Data Requirements for Freight Demand Models

Dinesh H. Vagadia
Lecturer
Department of Civil Engineering
Government Polytechnic Rajkot, India

Abstract— Movement of goods and people is very important for socioeconomic growth of any country. Transportation plays vital role in economic growth of society. Transportation cost and time determines market reach of any product. By modelling and optimising freight demand and supply chain, one can manage economic growth. For best results, it is very important to identify, collect and provide suitable quality data for as input in developed freight models.
Key words: Transportation, Freight Demand Models

I. Introduction

Transportation is basic needs of society and movement of freight play important role in economy of any country. Freight demand models are quite complex compared to demand models for passengers. Freight is of many types affecting selection of mode choice, routes and travel times. Demand of any freight highly depends upon transportation cost particularly for goods having high portion of transportation cost in their price. In urban area, vehicles used for freight movement are many times cause of congestions and accidents. Commercial vehicles used for freight movements are generally heavily loaded affecting the pavement conditions and designs also. Urban form and zoning are also of importance because sometimes roads connecting industrial zone may pass through and disturb residential area. The quantification of the freight movements occurring in each traffic zone, and then of the Origin-Destination trip tables due to the delivery of goods in the urban environment, is essential for evaluating the effects of any city logistic policy in terms of vehicle congestion and polluting emissions, based on the assignment of demand flows to the road network. Depending upon area and level of application, freight demand models may be of aggregate or disaggregate type. Grouping commodities and considering production-consumption areas and type of vehicles used in locality at various levels are main steps in freight demand modeling. Very little work has been done so far in India on freight demand models.

Urban logistics is concerned with the efficient transport of freights within urban areas, i.e., from production and stocking sites to shops, and then to offices and houses. Grocery and household articles which generally make up more than 80% of the total freight traffic in urban areas. These goods, organized into different supply chains depending on their characteristics and service requirements (e.g., fresh foods, frozen foods, dry foods, household articles etc.), are normally transported from different production sites to specific logistic centre, located near or within the city, where a first load rearrangement is performed, i.e., the goods are unloaded from the original vehicles and stocked. Then the goods are transported to shops within the city either by logistic agencies, each owning a fleet of vehicles to provide the delivery service, or by autonomous transporters.

The transportation agency wants minimizing the shipment industrial costs. Therefore, the main problem is finding the optimal routes to be used by the vehicles that shall provide the delivery service. This problem is dealt by Operations Research. The Public Administration wants moderating the social costs generated by freight mobility in the urban area. These are primarily connected with the impact on traffic congestion of the vehicles circulating for freight shipment, as well as of the road capacity reduction caused by the stationary vehicles for loading or unloading operations. The quantification of freight demand in terms of movements and flows of vehicles on each link of the road network due to the urban delivery of goods is essential for engineers and planners.

II. Classification of Freight Demand Models

There are a number of different ways in which freight demand models are classified.

A. *Based on Application Level*

1) Aggregate model
2) Disaggregate model

B. *Based on Modeling Principle*

1) Gravitational ($fij = dij^{-2}$)
2) Input-output (Economic activities Matrices)
3) Spatial price equilibrium (Distance/Location)

C. *Based on Geography*

1) Global Freight Transport Models
2) Intercity Freight Transport Models
3) Urban Freight Transport Models

III. Urban Freight Transport Models

The traditional method is to use four-step techniques resulting in a truck model. These models use either regression equations or trip rates to generate trucks and either a gravity model or Fratar model to distribute them. The demand generation and attraction of each supply chain is first determined for each traffic zone and then a gravitational model for distribution is applied to obtain an Origin-Destination (O-D) matrix to be assigned onto the road network taking into account access restrictions. The mode choice is usually not relevant here because it is strictly related with the considered supply chain considerably.
The modeling process has following steps:

A. *Partitioning*

The freight market is partitioned into several sectors that are internally consistent in terms of their demand and trip characteristics.

B. *Zoning*

In this step, zoning system is defined which will form the basis of the analysis of inter-regional freight movements. The zone boundaries created for person trip modeling may be adequate for freight modeling. Particularly, major freight trip generators and attractors (seaport, airport, rail terminals, major industries etc.) and concentrations of trucking depots and distribution centers should have specific zones.

C. Networks

Movements between the zones is modeled by overlaying the zoning system with a representation of the road network. However, the road used by different freight sector may be different depending upon type of freight (consumer goods, bulk goods, hazardous goods etc.), vehicle characteristic (dimensions and maneuverability) and city traffic policy.

The four step model has four basic components:

1) Trip generation
2) Trip distribution
3) Mode spit
4) Trip assignment

1) Trip Generation

This involves estimating total freight movements generated by and attracted by each zone, in terms of volume (tonnage), number of units or consignments, or vehicle trips. The standard techniques used for trip generations are:

- Historic trend extrapolation & growth factors methods
- Economic forecasts
- Regression techniques
- Trip generation rates.

2) Demand Generation

These models may be divided into commodity-based and truck-based approaches. The commodity-based models estimate the quantity of goods sold in each zone under the assumption that consumer demand in a given zone, which is strictly correlated to the number of residents, must be satisfied. This approach seems to be sound and robust, but it requires a vehicle loading model to convert the tons of goods into number of trips. But such a simplification is not acceptable for most of the goods travelling in the urban context, as observed by, since this share varies noticeably for different goods of a same category and often a single vehicle transports a bundle of goods. Because of this major weakness, many prefer truck-based models, which yield a direct estimation of the number of trips. On the other hand these models suffer transferability problems since, although the average quantities of consumed goods per inhabitant usually do not vary too much from one city to another in a same country, the organization of logistics in terms of dimensions of the shops and of the trucks may differ

3) Trip Distribution

Trip distribution involves estimating the volume of freight movement between each pair of zones, while retaining consistency with the zone totals for generation and attraction. The most common approaches to trip distribution are the aggregate techniques: gravity model and linear programming.

Gravity model's functional form is as under.

$T^kij = A^ki\ B^kj\ O^ki\ D^kj \exp(-\beta^k C^kij)$ where

k is a commodity type index;

T^kij tones of product k moved from i to j;

A^ki, B^kj are balancing factors with their usual interpretation;

O^ki , D^kj are supply and demand for product k at zone i (or j);

β^k are calibration parameters, one per product k; and

C^kij are generalized transport costs per tonne of product k between zones i and j

Here generalized cost can be given by following equation. (Omitting k for simplicity)

$Cij = fij + b1sij + b2\ \sigma sij + b3wij + b4pij$

where

fij is the out of pocket charge for using a service from i to j;

sij is door to door travel time between i and j;

σsij is the variability of time s;

wij is the waiting time or delay from request for service to actual delivery time;

pij is the probability of loss or damage to goods in transit.

The constants bn are generally proportional to the value of goods.

In Linear Programming, the total haulage costs normally in terms of money and rarely in terms of generalized costs are minimised subject to supply and demand constraints.

$$\text{Minimize } Z = \sum_{ij} \boldsymbol{T}_{\ ij} \boldsymbol{C}_{ij} ;$$

$$\text{subject to: } \sum_{i} \boldsymbol{T}_{\ ij} = Dj\ , \sum_{j} \boldsymbol{T}_{\ ij} = Oi$$

The output of the trip distribution process is the table that specifies the demand for movement of freight between each pair of zones. The table may be in units of freight volume (tonnage), number of consignments, or vehicle trips, depending on the trip generation methodology adopted for each market sectors. However it is advisable to convert the demand tables in appropriate unit like number of vehicle-trips by truck type.

4) Mode Split

For urban freight movement model, the mode split step is of less importance. In general, all freights can be assumed to be transported by road. Those commodity movements that are known to travel by another mode like barge, pipeline or railway can be extracted from set of freight flows at or prior to the demand generation step and treated separately.

5) Trip Assignment

With trip tables and network defined for each urban freight market sector, the final step is to assign the trips to the network. The algorithms used for assignment of urban freight vehicle trips are usually the same as for general transport network modeling. As freight vehicles have to move with passenger vehicles, it is desirable to have following approach.

- Load each category of freight vehicle trips (except the courier sector i.e. small packages) onto the uncongested network appropriate for that sector using all or nothing shortest path algorithm or other appropriate assignment method.
- Convert the truck trips on each network link into an equivalent number of PCU.
- Adjust the link capacity that is used for equilibrium assignments calculations by subtracting the total PCU equivalents for freight vehicles.
- Assign the courier and car trips to the adjusted network using an equilibrium assignment algorithm.

The output will be the pattern of freight (and passenger) vehicle movements in terms of the routes taken by freight vehicle and road traffic volumes by vehicle type. These results can be used to analyze congestion effects, transport efficiency, socio-environmental impacts and other transport system performance measures.

IV. Criteria for Freight Demand Modeling

Several criteria for best practice freight modeling can be identified as follows:

- An explicit linkage to economic forecasts is important.
- The study area is best placed within a global trading context.
- Capturing important dynamics is necessary within the model.
- Models are more effective when they include multimodal options.
- Commodity flows are important.
- Commodity flows converted to modal vehicle flows are more important.
- Sensitivity and the ability to evaluate policy options are keys.
- Minimizing data requirements ensures continued use.

If operational and proven to meet the needs of users, it will support decision makers.

V. Characteristics of Freight Demand Models

The main characteristics are as follows:

- An effective model is focused on producing an output that someone wants and knows how to use.
- An effective model includes the important variables that describe how the system works and represents their interactions clearly and correctly.
- An effective model operates in a way that is verifiable and understandable.
- An effective model is based on data that can be provided, so that it can be calibrated and tested.

VI. Data Needs for Freight Modelling

Data needs are generally dependent on the specific modelling techniques to be used. Nevertheless, some common data requirements can be identified in most cases. After all, high-quality data are required to effectively model any stage in the process of freight transport. The most of the data sources available nowadays have significant limitations in scope as they focus on a specific mode, commodity, or a given spatial aggregation level. Furthermore, several analyses in the freight market require "external" data sources not directly related to the freight transport task. For instance, information on route characteristics, environmental attributes and parameters, accident records, expected consequences, etc. Therefore, the combination of data sources, including demographic and socio-economic variables, and economic activity at industry sectors levels, arise as the natural approach to follow to overcome the data limitations. The data sources to be combined need common records to link and reference one and other, especially when geo-referencing is needed. The referencing process could be very expensive to achieve if the data sets were collected independently and without knowledge of the scope of their further use. On the other hand, planning ahead the attributes to be collected, the methodology to be used, and the spatial and temporal resolution, may dramatically decrease the cost of further data combination and database construction.

A. Data for Analysing Freight Transport at Global Scale Can be summarized as below.

1) Economic Activity

Most of the models have exogenous variables that measure the level of economic activity of the countries involved in the process of international transport. Thus for example, models based on the theory of international trade make use of national income, rewards on Labour and capital factors, technical coefficients of production, employment, etc.; models based on aggregate cost functions need at least production, materials and capital costs.

2) Transport Modes & Infrastructure

International freight movement is highly sensitive to the available physical infrastructure. This is especially true when two countries establish trading but different standards are found in the level of infrastructure.

3) Transport Services

In addition to the physical infrastructure, the commercial freight services already operating between two countries may play a crucial role in promoting trade through discount rates and services, especially as a result of policies to reduce trips with empty vehicles. Therefore, data on the transport rates structure and economies of scale and scope in the market under analysis are needed for modelling at the global level.

4) International Trade Conditions

Freight volumes moving from one country to another depend also on the bilateral commerce regulations, administrative procedures and efficiency of the customs and other public agencies involved in the acceptance of imported (exported) goods. Thus, the set of legal and administrative processes related to the trading conditions is essential to set the constraints in any modelling framework.

B. Data for Analysing Freight Transport at Intercity Scale can be summarized as below

1) Modal Split

At the aggregate level models typically regress the proportion of market shares (between pure modes) against some aggregate attributes such as prices, travel time and cost, etc. Therefore, at the very least, the modeler should have accurate data on modal split and some level of service attributes.

2) Fleet's Attributes & Composition

Intercity freight flows are often times analyzed as vehicles flows. This is especially true for models at disaggregate level, where mode choice has been the prevalent dependent variable. In fact, most of the behavioral models attempt to forecast the decision maker's mode choice and hence data on the vehicle characteristics are needed.

3) Network Characteristics

Intercity models are especially sensitive to the network resolution and level of service. Routing options as well as the costs at each arc have a tremendous impact on the quality of model results. The network costs structure is especially relevant when the freight flows are found as a result of an equilibrium process -usually under Wardrop's second principle.

C. Data for Analysing Freight Transport at Urban Scale can be summarized as below

1) Vehicle Fleet

Information is needed on the number, type and size of vehicles as well as their ownership pattern (e.g. for-hire operations, owner-drivers, and private operations). All this information should be obtained at disaggregate level, keeping in mind the possibility of Georeferencing and linkage with sociodemographic data.

2) Vehicle Flows

It is perhaps the most relevant information for infrastructure management. Vehicle flows are also instrumental for identification of freight activities in different locations and temporal variations of activities within a city. These types of data are nowadays widely available with a high degree of accuracy, due to the ample use of electronic counting devices. Vehicle counts are a main source of data to synthesize an origin-destination truck matrix.

3) Commodity Flows

Unlike vehicle flows, commodity flows are the direct manifestation of consumption and hence are a crucial piece of information, as far as modelling is concerned. Unfortunately, they cannot be observed from the roadside and some form of interview must be used to obtain this information. Typically, for each load being moved, origin-destination land use or industrial activity and commodity classification data should be collected, as well as load size (weight and/or volume), type of packing and handling, ownership and responsibility for transport (shipper, forwarder, carrier, etc.), and method of dispatch.

4) Major Freight Generators

This information is essential for modelling the economic impact of freight movement. There are two approaches for the analysis of freight generators. First is a metropolitan wide analysis including both freight-related data (e.g. volume and type of freight generated and its associated vehicle trips) and economic data (e.g. income, population density) to establish relationships between explanatory variables. The second approach is to focus upon specific freight generators, such as a truck terminal or airport. Useful information about such facilities includes origins and destination of truck movements and accessibility (e.g. delays, routes, etc.). Specific data may include weight by commodity by origin/destination, type of freight (general, containerized, bulk, etc.) and mode of transport to/from the facility.

5) Major Freight Corridors

For planning purposes it is necessary to identify the major corridors for the movement of goods within a metropolitan area. Freight corridors may include more than one mode (e.g. roads and rail tracks) therefore the estimated level of service offered in a corridor may exhibit significant variation and therefore it should incorporate all the modal possibilities. Identification of the corridors can be done upon the analysis of truck and commodity flows described above. Important characteristics of the corridors are commodity types being moved, vehicle types or services using them.

VII. CONCLUSION

Freight demand models differ from person trip models. They are very complex in nature due to many uncertain and temporal variables, unknown (difficult to identify) decision makers, large variety of commodity sector even after segmentation etc. In general, four step model is used for urban freight modelling with use of gravity model for trip distribution. Freight demand models are necessary as aggregate model at national level. Most of Indian metropolitan cities with mixed zoning need freight transport models along with passenger transport models for proper and effective planning because freight transport is also having major portion in total traffic.

A. Acronyms

1) DM: Decision Makers
2) FTD: Freight Transport Demand
3) LTL: Less than Truck Load
4) O-D: Origin Destination
5) PCU: Passenger Car Unit

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