systems.

The first two of these techniques have already been used extensively within the development of the earlier SCENES transport model (ME&P, 2002) for the European Commission. That model represented all passenger and freight movements across Europe on all modes of transport, but at a NUTS II rather than at the sub-NUTS III spatial level used in TRIMODE. The residual disutility methodology follows closely the approach originally developed by Williams & Beardwood (1993) when modelling congestion charging policies in London. The distribution chain methodology was initially introduced in a freight model of the State of Sao Paulo, Brazil (Williams & Echenique, 1978), was further developed in the EUNET EC research project (Jin et al. 2005) and was fully implemented in the BYFM (WSP, 2011) national freight transport model of Great Britain.

Previous freight transport models have often been designed in a form that is based directly on matrices presented in units of goods vehicle movements. That approach is suited to simpler studies where the primary requirement is to assess the impacts of local changes in network infrastructure supply on vehicle routing and on congestion levels.

However, when examining more wide-ranging transport policy measures over a longer time horizon the vehicle based approach is less helpful precisely because freight is a derived demand. The pattern of goods movement arises from the interplay between:

- the spatial pattern of the supply (production) and of the cost of goods;
- the spatial pattern of the demand (consumption) for goods; and
- the logistics structures that are in place to ship goods from producers (supply) to consumers (demand), via distribution centres / warehouses, using the most suitable combination of modes and of vehicle types for each individual logistic leg along this distribution chain.

The changes in the patterns of freight transport that arise in response to wider policy measures are best forecast by having a clear understanding of and representation of this underlying freight distribution system, using a more comprehensive modelling approach of the type presented here.

3.1 Spatial Representation

The TRIMODE model maintains the following geographical coverage:

(a) 28 EU Member States;

(b) 8 Candidate and potential candidate countries: Western Balkans (Serbia, FYROM, Albania, Bosnia and Herzegovina, Kosovo, Montenegro), Turkey, Iceland;

(c) 6 Other EU bordering countries: Norway, Switzerland, Belarus, Ukraine, Moldova, Russia;

(d) 10 Rest of the World groups of countries.

The main scope of the model is the EU28. Bordering countries are relevant primarily for their impact on transport activity and on externalities within the EU, so they are modelled in a more simplified way than that for the EU28 and its candidate countries.

The zoning system is primarily at the NUTS III level which generates 1342 zones within the EU28. Some of the larger zones are further disaggregated in order to avoid mixing major urban centres with large low density rural areas.

3.2 Demand segments

Because of the high degree of heterogeneity of freight transport requirements and of 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 within the freight demand model.

The freight categorisation distinguishes the EU’s current standard NST 2007 classification of *20* ***types of goods***.

For any given type of good, the characteristics of its distribution channels and the proportional split between these channels for a zone pair may differ significantly depending on the form of its consumption. This is why this ***consumption type*** dimension has also been included within the segmentation. For internal consumption zones the consumption type distinguishes two types of movements:

- ***final consumption*** of both domestic and imported goods by households, government and related sectors;
- ***intermediate consumption*** of domestic and imported goods by primary and secondary (manufacturing) industries or by services.

A variant on the second consumption type occurs in external consumption zones to denote exports of European goods to external countries.

This consumption type segmentation enables differences: in the product mix within a type of good category; in the consignment size; in the logistic patterns; etc. to be represented within the movements for an individual type of good. The shipments of goods destined for intermediate consumption in large factories will often be in large regular consignments leading to more efficient use of alternatives to road and to relatively few intermediate distribution activities along the way. In contrast, consumer goods destined for households may be stored in a sequence of 4 or 5 distribution centres prior to arriving to their final consumption location.

The combined classification into 60 joint categories of 20 NST types of goods by 3 consumption types is referred to in aggregate by the term: ***freight type***.

In discussions on logistics the wide variety of types of logistic legs can be grouped into three broad categories each with distinct transport characteristics:

- ***Primary logistic legs*** (e.g. from producers to distribution centres or to major individual consumers) – these will typically be single drop, regular, large consignments that are moved on rail, inland waterway (IWW) or large road vehicles that are fully and efficiently loaded (pallets) and often operating on a 24-hour basis;
- ***Secondary logistic legs*** (e.g. from distribution centres to major retailer outlets or to local distributors / cash-and-carries) - these will typically be relatively large consignments with few drops per vehicle but delivering using roll-cages rather than pallets;
- ***Tertiary logistic legs*** (e.g. from distributors to dispersed small-scale consumers) - these will typically be spread as multi-drops of smaller consignments, packages and parcels, often using vans or smaller truck sizes that may only be partially loaded and may only operate during the daytime hours when the receiving shops and offices are open for business. The rapid recent growth of e-commerce deliveries to private homes also falls within this category.

Accordingly, within the distribution channel choice model stage, the P-C movements are split among logistic legs that are classified into the above three classes. The relationship between distribution channels and logistic legs is further discussed later in section 5.

3.3 Modes and vehicle types

When analysing and then modelling the movements of freight, a convenient distinction is drawn between modes and their vehicle types:

- ***Modes*** are the superset of vehicle types that operate with broadly similar transport technologies;
- ***Vehicle types*** then represent within the mode the set of vehicles classified into individual homogeneous groups, within each of which there are broadly similar common characteristics of maximum load, loading characteristics, allowable speed, operating costs, etc.

Within the freight demand model, shipments of a specific freight type on a specific logistic leg type are first sub-divided amongst the competitive modes (section 6) for that leg and then they may be further split within each mode among the competitive vehicle types for that combination of logistic leg and mode type.

The set of six freight modes (road, rail, inland waterway, maritime, air and pipeline) and their 14 component vehicle types that are explicitly represented within the freight demand model are listed are listed in Table 1.

Table 1: Freight main modes and vehicle types for assignment

Mode	**Main mode**	**Vehicle types**
Road	Road	Articulated, any kind
	Road	Rigid 26 tonnes gross vehicle weight
	Road	Rigid 17.5 tonnes gross vehicle weight
	Road	Rigid 7.5 tonnes gross vehicle weight
	Road	Van
Air	Air Freight	Bellyhold or Freighter
Rail	Rail Intermodal	Intermodal train
	Rail Other	Unit train
Ship	Ship LoLo Container	LoLo container ship
	Ship LoLo Other	LoLo non-containership
IWW	IWW Container	IWW container ship
	IWW Other	IWW non-container ship
Pipeline	Pipeline crude	Crude petroleum network
	Pipeline products	Petroleum products network

The different vehicle types listed are used to represent the key differences within the mode in the operating characteristics and costs faced by different groups of shippers or for different freight types or for different logistic legs. For example, those consumer goods that are moving long distances from producers to primary distribution centres will be heavily containerised and if on road will move in the largest available trucks. In contrast, these same consumer goods when they are subsequently delivered over short distances from local distribution centres to retail establishments within cities may be transported in small trucks or even in vans if consignment sizes are small.

Main modes - mode combinations for multimodal chains

A fundamental feature of the freight mode choice model is that the components of the choice sets used in the mode choice algorithm (i.e. those listed in Table 1) are the ***main modes*** of a (potential) multimodal chain. For instance, one component of the choice set is “Air” freight. Whenever a plane is used for a trip, almost invariably other ***feeder modes*** are also used to complete the door-to-door journey (e.g. a truck from the producing factory to the departure airport, then the plane leg, then a van from arrival airport to the final destination). The mode choice model considers the main mode of the chain (e.g. air), while the travel times and travel costs determining this main mode choice will include all modal legs in the door-to-door multimodal chain.

Therefore, travel times and travel costs used in the mode choice algorithm are computed in the assignment model as the combination of single stages each related to one of the different individual modes that can be used in sequence when transporting goods from their origin zone to their destination zone on a specific logistic leg.

Each freight main mode is associated with an ordered set of feeder modes (Table 2). The ordering of the feeder modes defines admissible feeder mode sequences subsequent to leaving this main mode (and when reversed defines admissible feeder mode sequences prior to accessing this main mode).

Table 2: Freight main and feeder modes

Main mode	**Feeders in hierarchical order mode**
Air	1: Road
Ship LoLo Other	1: IWW Other 2: Rail Other 3: Road
Ship LoLo Container	1: IWW Container 2: Rail Intermodal 3: Road
IWW Other	1: Rail Other 2: Road
IWW Container	1: Rail Intermodal 2: Road
Rail Other	1: Road
Rail Intermodal	1: Road
Road	-
Pipeline	1: Ship LoLo Other 2: IWW Other 3: Rail Other 4: Road

Note that ferry is not shown as an explicit feeder mode. Instead links for all Ro-Ro shipping services, together with appropriate costs, are added to the road network. The actual sequence of feeder modes (if any) used within the main mode for a specific freight type moving on a specific O-D logistic leg is calculated within the ***mode sequence choice*** sub-model (Fiorello et al., 2017).

3.4 Mode of appearance / type of cargo

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 ***mode of appearance*** (MoA) classes. This aggregation leads to a significant reduction in the model size and run times. These MoA classes 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. The modes of appearance and their associated vehicle types are listed in Table 3 for the non-road modes.

Table 3: Mode of appearance in mode sequence choice – non-road modes

Main mode & Veh. type	**MoA**	**Main mode & Veh. type**	**MoA**
Air Freight	containers	Ship LoLo	containers
Rail intermodal	containers	Ship other	bulk liquid
Rail intermodal	accompanied trucks	Ship other	dry bulk
Rail intermodal	Unaccomp. trailers	Ship other	semi-bulk
Rail intermodal	trade cars	Ship other	Unaccomp. trailers
Rail other	bulk liquid	Ship other	trade cars
Rail other	dry bulk	IWW container	containers
Rail other	semi-bulk	IWW other	bulk liquid
Pipeline crude	bulk liquid	IWW other	dry bulk
Pipeline products	bulk liquid	IWW other	semi-bulk

An analogous matching is used for the road mode, which is further segmented by logistic leg type. The reason for the disaggregation by vehicle type is because the TRIMODE network model distinguishes the different operating costs and characteristics of different truck types. The reason why disaggregation by logistic leg type is included is that the vehicle loading efficiency varies significantly between logistic leg types, being highest for primary but lowest for tertiary logistic legs.

As indicated in Table 3, some main modes are relevant only to some MoA (e.g. pipeline can transport certain liquid bulk products but no other types of cargo, whereas road is a potential option for all cargo types).

3.5 Demand segments used for freight model stages

Table 4 summarises the many transformations of classifications, together with the units adopted for flows, which are used within the sequence of stages of the freight demand model. Here (X) denotes that the classes have been aggregated somewhat for use within the specified model stage, in order to reduce its overall storage size and its computational requirements.

Table 4: Classifications in use at each freight model stage

Model stage	Unit	Ind-ustry	NST	Consum-ption	Log. leg	Main mode	Veh. type	MoA
From Economy model	€	X		X				
Generation	tonne		X	X				
Distribution channel	tonne		X	X	X			
Main mode	tonne		(X)	(X)	(X)	X	X	
To mode sequence	tonne				(X)	X	X	X

4. FREIGHT TONNAGE GENERATION

4.1 Introduction to trade flows and to transport flows

The purpose of the freight generation model stage is to estimate the total tonnes of trade, segmented by type of freight, in that year between each NUTS-III zone pair. This information is subsequently transferred to the distribution channel choice model stage.

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. In order to understand the relationship between transport and the economy, it is necessary to draw a distinction between two separate matrices of movements that are used conceptually in the analysis of the demand for freight transport.

- **The pattern of economic trade in goods** from their initial producer to their ultimate consumer; this 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. This P-C matrix is not normally observable at a fine level of spatial detail because this would require access to business micro-data data on intercompany sales transactions. These are not normally available to model builders at a spatially detailed level. However, inter-country matrices of trade flows are published and these are a major input to the TRIMODE economy model, which 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; this 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 described below in section 5. Changes in this matrix are strongly influenced by changes *within* the freight transport and the distribution industry sectors. This matrix can either be observed through surveys of industry (e.g. Eurostat carriage of goods statistics) or through roadside interview surveys that record for passing vehicles the goods carried and their origin and destination zones.

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 (DCs) between each of these logistic legs. An industry-led policy to increase the number of distribution centres could, perhaps, generate a larger number of shorter logistic legs even at a time when there is an overall lengthening of trade. However, in the past, the broad trend has certainly been towards a smaller number of distribution centres but that on average are of larger size, which has had the effect of increasing the average length of haul of O-D shipments / logistic legs.

4.2 Trade growth factors

In the base year an initial base matrix of freight P-C tonnes is constructed synthetically, by making major use of observed modal freight flows to ensure that this synthetic base matrix matches well to the existing observed pattern of freight tonnes by NST category moved at the O-D level.

In future years or scenario tests, the P-C tonnages are calculated by multiplying each base year P-C tonnes matrix element by its corresponding growth factor. The trade growth factor is calculated for each element as: the ratio in constant prices of the total trade value for the future year/scenario relative to the base scenario for each corresponding industry sector, using the P-C trade values estimated by 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.

Using this approach the detailed economic information on changes in patterns of production and consumption of traded goods can be translated into changes in the patterns of the physical movements of goods in a manner that is fully consistent with the macro-economic model forecasts.

5. FREIGHT DISTRIBUTION CHANNEL CHOICE

5.1 Introduction

The purpose of this freight distribution channel choice model stage is to estimate the total tonnage generated in one year using the individual logistic legs between each NUTS III zone pair. This estimation includes intra-zonal freight movements that are further split among different distance bands. These tonnes are segmented by freight type. The resulting O-D matrices of tonnes will then be transferred to the main mode choice stage.

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 DCs, 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 vans; 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.

This explicit distinction between primary, secondary and tertiary logistic legs is an important component of the freight model. Within a freight type, it enables each of their distinct characteristics to be represented in a consistent and comprehensive fashion, including their differences in:

- trip length profile;
- average load per vehicle and proportion of empty vehicle running;
- the split in usage between modes and between the vehicle types within a mode.

5.2 Distribution channel choice model formulation

The formulation of this distribution channel choice model can be better understood through noting that there are in effect two distinct but intertwined structures that are to be solved simultaneously within the mathematical formulation:

- a ***spatial structure*** generating transport movements for traded goods from production zones to consumption zones. This is a conventional component of standard transport models. The corresponding monetary flow to pay for the goods that have been transported passes in the reverse direction: from the consumption zone to the production zone.
- a ***distribution (logistics) channel*** connecting a specific type of good from its original zone of production through DCs to its ultimate zone of consumption, being transported via various types of logistic legs. This builds on the functionality of a traditional SIO model.

The example in Figure 3 illustrates the conceptual shift from the left hand box (the Production – Consumption presentation) to the middle box, which represents the actual freight movements on a logistic leg by leg basis, through the stages of the **distribution chain**. The P-C transport flow is decomposed into a more general procedure that adds an extra layer into the model formulation. This layer builds up the transport flow in a manner that reflects the logistics options that are available at each distribution stage, through use of a succession of intermediate logistic legs along the distribution chain, as illustrated in Figure 3. The right hand box is the equivalent channel-based representation of the leg-based middle box. It illustrates the three distinct **distribution channels** that a consignment could take to traverse this example distribution chain.

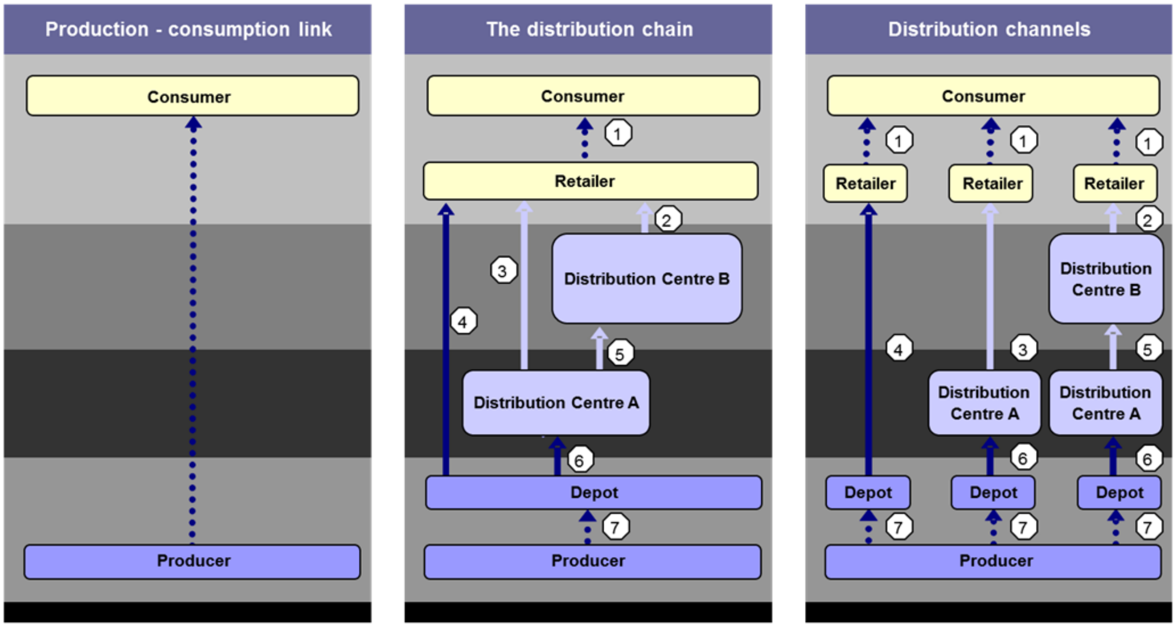

Figure 3: The production-consumption, distribution chain and distribution channel relationships

The logic behind this approach is now illustrated in the context of the example in Figure 3.

- The ultimate demand for a good by households in consumption zone *c* is satisfied by receiving these goods via some local retailer, denoted by logistic leg (1), illustrated in the "distribution channel" box.
- These goods arrive to that retailer through a number of different types of logistic legs:
  - *directly from a producing factory* - denoted by logistic leg type (4);
  - or else *indirectly from a distribution centre* in which the goods have been warehoused or cross-docked between logistic legs - denoted by logistic legs of type (2) and (3).
- For those goods that are output from the DC B, they will first have needed to be delivered there from DC A, using the logistic leg type (5).
- The solution algorithm continues moving up the distribution chain through the sets of distribution centres for all zones until all distribution chain legs (in this particular example just the further logistic leg type (6)) have been traversed back to the original production zones (the blue box denoting the depot of the factory at which the goods were first produced for dispatch).

The formal solution algorithm adopted is the distribution channel choice approach shown in the right hand box in Figure 3 rather than the distribution chain (leg choice) approach. Commencing with the ultimate consumption zone at the top of the right-hand box, a logit discrete choice procedure estimates the probability of choosing each available distribution channel type. This choice is based on the relative costs of transport plus warehousing for moving goods through to that consumption zone from all of the various available original production zones.

In practice this computation of the costs for each of the options in the distribution channel choice set is complex due to the inclusion of the spatial structure. Accordingly, for any given consumption (i.e. destination) zone and freight type combination, for each of its logistic legs within each of its types of distribution channel in Figure 3 there will be many DCs or many producers competing in different origin zones, so that the actual set of distinct options increases exponentially for any longer distance P-C relationships within this SIO structure. However, the dimensional scale of the solution algorithm is not overwhelming, provided that within a DC the goods are pooled and that the exact consumption or destination zone of each output shipment further up the distribution chain does not need to be remembered within this solution algorithm when it is selecting origin distribution centres or production zones lower down in the chain.

Within any individual logistic leg the spatial choice of origin (DC or producer) zone is represented again through use of a logit discrete choice model across the set of relevant origin zones.

In summary, the choice hierarchy for a given freight type and consumption zone is traversed by the following procedure:

1. allocate the consumption demand at the consumption zone end among the distribution channel choice options;

2. then for the first leg of the first distribution channel distribute its demand among the set of relevant DC zones;

3. then moving down each of the successive logistic legs in turn of this distribution channel, allocate goods among its relevant DC zones until the set of producer zones is reached;

4. this procedure is then repeated for each of the other distribution channel options.

Steps 1 to 4 sopra are then continued in a similar fashion until the demand for all consumption zones for all freight types has been satisfied by the output from production or from import zones at the bottom of the box.

Each resulting individual logistic leg movement stage is then accumulated into the O-D matrix to which the main mode choice model is applied (Section 6).

The O-D transport costs used in these choice models are first obtained as an output from this main mode choice model and are then accumulated up through the layers of the choice hierarchy in the reverse order to the steps 1 to 4 sopra, so as to inform each of the individual discrete choice models in sequence.

The influence of future changes in the value of the trade between regions is transmitted from the economy model through to this freight demand model through the application of P-C zone pair constraints on the volumes that are moved within this distribution channel choice stage. These constraints are applied through a residual disutility based methodology.

5.3 Intra-zonal modelling – Distance bands

A significant share of passenger and freight activity is intra-zonal and therefore, although the focus of the TRIMODE model is on mobility at the national and international level, intra-zonal trips are modelled explicitly. They choose among different distance bands and their respective modes, based on a hierarchical discrete choice formulation that was originally developed for use in the SCENES model (ME&P, 2000) of Europe. This approach has since been refined by combining it together with an area type based zoning system to provide the core functionality underpinning the Pass1 policy model component of the national passenger transport model of Great Britain (WSP, 2005).

Six distance bands, ranging from: < 1.5 km to > 20 km, are used to split intra-zonal movements. Each zone is allocated to one of 6 ***area types*** that indicate their general character on a continuum from: low density rural areas with dispersed populations; through to high density inner city areas of large metropolises. The modal transport costs and speeds that are applied to each distance band are an exogenous input and are differentiated by the area type of the zone. In congested metropolitan areas: road speeds will be slow and parking may be problematic. In contrast in low density rural areas, road speeds will be higher with fewer issues of parking.

The reason for developing this distance band methodology is to enable the supply characteristics of short distance passenger and freight trips to be represented adequately, while avoiding excessive computing costs. Model run times generally increase in proportion to the square of the total number of zones. However, this distance band approach alleviates the need to introduce a large number of small zones and so generates minimal extra computing burden, while providing a complete representation of total travel. In particular, it ensures that: some trips will switch from shorter intra-zonal bands either to longer intra-zonal bands or to inter-zonal trips if transport costs reduce; and vice-versa. This avoids the unrealistic cut-offs that can arise within large scale models that represent only the "long distance" component of passenger or freight trips.

6. MAIN MODE CHOICE & MODE SEQUENCE CHOICE

The purpose of this main mode choice model stage is to estimate the split among competing main modes of the total tonnage generated in one year for each of the individual logistic leg types between each O-D NUTS III zone pair. This estimation also includes the intra-zonal freight movements that are categorised among different distance bands. In the case of the road mode, there is a further sub-split among the relevant competing vehicle (size) types. The choice models are segmented by freight type and the resulting output O-D modal matrices of tonnes are then transferred to the network model where the mode sequence choice and assignment to the network are completed.

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 generalised cost of transport of each of the competing main modes. The structure of the choice hierarchy tree depends on mode availability, which will depend partly on trip distance (inter-zonal freight and intra-zonal freight). For the non-road modes, distinct types of vehicles or vessels (Table 1) are used to take account of the differences in operating costs (section 7) and characteristics between transporting containers and transporting various types of bulk goods.

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 size types for the particular logistic leg type and freight type combination.

The modal O-D generalised costs for all vehicle types are input from the network model. The different vehicle types listed within a mode are used to represent the main differences in operating characteristics and costs faced by different groups of shippers or for different freight types or for different logistic legs. For example, those consumer goods that are moving long distances from producers to national distribution centres will be heavily containerised and if on road will move in the largest available vehicles. In contrast, these same consumer goods when they are subsequently delivered over short distances from local distribution centres to small retail establishments within cities may be transported in small trucks or even in vans, if the consignment sizes are small enough.

6.1 Mode sequence choice

This main mode choice stage is only concerned with splitting movements between O-D zone pairs among main modes. The further subdivision of a main mode O-D movement among its feeder stages and its main mode stage (Table 2) is carried out separately within the network model as described in Fiorello et al. (2017).

This multi-modal assignment is formulated as a bi-level problem within the network model.

- At the upper level (***mode sequence choice***) the choice is between alternative mode sequences for a given main mode. The O-D demand for the main mode is received from the main mode choice 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. Generalised costs for each alternative are computed based on single-mode costs that are skimmed from the single mode assignments (lower level). Total demand for the O-D pair is distributed over these mode sequence alternatives, using a discrete choice model. Finally, for each single mode the 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 generalised cost of the mode sequences is passed as a main mode generalised cost to the main mode choice.

- At the lower level the leg-wise demand is assigned separately for each single mode (***single mode assignment***). Link volumes and paths are stored for each assignment. Generalised cost components are skimmed off each single mode assignment and passed to the upper level.

7. COST FUNCTIONS

For any origin to destination journey, the model needs to be able to choose between different modes, vehicle types and routes.

The freight market is largely cost driven, with cargo shippers striving to achieve the best value options. Therefore a calculation of the typical prices that a cargo shipper would pay a haulier for any cargo movement is likely to be the main factor in the choice of transport option.

The buyers of freight transport are typically well informed: they are often in charge of large cargo volumes where small savings per consignment can add up to large savings overall. It is therefore rational for them to make significant efforts to understand the market and the various options, along with their prices. The choices made by cargo shippers can be considered highly rational as compared to typical passengers.

7.1 Cost models

The model therefore needs an estimate of average prices paid from zone A to zone B for mode-of-appearance C (A-B, C) for each mode, vehicle type and route option. These are calculated using cost models.

Cost models aim to build up the costs of transport using the costs of the various components along with assumptions on their use, and then represent these in a generic format such as €X per hour + €Y per km for a road journey.

The various cost components include:

- capital cost of vehicles & interest rates;
- depreciation;
- fuel cost with associated consumption rate;
- taxes;
- maintenance & insurance;
- labour costs;
- overheads and office costs;
- charter cost for ships;
- terminal and port charges;
- track access charges and tolls.

Assumptions include:

- mean speed;
- annual distance travelled per vehicle and hours operational;
- hours worked per employee;
- tonnes of cargo carried per vehicle;
- waiting time at terminals (including ports);
- repositioning / backload opportunities;
- typical industry profit levels.

Once a cost model has been built up from the various cost components and assumptions, it must be validated against real-world average prices paid.

Once cost models are established for each mode and vehicle type, an initial temptation may be to allocate all (A-B, C) cargo to the cheapest available calculated option. However there is variation between the needs of individual customers, so the calculated costs can only be considered averages for (A-B, C) cargo.

There are also other considerations as well as the direct price such as:

- frequency of service;
- reliability;
- spreading of traffic amongst several options to avoid dependency;
- relationships between particular companies or within large companies;
- journey time for time-sensitive cargo.

It is difficult to robustly incorporate all of these factors into the cost models, so instead of allocating all traffic to the cheapest route, the model shares the traffic amongst the options to represent the variation between the customers, with the cheapest option gaining the highest share of the traffic.

An advantage of using cost models is that they incorporate real-world cost components. This gives the option for the model user to change values in the cost model to represent alternative scenarios. For example a user could investigate the impact of a variety of policy measures.

1. Introducing higher taxes for road. This would feed through the cost model into more expensive costs for road transport, without affecting the costs for other modes. Upon mode choice and assignment, this would lead to a mode switch from road to other modes.

2. Higher fuel prices. Modes for which fuel prices are a large proportion of their overall cost (such as road) would suffer a large increase in overall costs. However modes for which fuel makes up a small proportion of overall costs would only experience a small increase in overall costs. Upon mode choice and assignment, this would again lead to a mode switch from road to other modes.

8. CALIBRATING THE FREIGHT DEMAND MODEL

The main freight flow data source on which the model calibration is based is the modal freight dataset published by Eurostat[1] which contains the carriage of goods survey results that are collected annually by mode in each EU country. This use of a standard data source across Europe that is regularly updated will facilitate making future updates to the model to rebase it to a later base year than the current 2010.

For most modes there is reasonably complete and detailed data within this Eurostat database. However, for pipeline the available data is very limited, while for rail freight the database is incomplete for a number of countries and it contains less detail than that available for other modes. Accordingly, it has been necessary to also assemble national data sources to cover the various data gaps that have emerged.

Within the distribution channel choice model the main statistics that need to be matched through the estimation of its parameter values for each combination of freight type and country, include:

- average length of haul, differentiated by logistic leg type;
- handling factor which is defined as the average number of logistic legs traversed from production to consumption zones – typically little more than 1 for primary bulk products such as coal and ores, but may be 3 to 5 for consumer foodstuffs and other finished products.

Within the main mode choice model the main statistics that need to be matched through the estimation of its parameter values for each combination of freight type, logistic leg and country, include:

- proportional spread across modes;
- average length of haul by mode;
- national modal tonne kilometres.

An analogous separate calibration task estimates those parameters specific to the intra-zonal distance band and mode choice component.

When all of the parameter values have been estimated satisfactorily, based on realistic OD modal cost values, the freight demand model is then calibrated to ensure that it matches closely to observed aggregate O-D modal flow totals for the base year. This is carried out through iteratively applying the set of flow constraints that is required to match these observed totals. Each such constraint endogenously generates a residual disutility value that feeds through the choice structure to adjust the estimated flow values. The demand model is repeatedly solved, while iteratively readjusting these residual disutility values until the full set of observed constraints has been matched throughout. The resulting set of residual disutility values is then output, ready for use as one of the inputs to future forecasting or policy scenario runs of the model.

9. TRIMODE MODEL DEVELOPMENT SCHEDULE

The TRIMODE model is being developed in two sequential phases because of: its large size; its requirements for design innovations in many of its components; and the need to integrate all of these within a coherent, operational system.

The Phase I model is conceived as a test model to demonstrate that the methodological approach works and to provide useful indications about implementation aspects (e.g. the running times and the complexity of operation of the overall model structure). Therefore, the Phase I model development has been deliberately limited in its spatial coverage. Its transport and energy model components represent only six countries in full detail: Austria, Germany, Italy, Netherlands, Slovenia and United Kingdom. These six countries include 772 NUTS III zones, comprising 58% of the EU28 total number of NUTS III zones (1342). The remaining EU countries and all other countries are represented only in aggregated form. In contrast, the national economy model already includes all countries within Phase 1.

Phase I focused initially on model design and software implementation tasks, with the work on demand data collection and on model implementation gathering speed in 2017. By Summer 2017, all model components, with the exception of some parts of the freight demand model, were fully functional within an integrated system running through forecast years but they had not yet been calibrated. The freight demand model will be fully functional by Autumn 2017 and then will be calibrated and validated, by the beginning of 2018.

Phase II will proceed through to 2019 and will initially gather data to extend the Phase 1 model structure to cover all other countries in detail. It then will calibrate and validate all model components for this full Phase II study area.

10. CONCLUSIONS

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 both their underlying P-C matrices and their O-D matrices. The cost-effectiveness of individual distribution channels is highly sensitive to transport and logistics cost structures so the resulting spatial pattern of O-D movements should take full account of this sensitivity. The distribution channel choice procedure provides a computationally efficient method: for representing the complexity of the operation of logistics; for representing how the distribution structure varies greatly across both space and across broad types of goods; and for representing how it will evolve in the future in response to changes in the unit input costs and technologies of the transport and warehousing industries.

The greatest challenge in the implementation of this innovative distribution channel choice procedure lies in obtaining access to comprehensive data that describes the actual scale of usage of competing distribution channels and of how they vary across Europe. The residual disutility based methods for constraint matching have been developed in part to ensure that flexible and effective use can be made of whatever aggregate data does become available.

The methodological developments introduced above have been designed to improve the realism and performance of comprehensive operational freight modelling procedures for large study areas. In this way in conjunction with the other components of TRIMODE it will be able to test a wide range of policies such as: the impact of new or upgraded inland infrastructure; energy price changes; different infrastructure charging regimes; port capacity upgrade; land use strategies with respect to distribution parks; connected and/or autonomous vehicles; much longer freight trains; etc.

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NOTES

[1]The Eurostat freight database is downloadable from:
http://ec.europa.eu/eurostat/web/transport/data/database