# Overall design of the Danish National transport model

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## Abstract

*The objective of the new Danish national transport model is to establish a unified reference model, which will form a new basis for transport policy analysis in Denmark. There are a number of important benefits by developing a single model framework rather than relying on a variety of regional models. Firstly, as different projects is compared using the same model, potential model bias will be ruled out. Secondly, as more resources can be put into the development of a single model, it can also be more comprehensive and advanced in a number of respects. Thirdly, it becomes much easier to maintain and update the data foundation, which is a very important issue in model development. The aim of the present paper is to outline the general model structure and to discuss how the model will be able to address a range of scenarios. More specifically, we will discuss how different model components are linked and briefly present the forecast methodology.*

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# 1 Introduction

It has long been recommended (TRM, 2006; Heatco, 2005) that cost-benefit analysis of different infrastructure projects should be based on a common set of reference assumptions in order to do benchmarking. The use of generic value-of-time estimates is one example, which ensures that a saved hour of travel time is given the same value irrespectively of the location of the infrastructure. To that end, it is at least as relevant to make sure that the transport models underlying the cost-benefit analysis are consistent and comparable. Clearly, the best way of guaranteeing this requirement is to develop a unified model framework that is to be used for all project evaluations. This is the intention of the new Danish transport model and it follows the development seen in many other countries including Sweden, Norway, Netherland and UK. In fact also the European Commission has initiated a similar strategy in the focus on the European TRANSTOOLS[2] model as described in (Rich et al., 2009).

Although the idea of a single unified model framework is attractive from an assessment point of view, it raises a series of challenges. A very relevant challenge is that the model is to be used by many different organisations, with different aims and ambition levels in terms of the amount of details that need to be addressed. A key issue is therefore to consider how the model can be represented at different aggregation levels in a consistent way.

Clearly, if computation time was not an issue, the answer would be to work with the most detailed model representation throughout the simulation of the projects, and then in the final stage to aggregate results to the level requested by the user. This however is not practically feasible as the zone system at the most detailed level include 3,670 zones with an expected runtime of several days. It would also require that all details of a project should be coded – even in the initial phases of the project evaluation, e.g. that the entire public transport timetable should be updated for a rail project, or all details with regard to ramps, roundabouts, etc. defined for a road project.

A better approach is thus to build a model structure which can be applied to different modelling stages and levels. This will in many respects resemble the planning process, where in the beginning of the process the aim is to examine a wide spectrum of solutions without having to specify assumptions in many details and with short computation time. Later in the planning process, the model is used in more detail, with more emphasis on detailed assumptions and with longer computation time. The technical challenge by allowing for a multiple set of levels to be analysed, is how to minimize possible aggregation bias, and at the same time keep computation time at a minimum.

The aim of the paper is to provide an overview of the National model and it therefore refers to more detailed descriptions of the model components. A detailed description of the forecasting methodology can be found in Rich (2010a) and in Rich and Hansen (2010), a description of the demand model structure can be found in Rich et al. (2010) and Rich (2010b), a description of how tourism is modelled is described in Rich and Aagaard (2010), and descriptions of the route choice models in Nielsen (2010) & Nielsen & Frederiksen (2010). . In addition refer to Brems and Jensen (2010) for a description of long-term shifts in transport demand.

[2] DTU Transport developed the TRANSTOOL II model and will lead the development of the TRANSTOOL III model to be finalized end 2013.

The paper will be organised in the following way. In Section 2, we briefly describe the main data sources of the model. Section 3 include a discussion of the overall model structure with a brief discussion of the different model components. Section 4 is concerned with how the model can be defined in different configurations depending on the zone aggregation level. Finally, we offer a discussion in Section 5 where we will try to enumerate the various transport policies that can be analysed by the model and pinpoint limitations, and conclude the paper in Section 6.

# 2 Data and zone system

The model relies on several data sources and four zone systems. The two main data sources are the Danish Travel Survey (TU, from the Danish TransportvaneUndersøgelsen) and the national register, while additional data sources come from surveys that are intended to answer specific needs. The four zone systems are defined to allow flexibility for model users with different needs and objectives.

## 2.1 Travel behaviour data

The TU survey (Jensen, 2009) is a national on-going survey (1992-present) that collects travel diaries for at least 1,000 individuals every month[3]. TU data are the input to model short-term decisions, since the survey collects details about the daily activity and travel patterns of a representative sample of the Danish population. With this respect, it should be noted that the choice probabilities resulting from model estimates require being scaled to the entire population with factors calculated during the population generation phase.

Register data contain information on the entire Danish population and integrate TU data to model long-term and short-term decisions, since data contain information about income, education, work place, and number and type of vehicles. Register data provide the basis to construct the synthetic Danish population according to socio-economic characteristics at the household and the individual level, and to residential zones (Rich, 2010a).

An over-night survey focuses on collecting information about tours that involve spending at least one out-of-home night. By integrating with information extracted from TU data about over-night trips, this survey provides insight into long trips according to the concept that long and short trips should not be divided according to the distance covered, but rather to the distinction of whether or not the tour is completed within 24 hours. Note that this survey will likely oversample trips directed abroad, but the integration of often scarce information about international tours by foreigners and Danish citizens overshadows this shortcoming.

Data from stop interviews will be crucial to assess the amount of traffic entering and exiting Denmark at specific entry/exit points. The selection of the relevant entry/exit points is a major factor in designing the interviews (e.g., currently surveys in Copenhagen airport, at the Great Belt, and on the ferries across Femern are on-going), which obviously will focus on origin, destination, access/egress point, purpose, and traveller's characteristics. Stated preferences surveys for Femern

[3] From 2009-2011 the sample size has been increased to 2000 interviews per month to better support the development of the national model.

Belt crossing and time-of-day choice will be collected to obtain further information on the possible demand for the future fixed link connecting Denmark and Germany, as well as on the trade-off between congestion costs and departure time and the description of passenger preferences for specific time windows.

## 2.2 The zone system

The zone system is defined according to four different aggregation levels, which are all internally consistent in the sense that the more disaggregate levels add up to the more aggregate. As detailed in Tables 1 and 2, the most aggregate level is the municipality level ($L_0$) consisting of 98 zones, whereas the most disaggregate level ($L_3$) consists of 3,670 zones.

Level 0 is municipalities. The larger municipalities are split into more zones in level 1 (e.g. Copenhagen), and also municipalities with clearly divided centres (like Ikast Brande).

The aim when constructing the zone system at level 2 and 3 was that the zones should not differ much with regard to number of addresses, population and work places, that vicinity to stations should be a criterion, that the zones could be connected unambiguous to the road network, and that cities could be distinguished from rural areas (down to 3000 addresses in level 2 and 1000 in level 3). Special traffic terminals (airports, harbours, transport centres) are defined as individual zones according to importance. Islands are often smaller zones than others. If possible zones also further describes areas with homogeneous land use (industry, apartments, urban centres) – especially at level 3. As a third priority, various prior zones systems and administrative borders have been taken into consideration.

In order to answer the different needs of the model users in terms of spatial details, the different zone system can be mixed to give different model configurations for Zealand and Jutland/Fünen respectively. An example could be a regional analysis within the Copenhagen region: a configuration could be a detailed $L_3$ representation for Zealand in combination with a more hazy $L_0$ representation for Jutland and Fünen. Another example could be a “screening” model where a short run-time is of essence: a configuration could be a less detailed $L_0$ representation for both regions.

The challenges posed by the zone system concern the connection of the different zone levels across the Great Belt that separates Zealand with respect to Jutland and Fünen. Firstly, the network needs to be consistent in the sense that the more detailed networks are “embedded” within the more aggregated networks. Secondly, the aggregated networks need to be connected.

| Level | Description | Zealand | Jutland/Fünen | Total |
|---|---|---|---|---|
| $L_0$ | Municipality level | 45 | 53 | 98 |
| $L_1$ | Strategic level | 70 | 106 | 176 |
| $L_2$ | National level | 530 | 377 | 907 |
| $L_3$ | Regional level | 2234 | 1436 | 3670 |

**Table 1.1: Number of zones for the different aggregation levels.**

| Level | Region | Avg. addresses | Avg. size ($km^2$) |
|---|---|---|---|
| $L_0$ | Zealand | 19,522 | 204.5 |
| $L_1$ | | 12,919 | 131.5 |
| $L_2$ | | 2,355 | 24.4 |
| $L_3$ | | 612 | 15 |
| $L_0$ | Jutland and Fünen | 27,753 | 636.2 |
| $L_1$ | | 14,260 | 318.1 |
| $L_2$ | | 2,832 | 63.6 |
| $L_3$ | | 667 | 6.4 |

**Table 1.2: Size of the zones in the different systems.**

Another challenge posed by the zone system concerns the demand model. The demand model will be estimated at the $L_3$ level, and the parameters will be used for calculating aggregate measures to be used for more aggregate versions of the model. However, the utility functions, and in particular the zone specific variables, change as the zone system change. This issue requires that the utility functions are invariant with respect to the zone system and that a mechanism is designed to assign the correct utility functions depending on the model configuration. It should be noted that this "book-keeping" task is further complicated if the model applies random sampling for representing destination choice.

## 2.3 Transport networks

The road network build upon the Navteq map combined with various other data sources, and a lot of manual valuation. The network is coded in a way that different levels of aggregation correspond with the different level of aggregations of the zone systems. The network contains a number of attributes concerning speed, number of lanes, road type, capacity, etc. In addition various traffic counts are linked to the network. Refer to Nielsen (2010).

The public transport network is build upon the data from "rejseplanen.dk". This means that the network consist both of rail and bus lines, as well as the entire timetable. Various sources of traffic counts are being connected to be able to estimate the model. The public transport models will also be able to run at different level of aggregation, since – in the final model – it will be possible to choose between a detailed timetable-based model and a faster frequency based model. It will also be possible to choose whether local bus routes are being described, or included only as feeder modes represented as zone connectors. Refer to Nielsen & Frederiksen (2010).

Both the road and public transport networks have been connected to the zone system.

# 3 Model structure

An overall illustration of the model framework is illustrated in Figure 1.1. In a first stage, all of the assumptions in terms of population forecasts, network, and employment forecasts is defined. These are exogenous to the model. In the second stage, the model consists of two parallel blocks; (i) a passenger demand model, and a (ii) freight demand model. Both of these models will affect the route choice equilibrium, which in turn will spill-back on the demand.

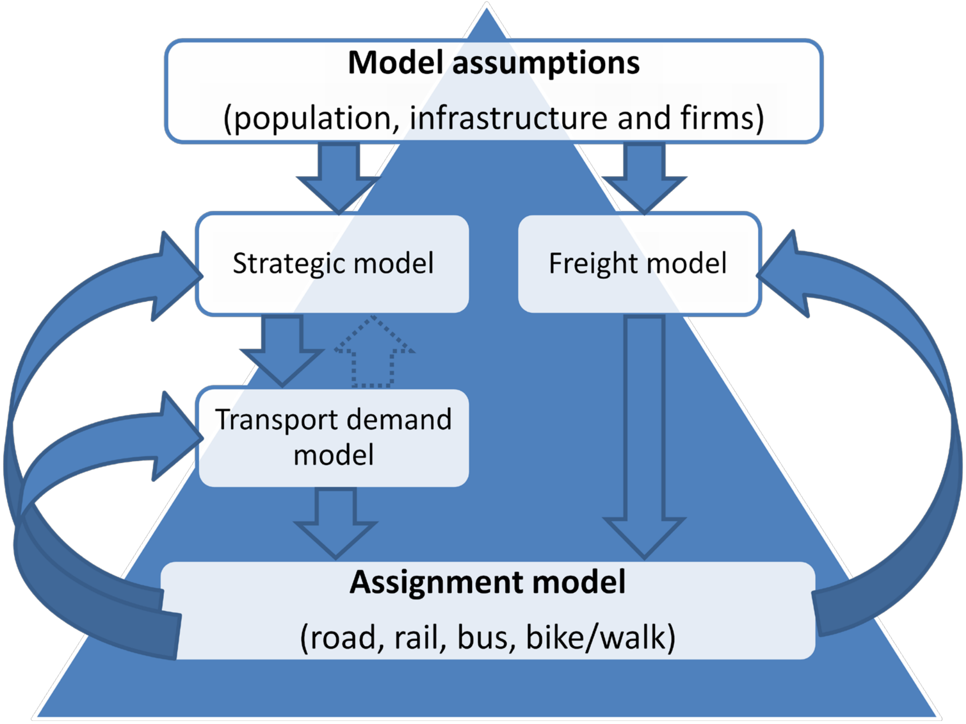


**Figure 1.1: Overall model structure.**

It is also noteworthy that the passenger model is decomposed into two sequentially linked parts; (i) a strategic model, and (ii) a demand model. Each of these models are linked in terms of logsums.

## 3.1 The passenger demand models

The model structure of the passenger model will be composed of a model for long-term choices and four different demand model segments as illustrated below in Figure 1.2.

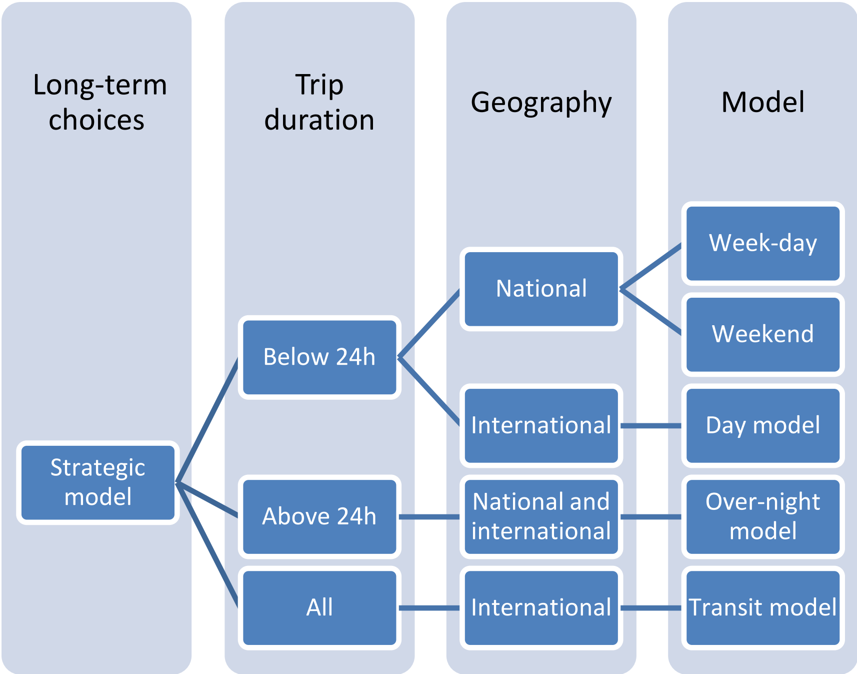


**Figure 1.2: Components of the demand model.**

## 3.2 The strategic model

The strategic model is a household based model, which does not directly address demand for transport. Rather, the strategic model defines pre-conditions for the transport pattern of the household. Three main choices are considered;

- Residential location choice
- Choice of work location(s)
- Choice of the number and type of cars

These three choices is a strategic choice that involves all members of the household. In particular, if there is more than one worker there will be dependencies in how the different workers choose their work-location (Rich and Nielsen, 2001; Van Ommern, 1998) and there will be a trade-off between the number of cars and the accessibility of public transport to and from the home. The three choices however, do not produce transport in itself. The fact that a work place is located in a given zone does not mean that we actually would go there. For instance, it could be that we were working home, were sick, or on vacation.

This distinction between strategic choices and transport is important for several reasons. The key argument for decomposing into a strategic model and transport demand models is that we hereby utilise the data as efficient as possible. The strategic model can be based on register data, with a complete description about the members in the household, the car availability and type, and the workplace for all members. This information about the complete household makes it possible to disentangle much of the interdependencies between the joint work location (when multiple workers exist) and the joint car availability.

## 3.3 The Demand models for person traffic

The demand models are decomposed into four different segments as seen from Figure 1.2Figure 1.2.

The national week-day model represents the majority of transport and are particular relevant for dealing with congestion as most congestion exist during weekdays. In many models including the OTM model only weekday traffic are considered. An average day of the year is then represented as a weekday scaled by some factor to include traffic during weekends as well. As the transport profile during weekends is very different in terms of the time-of-day patter, mode, and destination choice, it will introduce aggregation bias which is not favourable.

The model for international day will mainly cover (i) trips crossing Øresund, (ii) trips crossing the Danish-German border, and (iii) trips in and out of the Copenhagen airport.

The overnight model will cover all trips that include overnight stay whether they are national or international. The stratification on overnight versus day trips rather than trip length is motivated by the fact that time rather than length is the critical resource today. Per definition we will consider tourism in the overnight model. One-day tourist trips will be covered as “leisure” or “private” trips in the other models.

## 3.4 The route choice models

The main route choice models describe road transport and public transport. The whole model also includes a model for bicycle and walk as main mode.

The road transport model is feed with travel matrices predicted from the passenger demand model and the freight model, feeder transport to air ports, and preloaded bus routes (in order to model congestion). In the second phase of the model development, park & ride will be integrated into the modelling of public transport chains, and the resulting car traffic included in the road assignment model. Whilst version “0.1” of the model works at an “average level”, the second model explicitly model congestion and trips as a function of time (in a so-called pseodo-dynamic assignment model). Refer to Nielsen (2010).

The public transport model is a so-called schedule-based assignment model in the first phase of the project. In the second phase a new combined schedule- and frequency based model will be implemented, which adds flexibility with regard to calculation time and which level a detail a model user wants to use. If – for an example – the schedule-based model is used for rail, and a frequency-based for busses, then the user needs to define a new rail time-table for a given scenario, but the user do not need to re-define the entire bus-time table. Opposite if the user is a regional bus traffic company, then the focus would actually indeed be to fit the detailed bus-timetables with the train schedules.

## 3.5 The Freight model

The objective of the freight model is to forecast goods flows by mode on Danish infrastructure. The international component is stronger than in passenger transport, and hence the freight model covers all transport flows which relates to Denmark or potentially could use Danish infrastructure.

The freight model includes three sub-models: trade model, logistics model, and route choice models. The trade model aims to forecast trade between zones provided developments in international trade. It includes a separate model for forecasting of non-value goods (e.g. transport of waste). The output as a result of pivot-pointing to base year matrices is production-wholesale-consumption (PWC) matrices.

The logistics choices in the logistics model includes i) choice of frequency/shipment size, ii) choice of loading unit (e.g. containerised or not), iii) use of distribution centres, freight terminals, and ports, iv) mode used for each leg of the transport chain, and v) choice of crossing e.g. new Femern Bælt link. The location of trans-shipment points are assumed given but can be changed by the user in scenarios for the future. The logistics model determines their use and the number of legs in the transport chain. Since the logistics model operates at agent level, the aggregate PWC matrices are synthetically disaggregated to the level of firm before the logistics model is deployed. The aggregation of OD flows between firms to uni-modal OD flows between zones provides the result of the logistics model and input to the route choice models.

Whereas national van and truck trips are expected to be assigned to the road network simultaneously with passenger cars, international van and truck trips, freight trains, and ships are assigned in the freight model exclusively. The choice of crossing is likely to be determined by a combination of the logistics model and assignment models e.g. with a choice model for the choice between a fixed link and a set of available ferry routes and a restricted assignment routine for the choice of individual ferry routes. The route choice models are also used to calculate level-of-service (LOS). The feed-back loop to the logistics model is not expected to include congested transport times, because the complexity and run time for an iterative assignment-logistics model is unwanted.

## 3.6 Forecasting methodology

In transport modelling, two forecasting methodologies are used (e.g. refer to Rich, 2009); (i) prototypical sample enumeration (PSE) and (ii) matrix model forecasting. The idea of the PSE method is to apply the micro-data underlying the demand model in the simulation by expanding the survey to the population level by a set of expansion factors (Daly, 1998). In the matrix method, the demand model is reformulated at a matrix level (e,g., as in the OTM or TRANSTOOL II model). Theoretically, the PSE method is favourable because it rules out aggregation bias at the zone level. The problem, on the other hand, is that it requires a micro-data foundation, which is not always available.

In the present case, it is straightforward to apply PSE for trips carried out by Danes as these are covered by the register data. In practise it means that the weekday and weekend model will be developed using the PSE forecasting approach (refer to Rich, 2010a) as these are supported by TU and register data. However, for the international day trip model and the overnight model, the respondents will be a mixture of foreign and Danish travellers. In this case it is a problem that we do not have access to detailed register data for the foreign travellers. The natural solution is therefore to forecast these models within a matrix model design or alternatively, as illustrated in Figure 1.3, to divide into a model for foreigners and Danish citizens.

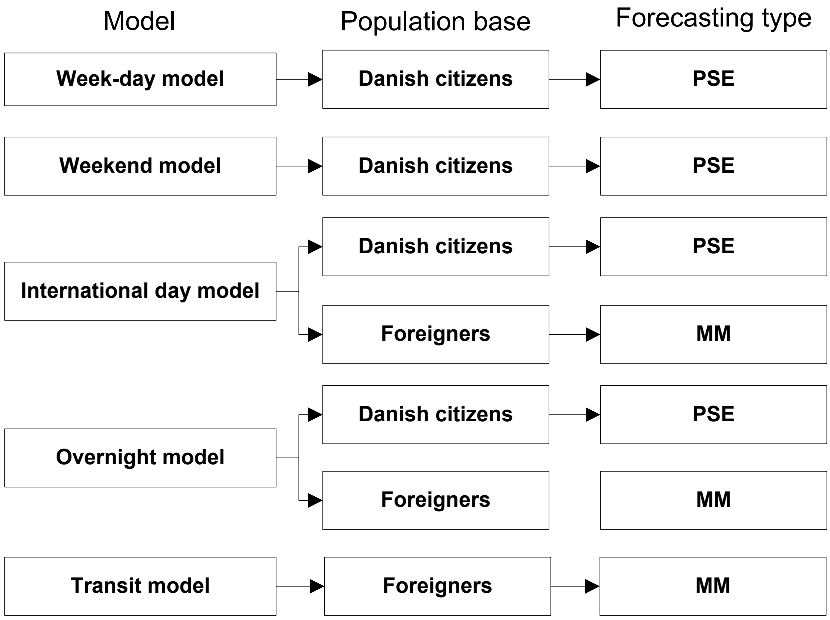


**Figure 1.3: Forecasting methodology in the Danish National model.**

The difference in forecast methodology is not problematic. It is basically a matter how the final tour matrices are created, either by expanding the micro sample or by simulating at the matrix level. Refer to Rich (2010b) for more details on this issue.

# 4 Linking different model levels

The question of aggregation and how to link the different modelling levels as defined by the zone system is relevant from an applied point of view. However, it does give rise to methodological challenges as well.

As illustrated in Table 1.1 and Table 1.2, the zone system consists of 4 different levels, which may be used in different contexts. The first challenge is to ensure that zones and the underlying network are consistent when aggregating. In other words, it should be able to aggregate Level 3 to Level 2 in a unique way and similarly for the other levels. In addition, the network should be consistent and "connected" irrespectively on the different aggregations.

The linkage across different aggregation levels is not trivial as the demand models are a function of the aggregation level in many respects. Firstly, the attraction variables describing trip attractiveness in the model will be a function of the zone aggregation level. As these variables are to be proportional to “size” the expression of the utility function will change in the choice model formulation. Secondly, as the demand models most likely will apply “stratified importance sampling” in the choice of destination, the sampling scheme will be a function of the zone system as well.

As a result hereof, the model needs to be formulated in different versions based on different aggregation levels. We have identified 15 possible different model applications (refer to Table 1 below) which are formed as combinations of three different zone aggregation levels for East and West Denmark respectively.

| **Model configurations** | **East** | **West** | **Outside DK** | **Description** | **Run-time** |
|---|---|---|---|---|---|
| M1 | L1 | L1 | Z1,Z2 | Screening model based on L1 | Very fast |
| M2 | L1 | - | Z1 | East screening model | Very fast |
| M3 | - | L1 | Z2 | West Screening model | Very fast |
| M4 | L2 | - | Z1 | East screening model based on L2 | Fast |
| M5 | - | L2 | Z2 | West screening model based on L2 | Fast |
| M6 | L2 | L1 | | East screening model with L1 West | Fast |
| M7 | L1 | L2 | | West screening model with L2 East | Fast |
| M8 | L2 | L2 | Z1-Z4 | National L2 model | Medium fast |
| M9 | L3 | - | Z1 | Local East model | Medium |
| M10 | - | L3 | Z2 | Local West model | Medium |
| M11 | L3 | L1 | Z1 | Local East model with L1 West | Medium |
| M12 | L1 | L3 | Z2 | Local West model with L1 East | Medium |
| M13 | L3 | L2 | Z1 | Regional East model combined with National L2 model | Medium-long |
| M14 | L2 | L3 | Z1,Z2 | Regional West model combined with National L2 model | Medium-long |
| M15 | L3 | L3 | Z1,Z2 | National L3 model | Long |

**Table 1.3 Outline of possible model applications.**

In addition to the standard model application listed in Table 1.3, it is foreseen that a range of specialised models will be developed under the “umbrella” of the national model framework. One of these models will be the Femern Belt model. Other possible models could be models for Funen and Copenhagen, the last with an L3 representation for Copenhagen and an L1 for Funen and Jutland.

A parallel issue is the linkage of freight and passenger demand. As the two models are formulated at different aggregation levels (freight is formulated at L1), but needs to be assigned simultaneously, freight needs to be disaggregated before assigning traffic to the network.

# 5 Discussion

As mentioned above the model framework with its different levels of detail can be used at different stages in the planning process and also for different purposes. The model framework is designed to be able to answer question related to a range of different policies. These requirements have been identified in a study of user needs and requirements among the potential user including the Ministry of Transport, road and public transport authorities, and transport operators.

Some of identified needs that the model is designed to cope with, are:

For the overall transport system

- Evaluation of infrastructure projects relative to the existing transport system
- Use of the transport system across modes for both passengers and freight
- Effects of changes in environmental taxes, congestion charges etc.
- Evaluation of external effects
- General use of "sub-model elements" including population forecast, zone system, matrices,..

For public transport authorities and operators

- Demand effects of rail infrastructure investments, especially the mode change from road to rail
- Design of the infrastructure, especially the use of public transport modes
- Design of the supply profile, e.g. in the priority of fewer faster trains relative to more trains with more stops

For road authorities on national and regional levels

- Demand effects of road infrastructure investments
- Improved formulation of congestion modelling
- Use of traffic forecasts for planning and budgeting of maintenance

The formulated needs are mostly related to the transport system and the associated taxes and charges. Furthermore, the model framework will be able to handle demographic as well as economic changes. On top of the model, there will be an economic assessment module that links demand with the proper values for external costs and social value-of-time estimates. The latter will make it possible to do socio-economic assessment, which will be comparable between all projects.

Since the model framework is primarily based on disaggregated data, some of the significant improvements compared to Danish and international models are the strategic elements of the model, which will among other things be able to evaluate effects of changes in the population e.g. aging and employment. Furthermore, the formulation of route choice for public transport will be developed. Another improvement compared to many other transport models is the formulation of different aggregation levels, which makes it possible to use the model framework for evaluating e.g. the main effects of an infrastructure project at an early stage in the planning process. A similar need has been formulated for national models in other countries over the last couple of years.

# 6 Conclusion

The paper has outline the overall model framework of the new Danish national transport model.

At first, it is stressed that having a unified model framework is a major benefit because all of the different proposals that are to be analyse by the model will be analysed according to the same metric system. In fact, it parallels the use of common value-of-time estimates and other estimates for external costs.

It is discussed how the different model components are linked and how different aggregation levels can be applied. We briefly discuss the overall decomposition of the demand model into strategic choice and transport demand choice, the coupling to the route-choice, and the parallel freight demand model.

The different aggregation levels of the model are born out of the zone system design, in which four zone levels are used. By coupling the different zone-systems at the Great-belt intersection, a total of 15 different model combinations emerge. In addition, it is stressed that there may be additional models, which serves special purposes. An example is the Femern belt model.

In a final section, we briefly outline the "policy domain" that can be analysed by the model.

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