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Review of Freight Demand Models

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Abstract: Movement of man and material is very important for development and survival the society. Transportation plays vital role in economic growth of any country. Transportation cost and time determines market reach of any product. By modelling and optimising freight demand and supply chain, one can manage economic growth.
Keywords: Freight, Demand, Models, Trip generation, Gravity

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.

II. IMPORTANCE OF 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. Figure1 shows conceptual framework of freight transport system.

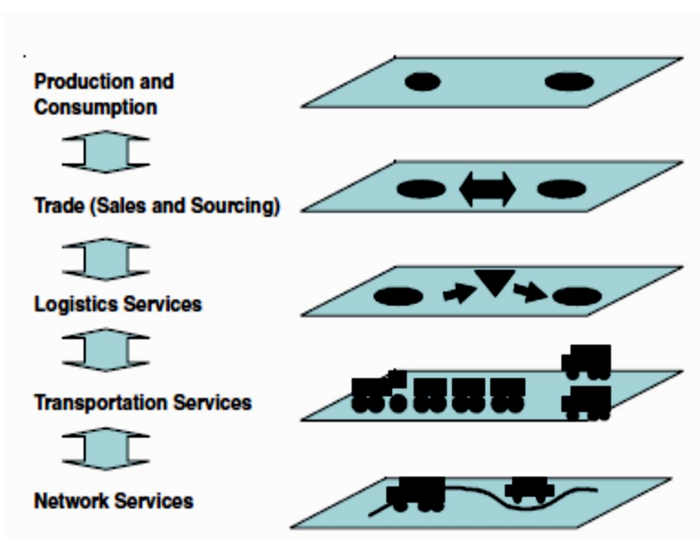

Fig. 1. Conceptual framework of Freight Transport

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.

III. MAJOR TYPES OF FREIGHT

Table-1 below shows various types of freight and relevant modes for transportation.

TABLE-1 MAJOR TYPES OF FREIGHT

Type	Example	Commodity characteristic	Relevant modes
Bulk	Coal, Oil, Gas, Ores, Minerals, Sand and Gravel, Agricultural	Cheap, Vast quantities, transport cost is a major concern	Rail unit train and multi-car shipments, Heavy truck , Barge and specialized ships, Pipeline
General Merchandise	Supermarket grocery	Higher value, Greater diversity of commodities, Many more shippers and receivers, Logistics costs are as important as transport costs	Rail general service freight car, Intermodal, Truckload , LTL (Less-than-Truckload)
Specialized Freight	Automobile Chemicals	Large volumes, relatively few customers, Specialized requirements to reduce risk of loss and damage, High value (can afford special treatment)	Specialized rail (multi-levels, tank cars, heavy duty flats) , Specialized trucks (auto carriers, tank trucks, moving vans) , Air freight
Small Package	Posts, Parcels, Coins, Gold, Ornaments, Diamonds	Very high value, Logistics costs are more important than transport costs, Deliveries to small businesses or consumers	LTL, Small packages services, Express services, Air freight

IV. FACTORS AFFECTING GOODS MOVEMENTS

A. *Location*

As freight is always derived demand and usually part of an industrial process; the location of raw material sources and other inputs to production process as well as the location of intermediate and final markets for their products determine the levels of freight movements and their origin and destinations.

B. *Range of Products*

Range of product is very high even after segmentation leading to many commodity matrices in any study of freight demand.

C. *Physical Factor*

The characteristic and nature of raw material and end products influences the way in which they can be transported: in bulk, packaged in light vans, in very secure vehicles if product is high value, in refrigerated containers if products are perishable, etc.

D. *Operational Factor*

The size of firm, its policy for distribution channels, its geographical dispersion, etc. Influence the possible use of modes.

V. COMPONENTS OF URBAN FREIGHT TRAFFIC

Urban freight traffic is made up of three distinct components: through trips, internal–external trips, and internal distribution trips. Each component is different with respect to what causes it, how it can be modeled, and what factors influence it. The relative magnitudes of these three components also vary significantly from one metropolitan area to another. Through trips are those whose origin and destination both lie outside the metropolitan area. They represent traffic that passes through the area because certain network links make up part of the shortest (or fastest, least congested, or most reliable as perceived by a driver or shipper) path between the origin and destination. Most through trips are routed on principal arterials and designated truck routes and are unlikely to be influenced by most policies implemented at the metropolitan level. Current estimates and forecasts of through trips can be developed from interregional truck flow models. Internal–external trips either originate or terminate within the metropolitan area but have their other end outside the area. While interregional truck or commodity flow models provide a useful starting point, the key to modeling internal–external trips is to identify and locate the principal origins and destinations within the metropolitan area and the commodities that they handle. Principal origins or destinations include intermodal freight terminals (airports, seaports, rail yards etc.), manufacturing sites, and truck distribution centers or warehouses. Depending on the commodity, models of internal–external trips may require local forecasts of economic growth (e.g., whether a particular industry will increase or decrease production in the area, whether there are plans to increase throughput capacity at a port) as well as the mode share of truck versus rail. As are through trips, most internal–external trips are routed on principal arterials or designated truck routes, with additional access links from the principal arterial to the specific terminal locations. Internal distribution trips represent the classic urban goods movement and consist of intraurban truck flows from distribution centers and warehouses to retail stores or directly to the consumer. Interregional truck or commodity flow models are of little or no use in determining the destinations or network paths of these trips. The origins of most internal trips are the same truck distribution centers located for internal–external trips. Destinations are located throughout the metropolitan area and are typically modeled by using some form of gravity model, where attractiveness is based on a measure of distributive capacity such as retail floor space or sales volumes. In contrast to other freight trip components, significant volumes of internal distribution trips use lower-level network links (e.g., minor arterials and collectors). Most operational urban goods models assign trips by using shortest-path routes and partitioning destinations according to the closest distribution centers. Use of more realistic tour-based models requires data and understanding of freight distribution practices that are typically not available to public-sector agencies.

VI. 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 ($f_{ij} = d_{ij}^{-2}$)
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
4) *Aggregate and Disaggregate models:* Broadly, the freight demand models are classified as being aggregate (i.e. the basic unit of observation is an aggregate share of a particular freight mode at the regional or national level) or disaggregate (i.e. the basic unit of observation is an individual decision maker's distinct choice of a particular freight mode for a given shipment). However both aggregate and disaggregate models must ultimately be derivable from individual firm behavior. Primarily the issue in the aggregate/disaggregate dichotomy is the nature of the data employed. In general, the aggregate models have tended to be either ad-hoc or based on cost minimizing behavior by firms while the disaggregate models have attempted to be more finely-tuned to the behavioral realities of freight transportation decision making. The disaggregate models are therefore more attractive than the

aggregate models from a theoretical point of view, but there are some practical drawbacks to these models, such as extensive data requirements.However, only gravitational models are applicable to the context of urban freight shipment, where the interested part is the produced trips to move the goods from the logistic centers to the commercial local units, which sell them to final consumers

5) *Input-output models:* Input-output models are typically commodity based or even monetary-based. This classical approach has two main drawbacks. The first one is intrinsic in the approximation introduced by arbitrarily aggregating the many different economic activities into a small group of categories. The second one lays in the fact that many deliveries are performed by a commercial vehicle within the same tour, so that before assigning the demand flows to the network one has to transform the pickups and deliveries into an O-D matrix of direct truck trips.
6) *Spatial price equilibrium models:* Spatial price equilibrium models are generally commodity based. Place utility of product decided its probable area of movement. Type of commodity, its quantity, specific requirement of mode, area of production and consumption are main input parameters. Here portion of transportation cost in total production and distribution cost plays key role and it decides the area within which trips are generated depending upon price affordability of particular product.
7) *Global Freight Transport Models:* The aim is to model the goods movement between different countries. This type of transport has experienced an explosive growth in the last decade due to the operations of multinational firms which operate (logistically) dispersed all over the world taking advantage of competitive prices for both materials and labour. The goods components are manufactured in different locations and hence need to be transported to a certain location to be assembled and shipped abroad again. Three main approaches are there to model global demand for shipping. The first approach follows the standard theory of international trade. The second approach relies on an aggregate cost function for a given industrial sector, from which a demand function for shipping is derived. The demand function is such that minimises the cost function. This approach allows working with an analytical expression for the demand function. This approach has two main drawbacks: the data requirement and the computational complexity of the solving process (a nonlinear multidimensional minimization). Indeed, the cost function for each sector requires an enormous amount of data, which are often private and not disclosed due to its potential strategic impact. The third approach is the use of spatial interaction models to estimate trade flows. So far, the most widely used model in this approach is the gravity model, generally used to estimate bilateral trade flows. This approach (unlike the previous two) models the vehicle movement directly (instead of modelling the demand for commodities) which makes them attractive for practical use in the medium and short run.
8) *Intercity Freight Transport Models:* Intercity freight transport models may be aggregate or disaggregate type. In aggregate models, one is the "abstract mode" model which assumes that the freight transport demand (FTD) for a mode depends on the attributes of that specific mode and the attributes of the available "best mode". Second model is "aggregate logit" modal split model which is a log-linear regression model whose dependent variable is the ratio between the market shares of two modes. This model's structure is very simple and not computationally demanding, making it attractive in practical applications, especially for large-scale problems In disaggregate models; there are "behavioural" and "inventory" models. Behavioural models focus on the mode choice decision made by either the consignee or the shipping firm, whereas inventory models analyse the FTD from the viewpoint of an inventory manager. The behavioural models attempt to explain the FTD as the result of a process of utility maximisation made by the decision-maker (DM). The data needs are the components of the level of service offered by the different modes, such as rates, travel time, flexibility of the service, reliability, insurance costs, etc. In addition, the “choice set” of each DM must be known to the modeller. One of the drawbacks of this approach (from the data viewpoint) is that the DM must be identified before the data are gathered. Inventory based models attempt to integrate the mode choice and the production decisions made by a firm. These type of disaggregate models can take the simultaneity of the decisions into consideration
9) *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
10) *Partitioning*: The freight market is partitioned into several sectors that are internally consistent in terms of their demand and trip characteristics.

11) *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.
12) *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.

VII. FOUR STEP MODEL

The four step model has four basic components

A. 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:

1) Historic trend extrapolation and growth factors methods
2) Economic forecasts
3) Regression techniques
4) Trip generation rates.

B. 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

C. 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.

$$T^k_{ij} = A^k_i B^k_j O^k_i D^k_j \exp(-\beta^k C^k_{ij})$$

where

k is a commodity type index;

T^k_{ij} tones of product k moved from i to j;

A^k_i, B^k_j are balancing factors with their usual interpretation;

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

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

C^k_{ij} 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)

$$C_{ij} = f_{ij} + b_1 s_{ij} + b_2\, \sigma s_{ij} + b_3 w_{ij} + b_4 p_{ij}$$

Where

f_{ij} is the out of pocket charge for using a service from i to j;

s_{ij} is door to door travel time between i and j;

σs_{ij} is the variability of time s;

w_{ij} is the waiting time or delay from request for service to actual delivery time;

p_{ij} is the probability of loss or damage to goods in transit.

The constants b_n 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 emand constraints.

$$\text{Minimize } Z = \sum_{ij} \boldsymbol{T}_{ij} \boldsymbol{C}_{ij} \text{ ; subject to: } \sum_i \boldsymbol{T}_{ij} = D_j ,\ \sum_j \boldsymbol{T}_{ij} = O_i$$

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.

D. 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.

E. 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.

1) 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.
2) Convert the truck trips on each network link into an equivalent number of PCU.
3) Adjust the link capacity that is used for equilibrium assignments calculations by subtracting the total PCU equivalents for freight vehicles.
4) 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.

VIII. CONCLUSION

Freight demand models are quite different 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. Very little work has been done in this area may be due to less attention and importance by administrating authorities. Normally, typical four step model is used for urban freight modelling with use of gravity model for trip distribution.

A. Acronyms

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

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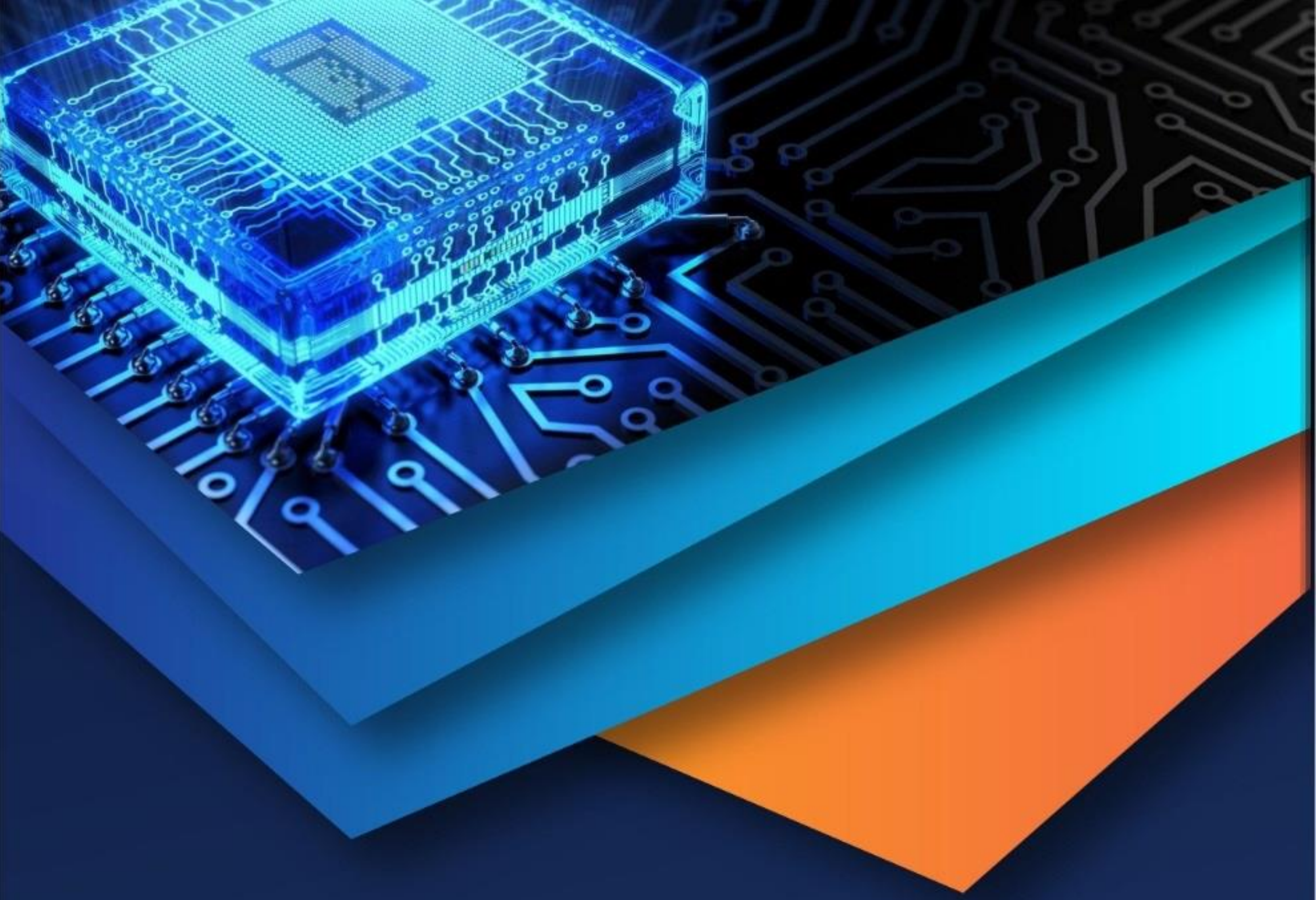

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