Main Principals of Transportation Modeling

Introduction

A model is a simplified representation of a part of the real world–the system of interest–which focuses on certain elements considered important from a particular point of view. Models are, therefore, problem and viewpoint specific.

Transport models are a systematic representation of the complex real-world transport and land use system as it exists. They are powerful tools for assessing the impact of transport infrastructure options and for identifying how the transport system is likely to perform in the future, which is essential for the development of effective urban planning practice.

The development and application of transport models are fundamental to the appraisal of many transport initiatives because they:

- Provide an analytical framework to assess existing demands on the transport system and project future demands to systematically test the impact of transport and land use options.
- Enable the generation of quantitative measures to provide key indicators in the business case assessment and economic appraisal.

A model is not only about having as accurate a model as possible, it is also about usefulness.

At the most fundamental level, transport models comprise:

- A demand model (trip generation, trip distribution, mode choice, and time of travel).
- A highway assignment model (road-based public transport, private vehicles, freight, and other commercial vehicles).
- A rail, bus, and ferry assignment model (public transport and freight).

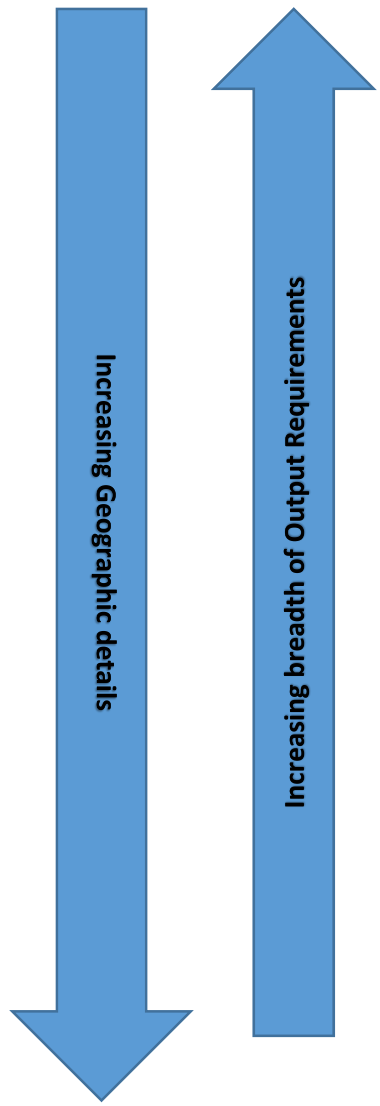
Generally, the development of a transport model requires:

- A Statement of Requirements
- A Functional Specification of the transport model
- A Technical Specification of the transport model.

A good transport system widens the opportunities to satisfy these needs; a heavily congested poorly connected system restricts options and limits economic and social development.

Hierarchy of transport modeling applications

Hierarchy of transport modeling applications		
Land use and transport interaction modeling	Examines and evaluates the impacts of transport policy and land use changes on urban form and transport	
Strategic modeling	➢ Examines 'what if?' questions in policy development and the definition of strategies ➢ Identifies and assesses broad metropolitan-wide impacts of land use, socio-economic, demographic, and transport infrastructure changes ➢ Assists in transport infrastructure project generation ➢ Provides metropolitan-wide forecasts of trip generation, trip distribution, mode choice, and assignment of trips to the transport network ➢ Considers travel needs, and multi-modal consideration of whether and how these are best satisfied ➢ Models and assesses pricing issues	
Scenario modeling	Assesses the implications of particular strategies at the metropolitan scale	
Project modeling	➢ Assesses strategy components, individual projects, specific land use strategies, and transport corridor issues ➢ Assesses the performance of the transport network along specific corridors and for nominated projects	
Operational design	➢ Assesses the detailed operational performance of specific transport infrastructure projects and initiatives (e.g. ramp metering), land use developments, and local area traffic management	



	➢ Priorities allocation of road capacity between different users (e.g. bus priority or pedestrian signal phasing) ➢ May assist in identifying the effects on delays and queues resulting from changes in transport system variables (i.e. signal phasing, lane configurations, ramp metering)	

Characteristics of Transport Problems

Transport problems have become more widespread and severe than ever in both industrialized and developing countries alike. Fuel shortages are (temporarily) not a problem. The general increase in road traffic and transport demand has resulted in congestion, delays, accidents, and environmental problems well beyond what has been considered acceptable so far. These problems have not been restricted to roads and car traffic alone. Economic growth seems to have generated levels of demand exceeding the capacity of most transport facilities. Long periods of under-investment in some modes and regions have resulted in fragile supply systems which seem to break down whenever something differs slightly from average conditions.

These problems are not likely to disappear shortly. Sufficient time has passed with poor or no transportation planning to ensure that a major effort in improving most forms of transport, in urban and inter-urban contexts, is necessary. Given that resources are not unlimited, this effort will benefit from careful and considered decisions oriented towards maximizing the advantages of new transport provisions while minimizing their money costs and undesirable side effects.

Characteristics of Transport Demand

The demand for transport services is highly qualitative and differentiated. There is a whole range of specific demands for transport which are differentiated by time of day, day of the week, journey purpose, type of cargo, the importance of speed and frequency, and so on. A transport service without the attributes matching this differentiated demand may well be useless. This characteristic makes it more difficult to analyze and forecast the demand for transport services: passenger kilometers are extremely coarse units of performance hiding an immense range of requirements and services.

The spatiality of demand often leads to problems of lack of coordination which may strongly affect the equilibrium between transport supply and demand. For example, taxi service may be demanded unsuccessfully in a part of a city while in other areas various taxis may be plying for passengers. On the other hand, the concentration of population and economic activity on well-defined corridors may lead to the economic justification of a high-quality mass transit system which would not be viable in a sparser area.

Finally, transport demand and supply have very strong dynamic elements. A good deal of the demand for transport is concentrated in a few hours of a day, in particular in urban areas where most of the congestion takes place during specific peak periods. This time-variable character of transport demand makes it more difficult–and interesting–to analyze and forecast. It may well be that a transport system could cope well with the average demand for travel in an area but that it breaks down during peak periods. Several techniques exist to try to spread the peak and average the load on the system: flexible working hours, staggering working times, premium pricing, and so on. However, peak and off-peak variations in demand remain a central, and fascinating, problem in transport modeling and planning.

Characteristics of Transport Supply

The first distinctive characteristic of transport supply is that it is a service and not a good one. Therefore, it is not possible to stock it, for example, to use it in times of higher demand. A transport service must be consumed when and where it is produced, otherwise, its benefit is lost. For this reason, it is very important to estimate demand with as much accuracy as possible to tailor the supply of transport services to it.

The provision of transport infrastructure is particularly important from a supply point of view. Transport infrastructure is 'lumpy', one cannot provide half a runway or one-third of a railway station. In certain cases, there may be scope for providing a gradual build-up of infrastructure to match growing demand. For example, one can start providing an unpaved road, and upgrade it later to one or two lanes with surface treatment; at a later stage, a well-constructed single and dual carriageway road can be built, culminating perhaps with motorway standards. In this way, the provision of infrastructure can be adjusted to demand and avoid unnecessary early investment in expensive facilities. This is more difficult in other areas such as airports, metro lines, and so on.

Moreover, transport investment has an important political role. For example, politicians in developing countries often consider a road project a safe bet: it shows they care and is difficult to prove wrong or uneconomic by the popular press.

In industrialized nations, transport projects usually carry the risk of alienating large numbers of residents affected by them or travelers suffering from congestion and delay in overcrowded facilities. Political judgment is essential in choices of this kind but when not supported by planning, analysis, and research, these decisions result in responses to major problems and crises only; in the case of transport, this is, inevitably, too late. Forethought and planning are essential.

One of the most important features of transport supply is congestion. This is a term that is difficult to define as we all believe we know exactly what it means. Congestion arises when demand levels approach the capacity of a facility and the time required to use it (travel through it) increases well above the average under low demand conditions.

In the case of transport infrastructure, the inclusion of an additional vehicle generates supplementary delay for all other users as well, see for example Figure 1. Note that the contribution an additional car makes to the delay of all users is greater at high flows than at low flow levels.

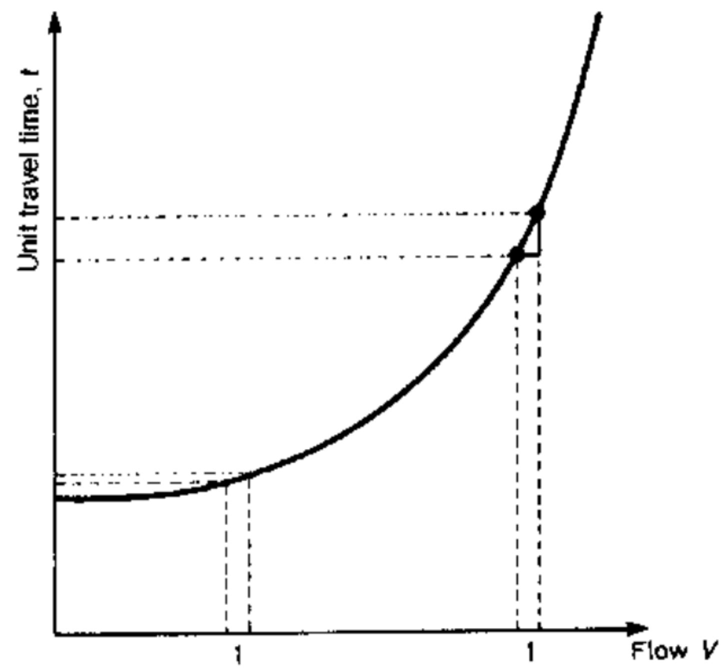


Fig. 1 Congestion and its external effects.

Models for transportation analysis

Models are a simplified representation of a part of reality. Their function is to give insight into complex interrelationships in the real world and to enable statements about what (most probably) will happen if changes occur or put in that (part of) reality. Models in transportation planning are abstract mathematical models, put into the form of (systems of) mathematical equations in which the behavior of a dependent variable Y (e.g. the number of daily train passengers in the study area) can be derived from one or more explaining or independent variables X (e.g. car ownership in the study area, train fares, etc.) and related parameters a:

$$Y = f(a, X)$$

The parameters describe the sensitivity of Y to a unit change in X.
We distinguish between so-called analytical models and design or programming models. Figure 2 describes the process of development of a validated model that is ready for application in a planning problem.

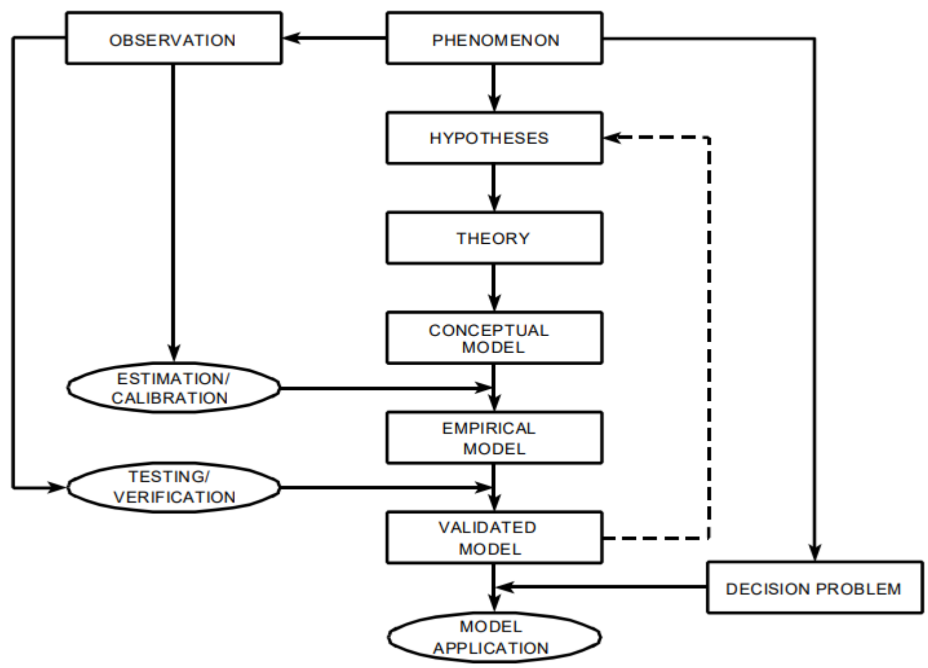


Fig. 2 Process of the developed model.

Equilibration of Supply and Demand

In general terms, the role of transport planning is to ensure the satisfaction of a certain demand D for person and goods movements with different trip purposes, at different times of the day and the year, using various modes, given a transport system with a certain operating capacity. The transport system itself can be seen as made up of:

- an infrastructure (e.g. a road network);
- a management system (i.e. a set of rules, for example driving on the right, and control strategies, for example at traffic signals);
- a set of transport modes and their operators.

Consider a set of volumes on a network **V**, a corresponding set of speeds **S**, and an operating capacity **Q**, under a management system M. In very general terms the speed of the network can be represented by:

$$S = f\{Q, V, M\} \qquad 1$$

The speed can be taken as an initial proxy for a more general indicator of the level of service (LOS) provided by the transport system. In more general terms LOS would be specified by a combination of speeds or travel times, waiting and walking times, and price effects. The management system M may include traffic management schemes, area traffic control, and regulations applying to each mode. The capacity Q would depend on the management system M and on the levels of investment I over the years, thus:

$$Q = f\{I, M\} \qquad 2$$

The management system may also be used to redistribute capacity giving priority to certain types of users over others, either on efficiency (public-transport users, cyclists), environmental (electric vehicles), or equity grounds (pedestrians).
As in the case of most goods and services, one would expect the level of demand **D** to be dependent on the level of service provided by the transport system and also on the allocation of activities **A** over space:

$$D = f\{S, A\} \quad (3)$$

Combining equations (1) and (3) for a fixed activity system one would find the set of equilibrium points between supply and demand for transport. But then again, the activity system itself would probably change as levels of service change over space and time. Therefore one would have two different sets of equilibrium points: short-term and long-term ones. The task of transport planning is to forecast and manage the evolution of these equilibrium points over time so that social welfare is maximized. This is, of course, not a simple task: modeling these equilibrium points should help to understand this evolution better and assist in the development and implementation of management strategies **M** and investment programs **I**.
Sometimes very simple cause-effect relationships can be depicted graphically to help understand the nature of some transport problems. A typical example is the car/public-transport vicious circle depicted in Figure 3.
Economic growth provides the first impetus to increase car ownership. More car owners mean more people wanting to transfer from public transport to car; this, in turn, means fewer public-transport passengers, to which operators may respond by increasing the fares, reducing the frequency (level of service), or both. These measures make the use of cars even more attractive than before and induce more people to buy cars, thus accelerating the vicious circle. After a few cycles (years) car drivers are facing increased levels of congestion; buses are delayed, are becoming increasingly more expensive, and running less frequently; the accumulation of sensible individual decisions results in a final state in which almost everybody is worse off than originally. Moreover, there is a more insidious effect in the long term, not depicted in Figure 3, as car owners choose their place of work and residence without considering the availability (or otherwise) of public transport. This generates urban sprawl, and low-density developments that are more difficult and expensive to serve by more efficient public transport modes. This is the ‘development trap’ that leads to further congestion and a higher proportion of our time spent in slow-moving cars.
This simple representation can also help to identify what can be done to slow down or reverse this vicious circle. These ideas are summarized in Figure 4. Physical measures like bus lanes or other bus-priority schemes are particularly attractive as they also result in a more efficient allocation of road space. Public transport subsidies have strong advocates and detractors; they may reduce the need for fare increases, at least in the short term, but tend to generate large deficits and protect poor management from the consequences of their own inefficiency. Car restraint, and in particular congestion charging, can help to internalize externalities and generate a revenue stream that can be distributed to other areas of need in transportation.

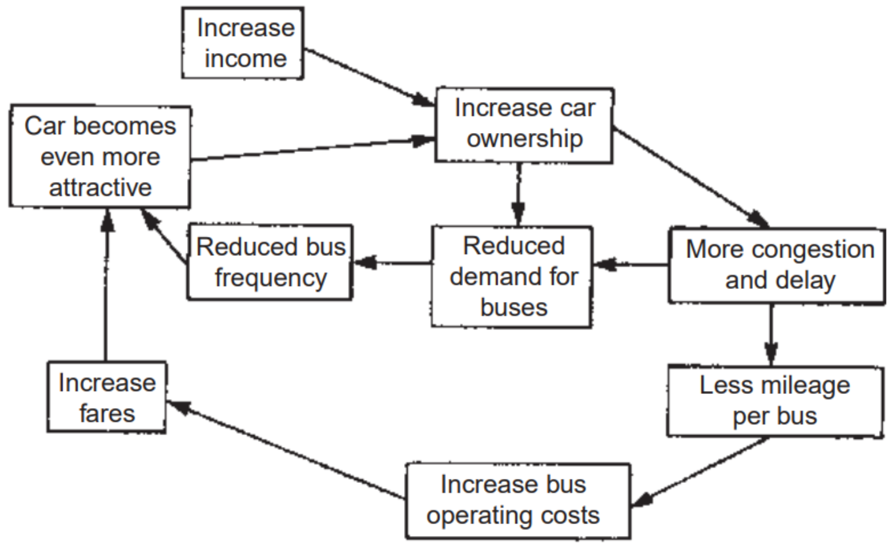


Fig. 3 Car and public-transport vicious circle.

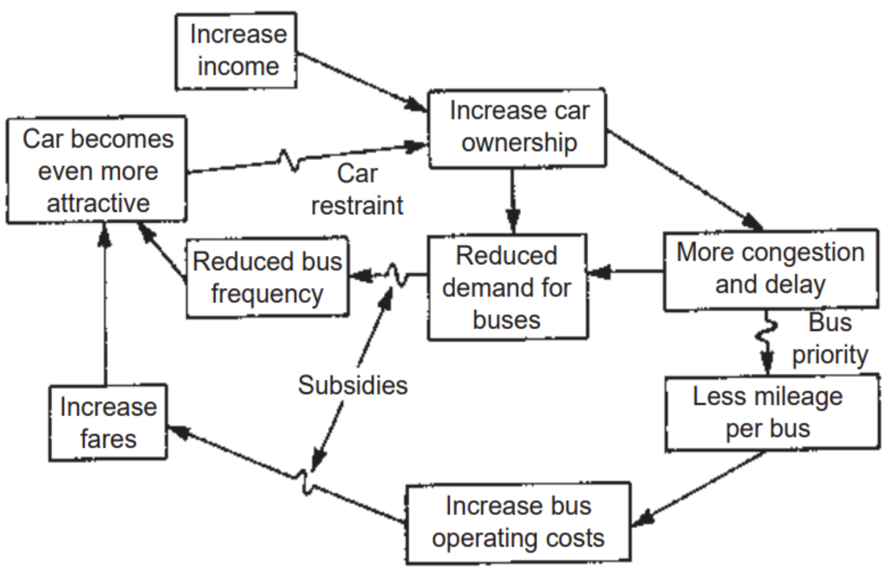


Fig. 4 Car and public-transport vicious circle.

The use of models in transportation analysis

Transportation models are being used to make predictions and forecasts of future changes in usage of traffic facilities for sake of facility design, control, and operation. Future changes in travel, transport, and traffic may be the result of autonomous developments, may be caused by economic, social, or spatial policy, or may follow transportation or traffic measures.

- Autonomous developments result from demographic changes (e.g. migration), increased car ownership, income changes, and international economic changes (e.g. oil price).

Characteristically, these developments rarely may be influenced by transportation planning.

- Typical for economic policy (e.g. gasoline taxes), social policy (e.g. working hours, labor force participation) and spatial policy (e.g. reduction of agricultural land use) is that these policies may have an impact on transportation but are not developed in the transportation field for transportation-related purposes.
- Transportation policy refers to plans designed by transportation professionals to change the transportation system directly (road or rail, public or private, car or bicycle, etc.).
- Traffic measures refer to changes in the operations of the traffic system such as traffic lights, parking, public transport services, etc. Decisions at this level mostly are of a technical kind.

However, models also are used to derive potential measures that can influence the transport system, analyze the effectiveness of measures, and show the side effects of such measures. In addition, transportation models are used to design transport and traffic facilities and services such as the required road capacity, optimization of network structure, design of environmentally friendly road alignments, improved line routings and services in public transportation networks, and design of intersection traffic control lights, etc. In the sequel, a number of such applications will be worked out in more detail.

Forecasting future developments

In the coming decades, the developments in the growth in car and truck use and the standstill or decline of public transport use will remain important questions. For several reasons we need to know whether the growth in car use will continue in the future. There are a number of societal developments that require a critical look at traffic forecasts.

On the one hand, we observe an increase in energy prices but also an increase in incomes. However, available leisure time increases. The number of households with young children is declining to give their mothers more opportunities to participate in out-of-home activities. The number of one-person households increases which gives rise to higher use of cars. Part-time employment most probably boosts mobility.

Decentralization of housing and work is increasing leading to increased travel distances and thus car use. Technological innovations are directed at lower energy use. Clean and fuel-efficient engines are developed and cars will be lighter due to the use of plastics. Our prediction models need to be able to estimate the probable impacts of such developments. Knowledge of the spatial distribution of trips, the modal split, and the spreading of peak periods are necessary for taking sound decisions. Of special importance is to know to what extent traffic during peak hours at bottlenecks will be influenced by the aforementioned developments.

Planning of new or improvement of existing infrastructure

Spatial planning impacts

The geographical location of housing, working and leisure areas influence transport flows. Transportation analysts are asked to calculate the probable transport and traffic implications of spatial planning. This refers e.g. to the consequences of new or enlarged residential areas or changes in employment levels in new business or industrial zones for the size of traffic flows. However, spatial developments in their turn depend on the quality of the transport system. Models are being developed that can indicate the implications of transportation planning actions for spatial changes. Such model applications are important for the calculation of:

- transport flows that are consistent with projections of population and employment;
- impacts of bottlenecks in the road network on spatial developments;
- the influence a good public transport policy can have to counteract further desurbanization of the big cities.

Improvement of the road and railway network

Capacity extension of roads and new roads and railways cause costs in terms of money, noise, exhausts environmental damage, spatial quality, etc. Gradually, the amount of available space declines more and more. Understandably, resistance to the building of roads and railways increases. This demands more attention to the environmentally friendly design of facilities for private and public transport. Infrastructures need to be built such that societal costs are minimal. Models are available that help in optimizing infrastructure networks and routings. Because of the strong resistance against new infrastructures, pertinent decisions need to be motivated convincingly which requires very accurate and valid prediction models.

Better utilization of available capacity

Currently, the capacity of roads is underutilized due to among others the lack of information on the part of the drivers about the prevailing traffic conditions, but also due to poor control of traffic flows. Models can help in calculating route and departure time advice for travelers (e.g. using Variable Message Signs, VMS) such that they will experience and thus cause less congestion. Models can assist in designing traffic lights and ramp metering facilities to control traffic flows such that less congestion will occur. The same holds for the design and control of buffers in motorways. Also planning and design of special target group facilities such as carpool and truck lanes may be facilitated by advanced traffic flow models. The planning of maintenance of the roads (where, when, and how) is another issue where models can assist in decision-making that minimizes costs and troubles (time losses) to road users.

Stimulating public transport use

Because of the negative impacts of car use and the societal goal to enable a minimum level of mobility for everyone, sufficient public transport provision is a must in our society. If public transport has to assist in curbing car use it needs to become a serious competitor to the car and thus asks for high-quality services. Models can help in designing the setup of networks of public transport lines, can help in calculating the patronage of the services given, and can indicate to what extent new or improved services indeed attract car users. An important issue is a strong interaction between land use and public transport provision.

Public transport stations and stops often are the nuclei of new activity developments and thus influence urban patterns, on the other hand, dedicated land use planning is necessary in order to give sufficient base demand for an efficient supply of services. Modeling this interaction between land use and transportation is at the heart of the transportation profession.