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Understanding Trip Length Distribution for Freight Transportation Planning

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Abstract—*Freight transportation planning is important for overall transportation planning process at urban, regional, and national level. However, much attention has not been paid from researchers towards understanding the movement of freight unlike passenger transportation. In developing economies like India, studies on freight transportation are scarce. The present study focuses on understanding the freight movements at national level from (to) a medium sized city in Kerala, India. Standard statistical analysis has been carried out to understand the movements in terms of size of shipment, vehicle kilometers traveled by the shipment, etc. The freight movements are analyzed in terms of production and attraction. It is hoped that this study will help in analyzing the trip length distribution of freight movements from (to) Kerala to several other cities in India.*

1. INTRODUCTION

Transportation has a very important role in day to day life. Development in all sectors of the society is influenced by transportation. Vehicles have revolutionized social life, but at the same time, increase in number of vehicles resulted into many traffic problems like congestions, accidents, pollution, etc. Only a well-planned transportation system can reduce these problems. It may be noted in this context that freight movements have significant impacts on transportation systems, regional welfare, and economic growth of a country. The economy of a country depends on the sales of goods and services. So the production of goods is the most important factor in the economic growth. Additionally, the movement of goods are vital for meeting the user demand as production and consumption does not take place at the same place. Therefore, it is worthwhile to understand the trip length patterns of freight (total or commodity wise) movements between several pair of origins and destinations. However, studies related to freight movements are comparatively less than the studies focusing on passenger transportations. This is probably due to the huge cost involved in collection of freight data such as commodity type, commodity value, annual volume in tonnage, shipment length, mode used, origin and destination of the freight movement, etc. In India, research related to freight activities has not received significant attention from researchers except some recent studies [5] [8] [12]. In this paper, an attempt has been made to understand the pattern of trip length of freight movement from (to) a medium sized city (i.e., Calicut) to (from) several cities in India.

2. NEED OF TRIP LENGTH DISTRIBUTION

Transportation modeling process involves demand models as well as network models. Demand models are used to forecast for a horizon year and network models are used to analyse the supply. One of the major limitation in the existing transportation planning scenario is that it is devoid of serious consideration to freight. Passenger transportation had always been the prime focus which in turn lead to a lacking effort in research and development of freight transportation. Freight movement is an important contributor to the collective welfare of any economy. However, in spite of this relevance, functioning of such a system is still poorly understood. Simplistic approaches with the assumption that freight trips follow the same behavioural mechanisms as passenger trips is pointed out to have methodological flaws [7]. Presence of multiple decision makers and multiple dimensions (volume, weight, frequency of trips) exacerbate the issue regarding modelling freight. Significant deviations in opportunity costs or time value of freight compared to passengers are another notable difference [2].

There can be different modelling approaches namely (a) four step models (b) Direct demand models, and (c) input-output models. Out of these different approaches, the traditional four step models attempt to explain the fundamental mechanism of freight transportation rather than dwelling upon the origin destination matrices of cordon counts. [2] Sequential transportation planning is successful in interpreting the rationale behind the cause of movements. Since various dimensions are attributed to freight traffic (volume, weight, number of trips), several modelling platforms can be developed based on the requisite. Out of these, commodity based platform and trip based platform are particularly noteworthy.

Commodity based models focus on the amount of freight measured in tons on the firm ground of belief that the fundamental economic mechanisms driving the freight movements essentially derive from the attributes of the commodities getting transported [14]. But, since the commodity based models focus on the actual quantity of cargoes being transported, it would be impossible to attribute the empty trips to the model. This can be a major disadvantage since the empty trips would essentially get excluded in this model which can be sizeable in nature. Another drawback of commodity based models are the requirement of commodity flow logistic information which can only be obtained as a part of elaborate questionnaire surveys.

Trip based models focus invariably on the number of vehicle trips rather than the quantity of commodity getting transported in that vehicle. One obvious disadvantage of this methodology is that the mode of transport of the commodity is prefixed and these models would not be having the modal split stage of four step modelling process. This is a huge constraint when multiple modes are present in the freight transportation scenario. But, the easily foreseeable advantage of this method is the easy availability of traffic data pertaining various study zones. And, since the advent of intelligent transportation systems and its application packages, tracking the movement of vehicles has become devoid of any hassle.

The purpose of the research reported herein was to develop an understanding of the trip length frequency distribution (TLFD) for freight movements.The need of trip length distribution is notably conspicuous in the trip distribution stage of four step modelling process. Trip distribution analysis involves with developing a procedure that synthesizes the trip linkages between various traffic zones. The rationale of this process lies in the idea that all trip attracting zones are in competition with each other to attract the trips produced by a particular zone. In spite of the obvious effect of inherent attractiveness of a particular zone, other intervening factors like spatial separation affect the choice of a certain destination zone. Such spatial separation can be explained in terms of distance between the zones, travel time, cost of journey, comfort, safety etc. This intervening difficulty of travel is denoted by impedance factor in trip distribution modelling terminology. Trip length distribution can be used as a surrogate measure for impedance factor and is essential for calibration as well as checking the correctness of calibration of spatial interaction models. An acceptable degree of closeness between observed actual trip length distribution and spatial interaction model generated trip length distribution is necessary for checking the correctness of calibrated model.

3. LITERATURE REVIEW

Demand for freight is considered a derived demand rather than a primary demand since the need for such a movement arise to serve an economic purpose. In other words, the demand for freight stems from the economic requirement to move goods from a production site to a market or between various intermediaries. One of the pertinent points worth consideration regarding the freight transportation is the externalities as well as its contribution to economy. Externalities can be denoted as the additional cost to the people not involving the transaction. Pollution is one pressing concern which can be deemed as the externality of truck traffic [1]. It is important to note that freight is carried by vehicles that move on the same roads used by the private and public vehicles transporting people. These vehicles make a significant contribution to congestion and environmental nuisances, such as emissions, noise, and so on, that impact adversely on the quality of life in urban centers, even though they provide essential life lines for commercial activity. On the same hand, the economic importance of freight transportation goes without saying also. Efficient freight transportation planning is imperative for the supply chain logistics which ultimately contribute to a growing economy like India and this demands increased research efforts.

In commodity distribution approaches, the gravity model is commonly used. Especially, Ogden (1978) made use of commodity trip data by applying gravity model in Melbourne, Australia to distribute commodities among zones [9]. One of the major challenge in developing an urban freight demand model is the discrepancy between the basic unit (ton) and trip. Bowyer (1991) approached to unify the commodity based-model and truck trip-based model for one [1]. Jose Holguin-Veras et al. (2000) attempted presenting a certain logical theory to gain a relationship by putting commodity based-model and truck trip-based model into Guatemala case. Namely, in his theory, if he is able to produce a suitable relationship between two different models by using TLD, he could be also able to presume the distribution of trucks and commodity.Freight planning models can be classified into commodity-based models and trip based models [2]. The commodity-based model estimates the freight tonnage production and attraction at each zone, and estimates the tonnage flow between origin-destination pairs. Usually, the commodity is classified and aggregated according to cargo that is similar in nature and transport properties. It is commonly believed that commodity-based models best reflect the economic factors affecting freight flows [1]. Trip-based (vehicle-based) models focus on vehicle traffic. The vehicle trips are generated, distributed, and assigned to the highway network. Traffic count data are used to verify the model. Trip-based models focus on vehicle trips, not commodity flow, and so may fail to recognize the cargo types and economic effects on the freight flow. Usually commodity flow can approximately be converted to vehicle trips [4]. No matter at which level the model is applied, a state wide freight-planning network usually includes these flows [5].

1. Internal - Internal: Both origin and destination zones are within the state area.
2. External - Internal or Internal - External: Either the origin or the destination is outside the state area.

3. External-External: Both origin and destination are outside the state area.

Understanding the nature of trip length distributions for each category of aforementioned movements will aid for effective planning process for freight transportation. Gravity Model is widely adopted in state wide freight trip distribution [5]. And, it should be particularly noted that gravity models are calibrated by comparing the trip length distribution and average trip length to the observed values [6]. It was found that the shape of the trip length distribution (TLD) curve is relatively smooth and unimodal in urban and suburban freight movements. But freight movements in the intercity level lead to irregular and multimodal TLDs [4].

4. IMPORTANCE OF TRIP LENGTH DISTRIBUTION

The purpose of trip distribution is to produce a trip table of the estimated number of trips from each TAZ to every other TAZ within the study area. The Gravity Model assumes that the number of trips between two zones is 1) directly proportional to the trips produced and attracted to both zones, and 2) inversely proportional to the travel time between the zones.

$$T_{ij} = P_i \frac{A_j * F_{ij} * K_{ij}}{\sum_j A_j * F_{ij} * K_{ij}}$$

T_{ij} = No. of trips produced in zone I and attracted to zone j

P_i = Total no. of trips produced in zone I

A_j = Number of trips attracted to zone j

F_{ij} = Friction factor (Represents the spatial separation between the two zones of consideration)

K_{ij} = Socio-economic adjustment factor.

Friction factors express the effect that travel time or trip length has on the number of trips traveling between two zones. Trips can be further divided into many depending upon the type of commodity in the case of freight traffic or purpose in the case of passenger traffic. Trip distribution essentially involves with the synthesis of the trip interchanges between traffic zones [15]. The rationale for the trip distribution is based on the fact that all trip attracting zones "j" in the region are in competition with each other to attract trips produced by zone "i". And, the intervening factor other than the intrinsic attractiveness of the zones are defined by impedance factor (W_{ij}). Impedance basically denotes a weighted sum of trip length between the zones, various types of times (walking, waiting, riding) and types of cost (fares, operating cost, tolls, parking cost). But, since trip distribution phase often culminates after assigning modal split to the trip ends of a zone, factors of cost, comfort and safety remains constant. In such cases, impedance is defined through friction factors which are functions of travel time or trip length. Though travel time is deemed as a better suited variable for denoting travel resistance of urban travelers, obtaining accurate travel time data between zones is a challenge. In inter-city travel, trip length is often considered as a surrogate measure for friction factor since it can be assumed to be a reflection of travel time.

Calibration of gravity model involves with estimating the parameters of the trip distribution model such that the model fits the observed data. It can be essentially summed up as the process of fixing the parameters of the gravity model so that the base year travel pattern is well represented by the model. Process of calibrating a gravity model depends on the assumed mathematical function of friction factor (F_{ij}).And, friction factor (F_{ij}) is expressed as a function of trip length. Popular functions adopted are polynomial functions, negative exponential functions, two-parameter functions, discontinuous functions for each segment of trip length etc. In fact, such a function for friction factor depends on the actual travel pattern pertaining the study area based on the existence of travel networks. The most widely used technique for calibrating the form of the gravity model is that developed by Bureau of Public Roads. The Bureau of Public Roads calibration procedure is directed toward the development of a travel time factor function, which is assumed to be an area wide polynomial function or subsequent discontinuous functions of inter-zonal trip lengths.

If the trip length frequency distribution produced by the gravity model does not meet these criteria, then a new set of travel factors may be estimated from the following expression:

$$F_{ij}^{*} = F_{ij} * \frac{OD\%}{GM\%}$$

Where, F_{ij}^{*} = the travel time factor for a given travel time to be used in next iteration.

F_{ij} = the travel factor used in the calibration just completed. OD% = the percentage of total trips occurring for a given travel time observed in the travel survey.

GM% = the percentage of total trips occurring for a given travel time observed in the simulated by the gravity model.

The procedure is repeated until the calculated and observed trip length frequency distribution curves match with each other. It is suggested that the gravity model simulated and observed trip-length –frequency distributions should exhibit the following two characteristics:

1. The shape and position of both curves should be relatively close to one another when compared visually.
2. The differences between the average trip lengths should be within ± 3 percent.

Essentially, trip length distributions aid the transportation planners acting as a surrogate measure for friction factor of spatial deterrence. The initial estimate of the trip interchanges is used to obtain the estimated trip length frequency distribution for each trip purpose and mode. A comparison of the observed and estimated trip length frequency distributions

are to be made and successive iterations are to be carried out as mentioned before until a close agreement occurs between both TLFDs. Since the accuracy of the calibrated gravity model decides the accuracy of the trip interchange synthesized between the zones, a detailed study on trip length distributions are warranted. Particularly in the context of freight transportation, where several factors influence the travel itinerary of goods. A supply network of freight not only consists of nodes and links but also of terminal nodes like freight hubs, logistic centers, shunting yards, warehouses with specific characteristics concerning capacity and transfer delay time. For these reasons, a separate modeling approach and hence separate study on friction factors to explain the travel deterrence is required for freight studies. The complex interaction between the actors is one reason for the complexity in freight studies. Another important reason is the numbers of decision units in freight transport are significantly smaller. In such a context, a detailed study on trip length distribution to explain the area-wide effect of spatial separation on trip interchange between the zones is highly relevant.

5. STUDY AREA

Calicut, is a city in the state of Kerala in southern India on the Malabar Coast. It is the third largest city in Kerala and is part of the second largest urban agglomeration in Kerala with a metropolitan population of 2,030,519 as per 2011 census. The city lies about 380 kilometers north of the state capital Thiruvananthapuram. It is unarguably one of the main commercial cities of Kerala. The economy is mainly business oriented. The city currently is the major trade hub of North Kerala with good connectivity through road, rail and air. It also has large timber yards along the banks of the Kallayi River. It is widely known for the export of spices, fish products and handloom. Similarly, Calicut acts as a major hub for the freight transport in the northern and the central part of the Kerala. Beypore port which is situated approximately 10 km south of Calicut is the second biggest port in Kerala and it handles around 100,000 tonnes of cargo per year. Existence of such a port which acts as a major channel for freight traffic to Lakshadweep as well as Sri Lanka clearly indicates the importance of Calicut as a commercial hub. Since it is well connected through rail, road as well as sea, major chunk of freight generated towards Kerala essentially passes through Calicut. Imports of marble, granite, minerals, stones, ores, chemicals, food grains from other parts of India is conspicuously prominent in Kerala as a consumer state. Similarly, rubber, spices, timber, packaged food products are exported in large quantities from Calicut to other states as well as abroad.

6. STUDY DATA

The data used in this paper were part of an extensive commodity flow origin-destination survey conducted as a part of a research effort involving freight demand modelling pertaining to the area. A convenience sampling survey was conducted for the data collection because of the relative advantage of time and money inherent in this method of sampling [11] [13]. The items for the sample are selected deliberately by the project team; our choice concerning the items remains supreme. The shippers chosen for the survey are selected on the basis that the small mass that we so selected out of a huge one will be typical or representative of the whole. A questionnaire was prepared including questions that reveal the preference of the shipper in mode selection. 184 shippers were interviewed and 1370 data points were collected. Area wide O-D survey was later extended out to 9 districts of Kerala including northern and central part of the state. Numerous shippers linked with several typed of commodities were interviewed for deriving a lucid picture about the movement freight flow from (to) Kerala. Origin-destination questionnaire included questions about origin, destination, vehicle type, commodity type, shipment details, value of shipment, tonnage, reasons for selecting the mode.

7. DESCRIPTIVE ANALYSIS

To get a segregated commodity-wise understanding of the freight movement in an across Kerala, Commodities were classified based on the NIC (National industries classification) code developed in 2004. Commodity details collected from the establishments were judiciously grouped into 8 categories based on their nature and establishment type. Respective classifications are given below.

Notation	Commodity Classification
C1	Electrical Appliances and Fittings
C2	Alloys and metals & Vessels
C3	Construction Requirements
C4	Food grains, flours and pulses
C6	Oil, Minerals, Chemicals & Mining
C6	Fruits, Vegetables and packaged food items
C7	Light Industry
C8	Miscellaneous Items

It was seen from the analysis that 456 tonnes of freight was getting generated from the aforementioned study area on a daily basis. The study area was found to have an incoming freight movement of 907 tonnes at the same time.

In the case of goods generated from the establishments located in the study area, revealing trends can be seen in Fig. 1. Construction requirements and fruits and vegetables constitute most of the goods generated from Calicut. Presence of large quantity of perishable commodities underline the need for planning towards a better transportation system with reduced travel time and congestion.

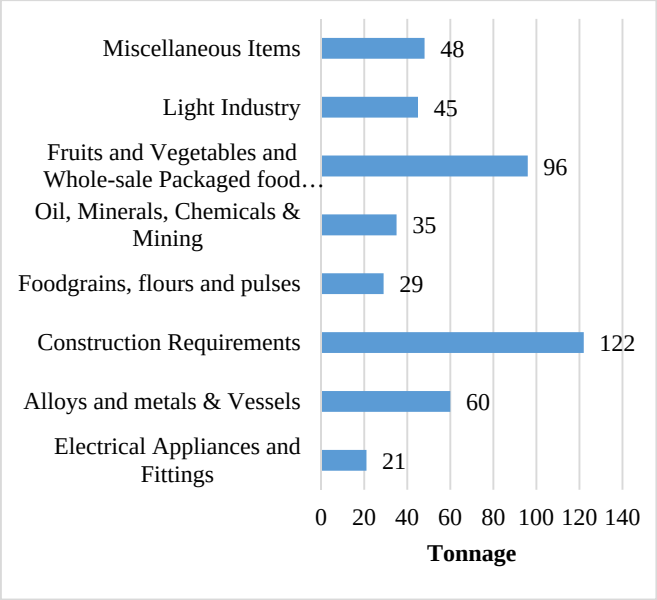

Fig. 1: Daily freight tonnage generated from Calicut

It can be seen that the majority of the freight movements towards Calicut are characterized by perishable commodities such as Fruits, vegetables and packaged foods [Fig. 2]. The presence of flourishing construction activity is noticeable in the large amount of construction requirements getting transported to the study area. Since the study area is a commercial hub in the northern region of Kerala, it is characterized with movement of food grains, flours and packaged food products as well.

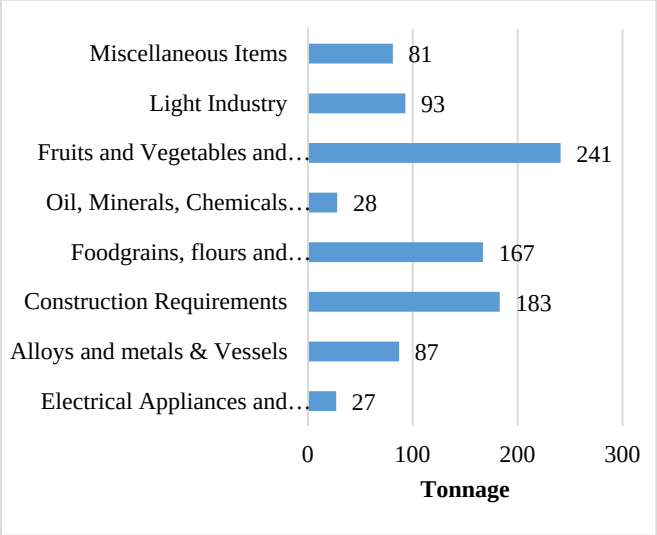

Fig. 2: Daily freight tonnage attracted towards Calicut

Descriptive analysis showed that the average trip length of the freight interchanges stemming from Calicut is 87.32 Km and for those interchanges attracted towards Calicut is having an average trip length of 102.05 Km. Various statistical measures related to trip length and tonnage are given in table 1. The Standard Deviation is a measure of how spread out numbers are. Presence of large standard deviation value essentially indicates the presence of shorter trips as well as the longer trips in the collected data. Since various types of commodities and establishments are included in the survey, aforementioned standard deviation is expected.

Table 1: Statistical measures related to freight movement

Statistical Measures	Calicut Production		Calicut Attraction	
	Length (km)	Tonnage (t)	Length (km)	Tonnage (t)
Mean	87.32	5.24	102.05	5.68
Std. Dev.	51.63	4.70	70.45	5.82
Median	86.00	2.25	86	2
Trimmed	80.82	4.70	93.66	4.77
MAD	53.37	1.85	53.37	1.48
Min	10.80	0.05	10.80	0.05
Max	324.0	19.9	504	22
Range	313.20	19.85	493.20	21.95
Skew	1.57	0.86	1.98	0.96
Kurtosis	3.65	0.13	6.34	0.23
Std. Error	4.67	0.43	4.53	0.37

Another measure of central tendency median was also calculated. Trimmed mean of trip length was found out to be 80.82 km for freight attracted towards Calicut and as 93.66 km since it is a more refined measure of central tendency by removing a small percentage of the largest and smallest values before calculating the mean. Other statistical measure of variations as mean absolute deviation (MAD) is given in the table. Descriptive details of the data collected including minimum, maximum and range are also included in the table.

Skewness is a measure of symmetry, or more precisely, the lack of symmetry. It can be seen that the distribution of trip length as well as tonnage is positively skewed which indicates that the "tail" of the distribution is more stretched on the side above the mean. Kurtosis is a measure of flatness of the distribution. Heavier tailed distributions have larger kurtosis measures. Kurtosis values of both distributions are exhibited in the table.

Characteristics of freight movements will vary based on the weight of the commodity getting transported. Therefore the entire data set was divided into two on the basis of commodity tonnage and the respective trip length distributions were compared using standard descriptive statistical measures. The results of aforementioned comparison is given in table 2.

Table 2: Trip Length Distributions based on commodity tonnage segmentation

Statistical Measures	Calicut Production		Calicut Attraction	
	0 – 9.9 tonne	10-19.9 tonne	0 – 9.9 tonne	10-19.9 tonne

Mean	86.73	89.04	95.77	143.2
Std. Dev.	52.89	48.56	70.34	56.65
Median	86	91	86	170
Trimmed	79.67	85.05	84.89	150.10
MAD	53.37	45.96	53.37	19.27
Min	14.00	10.8	14.00	10.8
Max	324	215	504	215
Range	210	204.2	490	204.2
Skew	1.76	0.75	2.44	-1.05
Kurtosis	4.35	0.29	8.45	0.16
Std. Error	5.54	8.72	4.85	10.0

It can be seen that heavier shipments (10-19.9 tonne) are coming to Calicut from longer distances compared to lighter shipments which can be attributed to the increase in value associated with the commodity. But, the freight generation from Calicut is associated with a certain mean trip length less than 90 km regardless of the commodity tonnage. Presence of fewer manufacturing establishments in the study area can be cited as a reason for the aforementione behaviour. Longest distance from which freight movement can be observed towards calicut can be seen as 504 km from the table and smallest movement is observed as 14 km.

8. CLOSING REMARKS

The purpose of this study is to understand the freight movements at national level from (to) a medium sized city in Kerala, India. Standard statistical analysis has been carried out to understand the movements in terms of size of shipment, vehicle kilometers traveled by the shipment, etc. It is worthwhile to note that the spatial separation between origins and destinations can be explained in terms of distance between the zones. This intervening difficulty of travel is denoted by impedance factor in trip distribution modelling terminology. Trip length distribution can be used as a surrogate measure for this impedance factor and is essential for calibration as well as validation spatial interaction models. An effort has been made to understand the trip length associated with freight movements from (to) Calicut, a medium sized city in India. Such an understanding of the nature of trip length distributions will aid for effective freight transportation planning process.

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