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Development of urban freight travel demand model

Madhu Errampalli[a,] *, Ravinder Kayitha[a], Ravi Sekhar Chalumuri[a], Loriant A. Tavasszy[b], Jeroen Borst[c], Satish Chandra[d]

[a] *Principal Scientist, Transportation Planning and Environment (TPE) Division, CSIR-Central Road Research Institute (CRRI), New Delhi 110025, India*

[b] *Professor, Civil Engineering and Geosciences , Delft University of Technolgy (TU-Delft), Stevinweg 1,2628 CN, Delft, The Netherlands*

[c] *Senior Consultant Smart Cities,TNO, 2509 JE, The Hague, The Netherlands*

[d] *Director, CSIR-Central Road Research Institute (CRRI), New Delhi 110025, India*

Abstract

India spends 15-20% of its GDP on transport and logistics and Indian freight transport market is expected to grow at a CAGR of about 13% by 2020. Road freight constitutes around 63% of total freight movement and the average speed of trucks on Indian roads is about 20 km/hr covers only 250-300 km a day compared to 700-800 km in developed countries. Moreover, the total trip expenses increases about 15% due to the delays at check-posts by Transport Department and Traffic Police, Toll Plazas etc. The working conditions of truck drivers also deteriorate as they work for long hours, resulting in high stress and fatigue leading to accidents. The need is recognized for collaboration amongst stakeholders to identify optimal freight policies and pursue a rapid deployment of improvements. In this direction, creating better data and models are needed to enable planners to better predict freight movement and design better informed policies. In the present study, the freight travel demand model has been developed by collecting urban freight characteristics exhaustively including zonal based socioeconomic and land-use data from the city of Delhi. A traditional four-stage freight demand model has been developed considering freight trip generation, freight trip attraction, freight trip modal spilt and freight trips assignment. From the developed model, the total freight trips have been estimated for the year 2017 and 2021. The developed freight travel demand model would be highly useful to evaluate appropriate freight related transport policies for their effective implementation on the urban road network.

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Keywords: Urban Freight; Delhi City; Freight Travel Demand Model; Trip Generation; Trip Distribution; Modal Split; External Travel;

* Corresponding author. +91-11-26312268; fax: +91-11-26845943.
E-mail address: errampalli.madhu@gmail.com, madhu.crri@nic.in

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1. Introduction

1.1. Freight Transport in India

Transport is a key element in the infrastructure of a nation as it provides services essential for promoting economic and social development and plays a significant role in influencing the pattern of distribution of economic activities and improving productivity. India spends 15 to 20% of its GDP on transport and logistics compared to an average 8 to 10% in other developing countries. Indian freight transport market is expected to grow at a Compound Annual Growth Rate (CAGR) of about 13% by 2020. In India, road freight constitutes around 63% of the total freight movement consisting of 2.2 million heavy duty trucks and 0.6 million light duty trucks covering more than 18,00,000 km of road length carrying more than 3000 MMT (million metric ton) of load annually. Owing to poor road conditions and check-post delays, trucks in India travel for 20 days a month with an average speed of about 20 km/ hour covering only 250-300 km a day compared to 700-800 km in developed countries such as the US and Europe (TCI and IIM, 2016). The delays due to check-posts, on-road filling forms, collecting highway toll and taxes etc. could range from 5 to 25% of total journey time and total trip expenses increases about 15% due to these delays. The working conditions for the truck drivers also deteriorating and they work for long hours, resulting in high stress and fatigue, which leads to accidents.

Further, urban freight transport also involves lot of challenges such as traffic restrictions on roads and timings, physical checking of freight vehicles by police, absence of loading and unloading infrastructure facilities, poor circulation plans around freight terminals, market places, commercial centres etc. These would contribute to increased delays and increased transport cost and also increasing congestion, road crashes and environment pollution on already over burdened road network in urban areas. There is increasing recognition in India that absence of appropriate transport infrastructure could become a serious bottleneck for future economic growth which has to be dealt in coordination with all respective agencies. The need is recognized for collaboration amongst stakeholders to identify optimal policies and pursue a rapid deployment of improvements especially in the area of urban freight.

1.2. Delhi City as Study Area

The present study considers Delhi urban road network as object of study. As per the Census of India (Census, 2011), Delhi has 16.75 million population which recorded a decennial population growth of about 20%. The increase in urbanization leads to growth of vehicular population in urban areas and this scenario accelerates various traffic problems such as congestion, air pollution, and reduction in safety. There is significant momentum in government to take the city logistics system as sustainable development priority. Recent verdict by National Green Tribunal (NGT) of India on banning 10 years old trucks to enter into the city of Delhi in view of high pollution emission by these vehicles. In order to study and understand these issues, new policies are needed and innovation needs to be promoted. The roads of Delhi have number of time restrictions for goods vehicles and there is 24 hours ban for some roads. The restriction is from 7:00 AM to 11:00 AM and 5:00 PM to 11:00 PM for most of the roads in Delhi.

1.3. Need for the Present Study

Delhi is known as one of the most air polluted cities in the world as the air quality index (AQI) of most areas is above 150 (Delhi Air Pollution: Real-time AQI, 2017). AQI from 0 to 100 is in range of good to moderate. AQI more than 150 is considered unhealthy (Air Now, 2017). Emission from motor vehicles is one of the major reasons for poor quality in Delhi. The traffic congestion on Delhi road is as intimidating as the polluted air. It was also revealed from the past studies that about 100,000 freight vehicles crossed 10 count stations at the borders of Delhi in a day (CRRI, 2009). Clearly, freight transportation has its fair share in pollution and congestion of Delhi. The average share of freight transportation vehicles in Delhi is relatively low in overall situation. However, due to time window restrictions by local authorities, the share of freight vehicles varies during different time of the day/night. For instance, certain types of freight activities (e.g. furniture delivery, milk van, etc.) are allowed between 8:00 AM and 4:00 PM. During that time the share of freight vehicle increases to 15-20%. In the night after 12:00 AM, all freight vehicles are allowed in the city resulting in majority of freight vehicles on Delhi road network. LCVs, trucks

and auto rickshaws form backbone of urban goods movement in Delhi for longer distances. For short distances, non-motorised vehicles (e.g. animal cart, hand cart, head load, cycle rickshaw) are extensively used, especially in highly congested parts of the Delhi (Gupta, 2017). Another interesting fact is that with online shopping spree companies are using Motorized Two Wheeler (TW) trips, used as a way to navigate the high density and congestion of Delhi (Nilanjena, et. al., 2016).

Understanding and forecasting freight movements is critical to plan for future transportation in terms of capacity augmentation, operation, preservation, safety and security, energy and economy investment needs. Many demand forecasting models and data sources are more appropriate for passenger transportation than for forecasting freight movements and understanding freight travel behaviour. Creating better data and models is needed to enable planners to better predict freight movement and design better informed policies. In view of this, the objectives of the present study have been conceptualised and are presented in the next section.

1.4. Objective and Scope of the Study

The main objective of the present study is to develop urban freight travel demand model. The traditional four-stage travel demand modelling has Trip Generation, Modal-Split, Trip Distribution and Traffic Assignment. The scope of this paper is only freight trip generation, freight trip distribution and freight modal split models and freight traffic assignment has been considered as beyond the scope of this paper. The city of Delhi i.e. National Capital Territory of Delhi (NCTD), India has been selected as study area for this study. The geographical area coverage and the road network for the study area of NCTD have been shown in the Fig. 1. For this purpose, an extensive pilot study consists of different field surveys, has been carried out for the city of New Delhi. Accordingly, forecasting of the total freight trips of Delhi city are proposed from this study.

1.5. Organisation of the Paper

As there has been very limited research carried out in India related freight transport in urban areas, the present study which focuses on such issues becomes more relevant. Accordingly, the transport scenario of India and Delhi city has been discussed in Section 1. In this section, the need for the present study on freight traffic and estimation of freight travel characteristics along with the details of the objectives and scope of the present study are given. The data collection by carrying out various field surveys is discussed in Section 2. The estimation of results in terms of freight traffic characteristics at outer cordons and within the city are given in Section 3. The development of four-stage freight travel demand model of Delhi is discussed in Section 4. In Section 5, the total estimated freight trips and network level freight estimations in terms of vehicle kilometers travelled (VKT) for future years are discussed. Finally, Section 6 discusses the conclusions emerged out of this study.

2. Data Collection on Logistic Metrics

2.1. General

As mentioned in the previous sections, the main objective of the study is to develop logistics metrics for city of Delhi. In that direction, the first and foremost task is to collect the necessary data and a database needed to be created by collecting freight travel behaviour data, road network, economic data etc. For this purpose, a number of traffic surveys have been proposed to be carried out. The details of the field studies carried out in the present study are explained in detail in the following section.

2.2. List of Field Surveys

Keeping the objective of the study in view, the following traffic surveys have been undertaken in the present study:

1. *Outer Cordon Traffic Survey:* This is to estimate the quantum of traffic entering or exiting city of Delhi and the share of freight traffic

2. *Outer Cordon Questionnaire Survey:* This is to collect the travel behaviour of freight traffic entering or exiting city of Delhi so as to estimate origin-destination (OD) trip pattern
3. *Focal Point Survey at Commercial Areas/ Market Places:* This survey is to collect the travel behaviour of freight traffic plying within Delhi so as to estimate OD trip pattern
4. *Mid Block Traffic Survey:* This survey is to estimate the quantum of traffic and share of freight traffic on the road network of Delhi

The details of the above surveys and data collected have been described in the following sections.

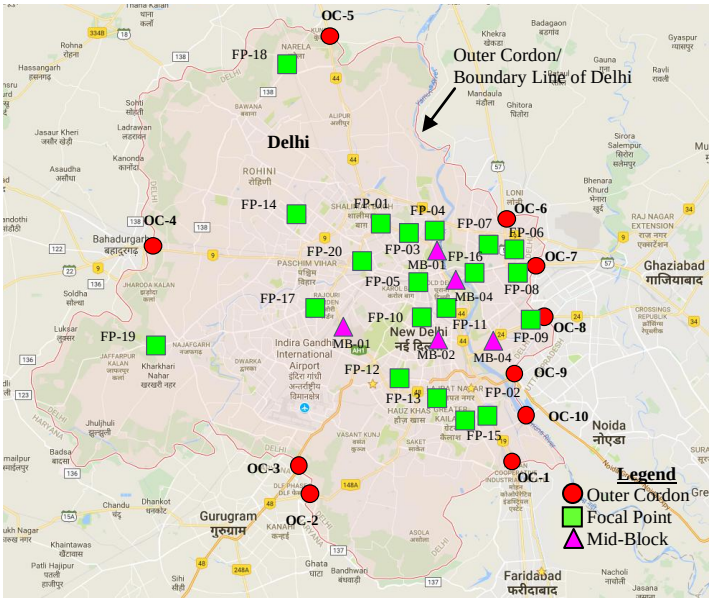


Fig. 1. Selected Study Area of National Capital Territory of Delhi (NCTD) and Survey Locations (Source: Google Maps).

2.3. Outer Cordon (OC) Traffic Volume Survey

The significant amount of freight traffic enters and leaves daily city of Delhi from different parts of the country, this traffic can be captured at the outer cordon locations. In the city of Delhi, there are more than 100 entry and exit locations from which the freight traffic can enter and exit from the adjoining states namely Utter Pradesh and Haryana. However, about 95% of the freight traffic enters/ exits through 10 major outer cordon/ entry-exit locations and accordingly these locations have been selected for data collection purpose. The geographic locations of these are shown in Fig. 1. The details of these locations have been given in Table 1.

To collect the freight traffic volume data that are entering into or exiting from city, manual method of enumeration has been adopted in this study. The enumerators have been given sufficient training and deployed in the field to perform manual count of all the vehicles types which are entering and exiting the outer cordon location. The survey has been carried out for 24 hour duration starting from 8:00 AM to 8:00 AM. The enumeration of the traffic has been done in every 15-minute and accordingly recorded in predesigned proforma. The traffic volume enumeration of vehicles has been done for all the vehicle types in order to understand the share of freight traffic in that. The vehicle types mainly considered include all private vehicles, public transport, intermediate public transport, freight vehicles and non-motorised transport vehicles. However, the vehicles types considered for Freight Transport are described in Fig. 2.

2.4. Outer Cordon Freight Traffic Interview Survey

Apart from the classified traffic volume count that has been conducted at these 10 outer cordon locations, interview survey also carried out to collect the travel behaviour of the freight vehicles that are entering and exiting Delhi through these locations. The survey has been carried out using predesigned questionnaire (given in *Appendix*)

comprising the questions related to vehicle data, trip data and commodity data. The questionnaire survey has been carried out for 24-hour duration and collected data from the freight vehicles on sample basis. The sample size collected at different outer cordon locations are given in Table 1. From the Table 1, it can be seen that a total of 8,391 samples of freight vehicles were interviewed and collected the vehicular and travel behaviour data. The data collected at the above outer cordon locations would be further analysed to understand the freight vehicular characteristics and travel behaviour of freight vehicles.

(a) Goods Auto Rickshaw (GA) *(b) Goods Van (GV)* *(c) Light Commercial Truck (LT)*

(d) Heavy Commercial Truck (HT) *(e) Multi-Axle Commercial Truck (MT)*

Fig. 2. Typical View of Selected Vehicles Types Considered under Freight Transport in the Present Study.

Table 1. Selected Outer Cordon Locations for Freight Traffic Data Collection for 24-Hour Duration.

S. No	OC Code	Name of the Outer Cordon Location	Sample Size of Freight Vehicles Interviewed
1	OC-1	Badarpur Border (NH -2)	900
2	OC -2	Aya Nagar Border (Mehrauli - Gurgaon Road)	415
3	OC -3	Rajokri Border (Delhi-Gurgoan Expressway NH-8)	1,191
4	OC -4	Tikri Border (NH-10)	1,000
5	OC -5	Singhu Border (NH-1)	756
6	OC -6	Loni Border	764
7	OC -7	Apsara Border (G.T. Road at Shahadara)	1,000
8	OC -8	NH-24 Bypass (Ghazipur)	763
9	OC -9	Chilla Border (Mayur Vihar - Noida Link Road)	767
10	OC -10	Kalindi Kunj Border (Sarita Vihar - Noida Road)	835
		Total	8,391

Note: NH represents National Highway

2.5. Focal Point Freight Traffic Volume Survey

The focal point traffic volume survey has been proposed with an aim to collect freight traffic that is primarily plying within the city. The intra-city movements by various commercial vehicles have been captured in this survey. To collect the freight traffic volume data that are entering into or exiting selected focal point/ market area, manual method of enumeration has been adopted in this study. The enumerators have been given sufficient training and deployed in the field to perform manual count of all freight vehicles types which are entering and exiting the selected focal point location. The survey has been carried out for 24 hour duration starting from 8:00 AM to 8:00 AM. The enumeration of the traffic has been done in every 15-minute and accordingly recorded in predesigned proforma. The traffic volume enumeration of vehicles has been done for all the freight vehicle types in order to understand the

quantity of freight traffic in that area. The vehicles types considered for Freight Transport are given in the Fig. 2. The selected locations for this survey are given in Table 2. These locations have been selected considering market areas and shopping areas. The geographic locations of these points are shown in Fig. 1.

Table 2. Selected Locations to Conduct Focal Point Survey in Delhi (24 hours).

S. No	FP Code	Name of the Focal Point	Nature of Land Use/Business Activity	Sample Size of Freight Vehicles Interviewed
1	FP-01	Azadpur Sabzi Mandi	Fruit & Vegetable	500
2	FP-02	Okhla Sabzi Mandi	Fruit & Vegetable	650
3	FP-03	Arya Pura Sabzi Mandi	Fruit & Vegetable	550
4	FP-04	Ghanta Ghar Sabzi Mandi	Fruit & Vegetable	496
5	FP-05	Old Delhi Sabzi Mandi	Fruit & Vegetable	858
6	FP-06	Shahdara Sabzi Mandi	Fruit & Vegetable	468
7	FP-07	Mandawali Sabzi Mandi:	Fruit & Vegetable	250
8	FP-08	Shahdara	Fruit & Vegetable, Food Grains, Fodder	398
9	FP-09	Gazipur	Fish & Poultry	634
10	FP-10	Connaught Place	Retail Shopping areas	240
11	FP-11	Chandni Chowk,	Retail/Whole Sale Shopping areas	506
12	FP-12	Sarojini Nagar	Retail/Whole Sale Shopping areas	202
13	FP-13	Lajpat Nagar	Retail/Whole Sale Shopping areas	402
14	FP-14	Pitampura	Retail/Whole Sale Shopping areas	252
15	FP-15	Nehru Place	Retail/Whole Sale Shopping areas	194
16	FP-16	Gandhi Nagar	Whole Sale Shopping areas	1,200
17	FP-17	Rajouri Garden	Retail/Whole Sale Shopping areas	461
18	FP-18	Narela	Food Grain	650
19	FP-19	Najafgarh	Food Grains	650
20	FP-20	Keshopur	Fruit & Vegetables	458
			Total	10,091

Note: Subzi Mandi means Fruit and Vegetable Market

2.6. Focal Point Freight Traffic Interview Survey

Apart from the classified freight traffic volume count that has been conducted at these 20 focal point locations, interview survey also carried out to collect the travel behaviour of the freight vehicles that are entering and exiting these market locations. The survey has been carried out using predesigned questionnaire comprising the questions related to vehicle data, trip data and commodity data (given in *Appendix*). The questionnaire survey has been carried out for 24-hour duration and collected data from the freight vehicles on sample basis. The sample size collected at different Focal Point locations are given in Table 2. From the Table 2, it can be seen that a total of 10,091 samples of freight vehicles were interviewed and collected the freight vehicular and travel behaviour data. The data collected at these locations has been further analysed to understand the freight vehicular characteristics and travel behaviour of freight vehicles. The Origin - Destination (OD) data also analysed with respect to traffic analysis zones (TCZ) to assess the external travel and also to create data base primarily to estimate total freight trips and OD matrix to develop travel demand models namely trip generation and trip distribution models.

2.7. Mid Block Traffic Volume Survey

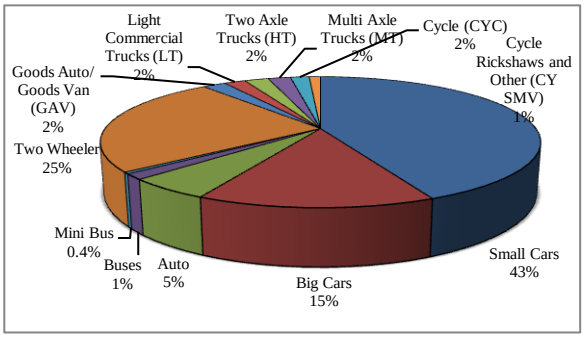
In order to assess the current traffic volume situation on the road network of Delhi, classified traffic volume count surveys at five locations has been proposed and their geographic locations are shown in Fig. 1. These selected locations on Mid-block traffic volume count locations are: (1) MB-1: Ring Road (Rajghat), (2) MB -2: Connaught Place Outer Circle, (3) MB -3: Ring Road (Naraina), (4) MB -4: I.T.O. Bridge and (5) MB -5: NH-24 Bypass.

To collect the freight traffic volume data that are plying on the selected locations in the city, manual method of enumeration has been adopted in this study similar to outer cordon traffic volume count survey. The enumerators have been given sufficient training and deployed in the field to perform manual count of all the vehicles types which are crossing that mid block location. The survey has been carried out for 24 hour duration starting from 8:00 AM to 8:00 AM. The enumeration of the traffic has been done in every 15-minute and accordingly recorded in predesigned proforma. The enumeration of vehicles has been done for all the vehicle types in order to understand the share of freight traffic in that. The vehicle types mainly considered include all private vehicles, public transport, intermediate public transport, freight vehicles and non-motorised transport vehicles. In case of traffic volume data on the remaining sections, the study conducted by CRRI (2017) at various intersections and mid-block section in Delhi have been utilised. Accordingly the current traffic volume at other locations has been estimated from that.

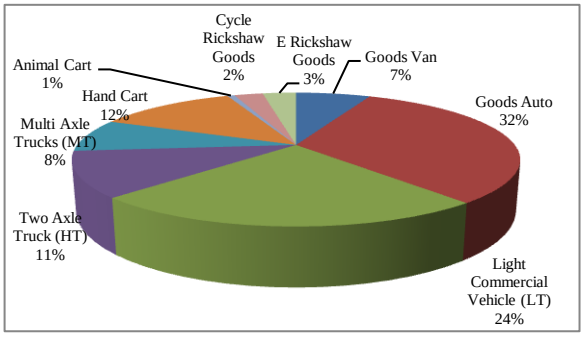
3. Freight Traffic Characteristics

3.1. Freight Traffic Composition

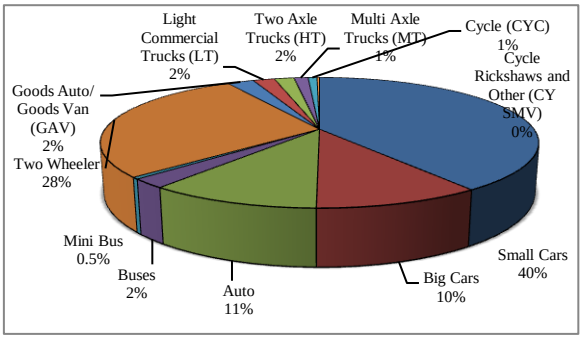
The collected traffic data at Outer Cordons, Focal Points and Mid-Blocks has been analysed in terms of hourly vehicular traffic distribution and traffic composition for all the locations. The trends of traffic composition at these locations are presented in Fig. 3. From Fig. 3(a), it can be inferred that about 85% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 8% mainly consists of GA, LT, HT and MT. From Fig. 3(b), it can be inferred that about 40% are consisting of Goods Auto and Goods Van. The vehicle types of LT, HT and MT are in the range of 24%, 11% and 8% respectively. The other freight vehicles are about 18%. From the Fig. 3(c), it can be inferred that about 80% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 7% mainly consist of Goods Autos, LT, HT and MT.



(a) Outer Cordons



(b) Focal Points



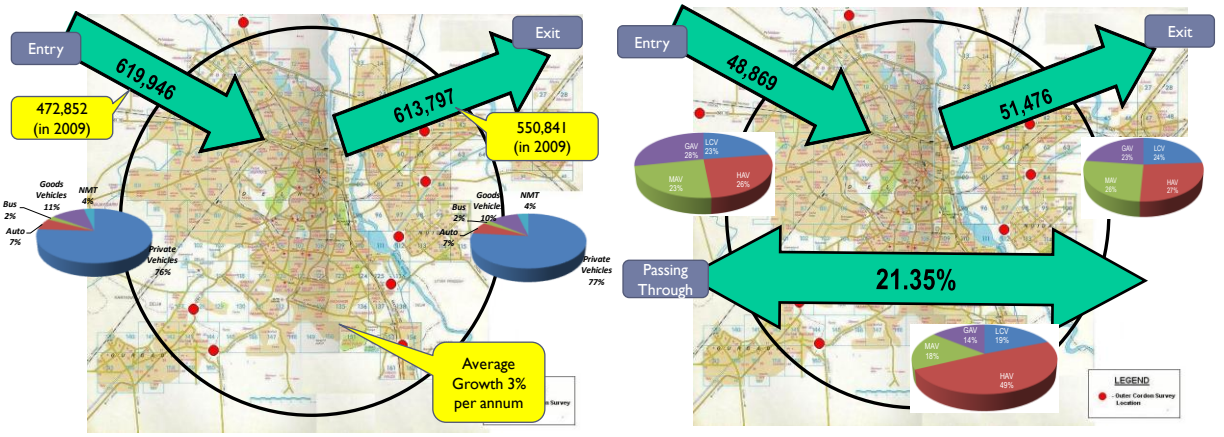
(c) Mid-Block Points

Fig. 3. Freight Traffic Composition at Different Locations of Delhi.

3.2. External Freight Travel

From the analysis of roadside interview data at the selected 10 outer cordon locations, overall pattern of external traffic of the city on a normal working day along with their composition was estimated and shown in Fig. 4. The results reveal that a total of about 1.24 million vehicles enter and leave Delhi city on normal working day which was about 1.02 million vehicles in 2009 (CRRI, 2009). From this result, it can be observed that the external traffic has grown with 3% per annum. It can also be noticed that the goods traffic forms about 10% of the total traffic with another 4% of traffic is composed of slow moving vehicles (SMV) like bicycle, animal carts etc. The pattern of external freight traffic in the city on a normal working day along with their composition was estimated and shown in Fig. 4. The results reveal that a total of about 100 Thousands freight vehicles enter and leave Delhi city on normal working day and about 21% of these freight vehicles are found to be passing through the city which was also almost same in the year 2009 (CRRI, 2009).

From these results, it can be observed that though the total traffic increased, freight traffic remain stagnated at outer cordons because of new bypass roads come around the city of Delhi such as Noida-Greater Noida Expressway, Yamuna Expressway, Kundli-Manesar-Palwal (KMP) Expressway etc. In case of passing through traffic, HT has almost 50% share followed by MT and LT has share of about 18% each. Smaller Goods Vehicles namely GA and GV has a share of about 14% of passing through traffic. This can be attributed to the fact that the heavy vehicles travel long distances compared to light and small vehicles.



(a) Total Traffic (b) Freight Traffic

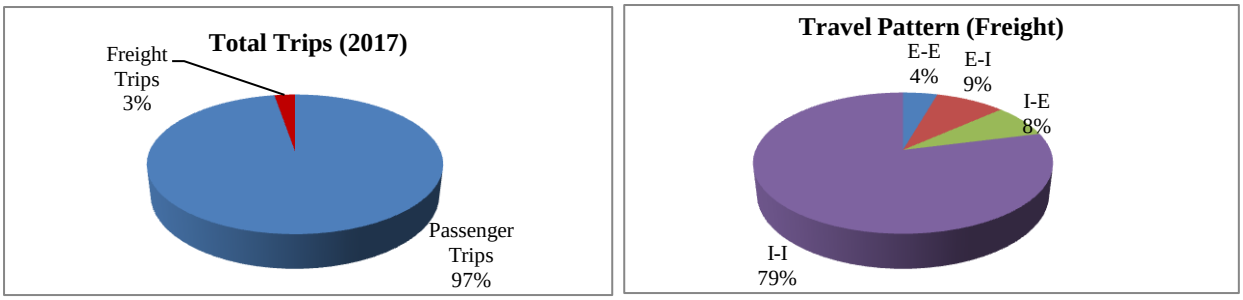
Fig. 4. Pattern of Total External Traffic at Outer Cordons of Delhi.

3.3. Pattern of Total Freight Trips

In the present study, the total trips have been estimated from all the zones which are in the order of about 500 thousands of freight trips generated daily in the city of Delhi. The comparison of total freight trips are made with passenger trips in order to understand the share of freight trips in the city of Delhi and shown in the Fig. 5. From the Fig. 5(a), it can be observed that the share of freight trips is only about 3% which is very insignificant, however it is going to influence huge in traffic congestion, air pollution and road safety related issues of the city of Delhi. The pattern of total freight trips are classified under four categories. They are:

- ❖ External - External (E-E)
- ❖ External - Internal (E-I)
- ❖ Internal to External (I-E)
- ❖ Internal - Internal (I-I)

Accordingly the freight trips are analysed and results are shown in Fig. 5(b). From the Fig. 5(b), it can be seen that the majority of freight trips are Internal - Internal which is almost 80%. The Internal-External and External-Internal are almost same about 8% each and External-External trips (passing through) are about 4%.



(a) Share of Freight Trips in Total Trips (b) Pattern of Freight Trips

Fig. 5. Share and Pattern of Freight Trips in Delhi.

The modal split of these freight trips has been analysed and presented in Fig. 6. From the Fig. 6, it can be observed that heavy freight vehicle share is about 26% in case of I-I Trips, about 43% in case of I-E Trips, about 53% in case of E-I Trips and about 61% in case of E-E Trips. In the present study, forecasting of the freight trips are also carried out based on the developed freight travel demand model (CRRI, TU-Delft, TNO, 2018) and it was found that the total freight trips are going to be around 572 thousands in the year 2021 with a growth rate of 4% per annum.

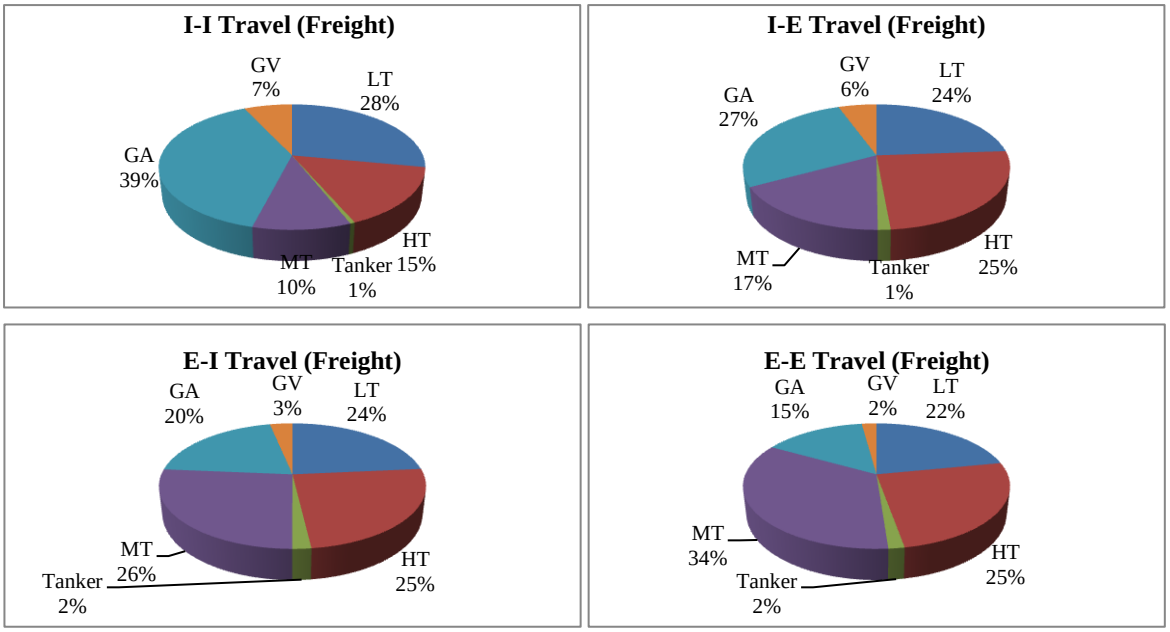


Fig. 6. Freight Modal Split for Different Types of Trips in Delhi.

4. Development of Freight Transport Demand Models

4.1. Background

Generally, passenger transport models are developed based on the observed travel pattern and the socio-economic characteristics of commuters of the city. The traditional approach of four-stage modelling has following transport sub-models are: (i) Trip Generation (ii) Modal-Split (iii) Trip Distribution (iv) Traffic Assignment. In the present study, freight transport demand model has been proposed to develop considering same traditional approach of four-stage modelling as passenger travel demand modeling. However, in this paper, freight trip generation, freight trip

distribution and freight modal split models have been discussed. The freight traffic assignment has been considered as beyond the scope of this paper. In order to develop freight travel demand model, development of existing transport network is the foremost data input requirement besides the observed travel characteristic data and planning parameters at traffic zone level.

4.2. Traffic Zones, Road Network and Socio-economic Data

The study area i.e. NCT of Delhi is divided into 360 administrative wards and the same has been adopted in the present study. These zones are also called as Traffic Analysis Zones (TCZ) and these 360 zones of the study area have been shown in Fig. 7. The zone wise socio economic data such as Population, Land Use Types, Number of Households, Employment, Total Land in Hectares, Commercial Area, Industrial Area, Residential Area, Recreational Area, Public & Semi Public Area etc. which are going to be used for development of travel demand modelling is also collected from the secondary source namely Census data (Census, 2011) and Master Plan for Delhi - 2021 (DDA, 2010). The road network of study area i.e. NCT of Delhi has been created from the exiting maps and field visits. The network has been developed by creating links and nodes as shown in Fig. 8. The Traffic Zone Centroids have been serially numbered starting from 1 onwards for each of the Traffic Zone of NCT of Delhi (1-360) and external zones (361-368). The transport network has been prepared for the whole of NCT of Delhi area including external zones.

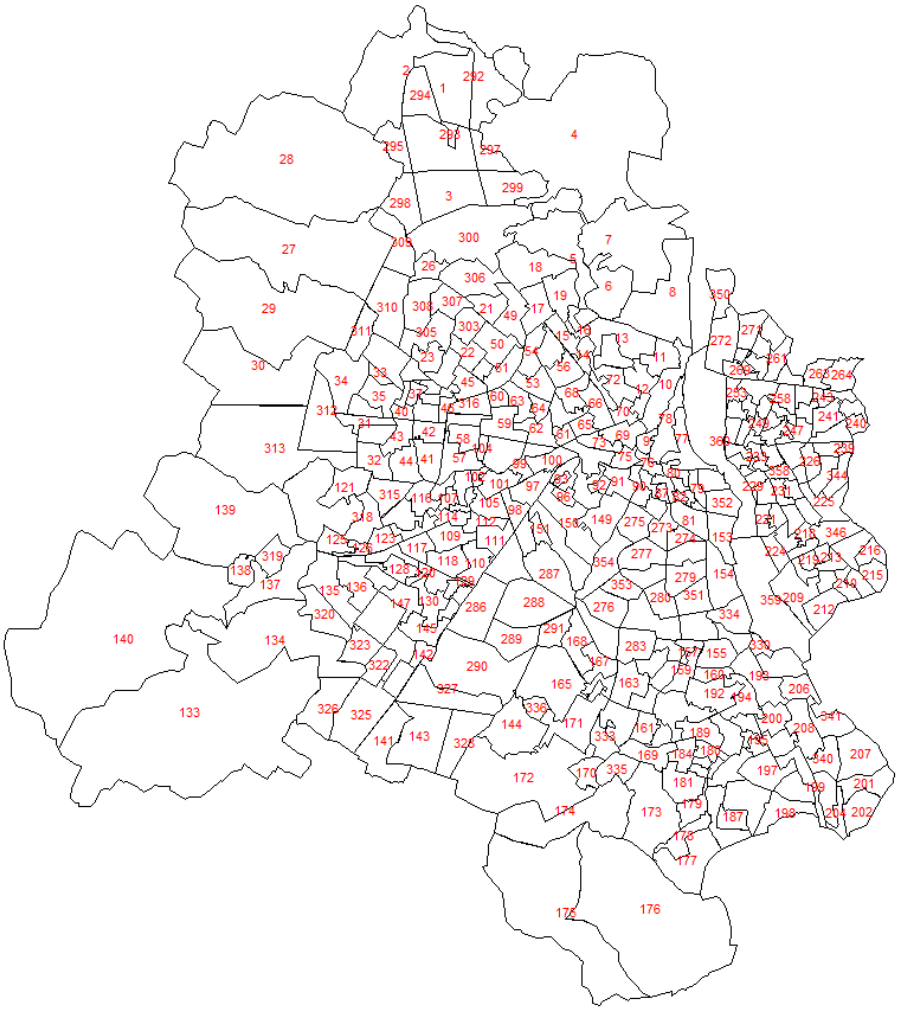


Fig. 7. Traffic Analysis Zones (TCZ) considered for the City of Delhi.

The existing transport network of Delhi city consists of only roads as the road based mode is only considered at present. The road network has total 2263 Links and 1500 nodes and included road link characteristics: link-type, length, observed carriageway width, no. of lanes, divided/undivided, and speed, capacity, etc. The transport network of existing roads is shown in Fig. 8. As speed and delay studies were conducted, the speeds for different links are taken from the surveys separately for different type of roads namely major roads, intermediate roads, connectors etc.

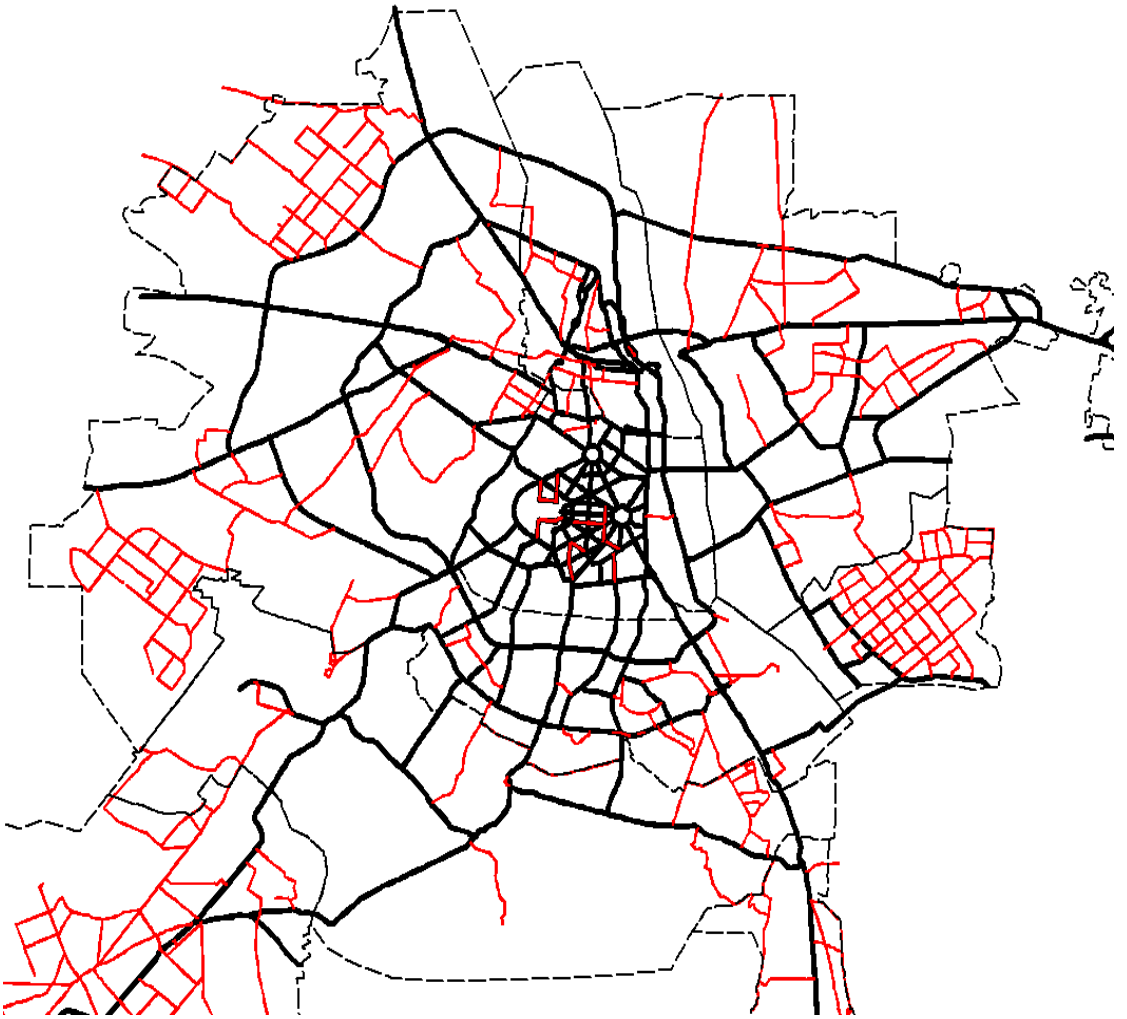


Fig. 8. Created Road Network (Links and Nodes) for the City of Delhi.

4.3. Freight Trip Generation Models

Freight Trip Production Models

The freight trip data has been analysed based on zone wise and estimated the trips generated from that zone. Multiple Linear Regression (MLR) Analyses technique has been used to model the Freight Trip Productions. The form of the freight trip production equation is given below:

$$T=X\beta+\varepsilon \qquad \text{---------- } Eq.\ (1)$$

Where,

T is number of freight trips produced or attracted

X is vector of independent variables (socioeconomic and land use intensity)

β is parameter vector to be estimated

ε is unexplained error term and a constant can be considered for this

Out of the socio-economic and land use parameters discussed in the Section 4.2, the following variables are taken as influential parameters in estimating freight trip productions in zonal level:

- Population (*P*)
- Employment (*E*)
- Commercial Area (*C*)
- Industrial Area (*I*)

Using the above variables, the zonal trip productions are modelled and developed zonal level trip production regression models. For this purpose SPSS 18 Software has been utilised to estimate the parameters and statistical validation. The developed model for freight trip production is given below:

$$P^F_i = 0.021*P_i + 0.003*E_i + 14.499*C_i - 17.858*I_i \quad \text{---------- Eq. (2)}$$

Where, P^F is Freight Trip Productions

i is zone number

The statistical parameters in terms of standard error of coefficient, t-value and F-value for the Eq. (2) are given in Table 3. From the Table 3, it can be observed from the standard error and t-values that variables Population (P) and Industrial Area (I) are more significant compared to variables Employment (E) and Commercial Area (C). From the F-value (2.962) and R^2 values (0.3), the above regression equation can be considered as relatively good statistical significance.

Table 3. Statistical Parameters of Freight Trip Production Model.

S. No	Variable	Coefficients	Std. Error	t-value	Significance	F-value	R^2-value
1	Population (P)	.021	.010	2.174	.038	2.962	0.3
2	Employment (E)	.003	.008	.368	.715	(Sig. 0.036)	
3	Commercial Area (C)	14.499	39.580	.366	.717		
4	Industrial Area (I)	-17.858	15.875	-1.125	.270		

Freight Trip Attraction Models

Similar to freight trip productions, Multiple Linear Regression (MLR) equation as given in Eq. (1) has been used to model the Freight Trip Attractions with the same set of independent variables in the first instance has been considered. Using those variables, the zonal trip attractions are modelled and developed zonal level trip attraction regression models. For this purpose SPSS 18 Software has been utilised to estimate the parameters and statistical validation. Based on this, the variable Industrial Area (I) was found to be insignifcant and hence removed from the equation. The final developed model for freight trip attraction is given below:

$$A^F_i = 0.026*P_i + 0.002*E_i - 17.564*C_i \quad \text{---------- Eq. (3)}$$

Where, A^F is Freight Trip Attractions

The statistical parameters in terms of standard error of coefficient, t-value and F-value for the Eq. (3) are given in Table 4. From the Table 4, it can be observed from the standard error and t-values that variable Population (P) is more significant compared to variables Employment (E) and Commercial Area (C). From the F-value (5.812) and R^2 values (0.38), the above regression equation can be considered as relatively good statistical significance.

Table 4. Statistical Parameters of Freight Trip Attraction Model.

S. No	Variable	Coefficients	Std. Error	t-value	Significance	F-value	R^2-value
1	Population (P)	.026	.010	2.669	.013	5.812	0.38
2	Employment (E)	.002	.007	.214	.832	(sig. 0.003)	
3	Commercial Area (C)	17.564	23.414	-.750	.459		

Estimation of Total Freight Trips

From the developed Freight Trip Production and Attraction Models given in Eq. (2) and Eq. (3), the total trips have been estimated from all the zones and presented in Fig. 9. From the Fig. 9, it can be seen that about 500 thousands of freight trips are generated in terms of productions and attractions daily in the city of Delhi. This result

can also be introspected by observing coefficients of the variables in Eq. (2) and Eq. (3) which are almost same that would lead a result of same productions and attractions at zone level. As the empty trips were not considered separately in the study, slight variation in the productions and attractions can be observed.

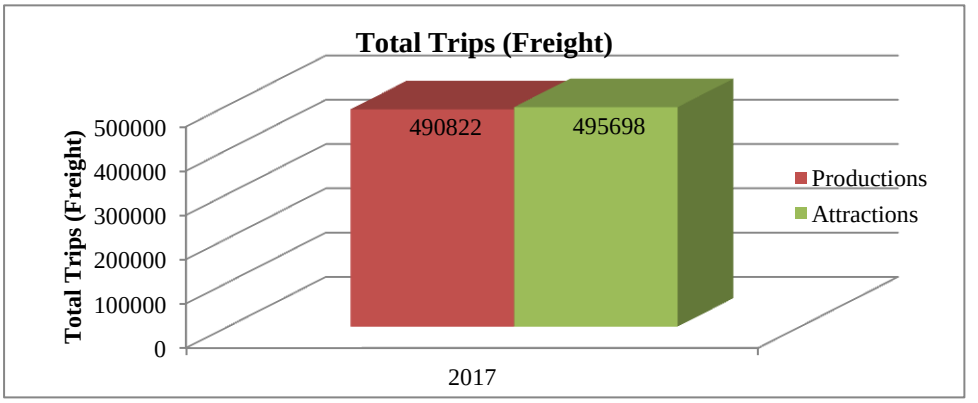


Fig. 9. Estimated Total Freight Trip Productions and Attractions in Delhi (2017).

4.4. Freight Modal Split

In the present study, modal split has been estimated from the observed traffic composition within the city at focal points and also at outer cordons as given in Fig. 3 and 6 respectively. Taking the freight vehicular volumes into consideration, the weighted average of share of each freight vehicle type has been determined to estimate final freight modal shares. The final freight modal split is shown in Fig. 10. From the Fig. 10, it can be observed that all different freight vehicles namely GA, LT, HT and MT form almost equal share varying between 22-25% where as GV is about 5% share.

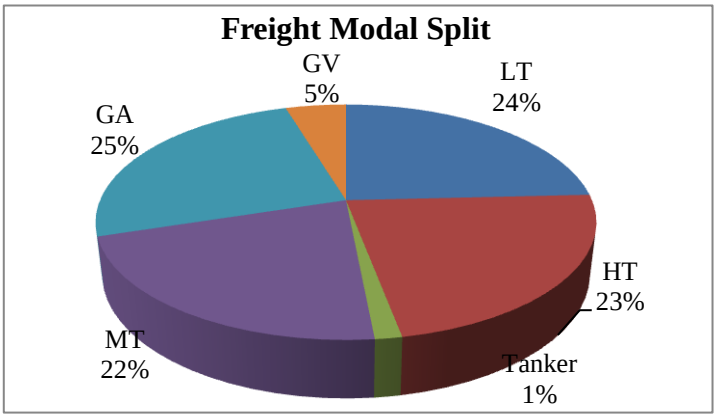


Fig. 10. Modal Split of Total Freight Trips.

4.5. Freight Trip Distribution Models

Gravity Model Formulation

Gravity Model formulation shown in Eq. (4) has been used for Trip Distribution Model calibration.

$$T_{ij} = A_i * B_j * P_i * D_j * F(c_{ij}) \quad \text{----------(4)}$$

Where, T_{ij} : Trips generated from origin zone *'i'* to destination zone *'j'*

$A_i * B_j$: Balancing factors

P_i: Production from i^{th} Zone

D_j : Attraction to j^{th} Zone

$F(c_{ij})$: Deterrence Function

The $F(c_{ij})$ is used from Tanner's function as shown in Eq. (5).

$$F(c_{ij}) = (c_{ij}^{X_1}) * (e^{X_2 * c_{ij}}) \quad \text{---------- (5)}$$

Where, c_{ij} : Generalized Cost of Travel from zone *'i'* to zone *'j'*

X_1 and X_2: Calibration Parameters

Gravity Model Calibration and Estimation of Freight O-D Matrices

In order to calibrate the gravity model given in Eq. (4) and (5), the generalized cost data is required. For this purpose, VISUM 11 software has been utilized. The road network and zones have been coded in VISUM environment as shown in Fig. 7 and 8. Using VISISM, the skim matrices based on travel time have been generated from the coded network of existing roads and subsequently Gravity Model has been calibrated using total productions and attraction from each of the zone. In the present study, the total number of zones taken as 368, out of which 360 are internal zones and 8 are external zones. The size of O-D Matrix would be 368 X 368. The observed O-D matrix has been utilized for validation purpose. Utilizing these data, the freight O-D matrices for different vehicle types have been estimated in VISUM. The desire line drawings have been developed in order to appraise the trend and intensity of trips between origin and destination using VISUM Software and shown in Fig. 11.

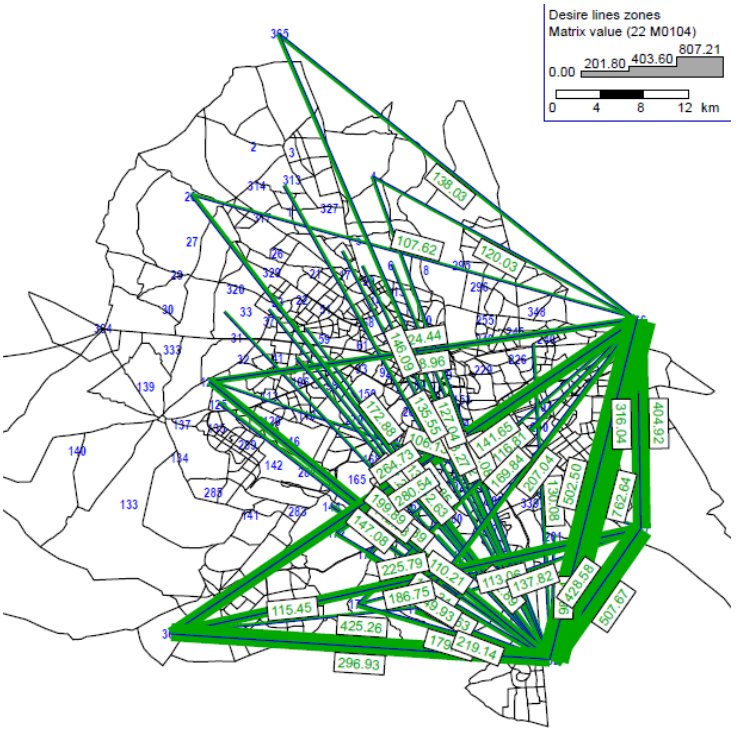


Fig. 11. Desire Line Diagram of O-D Matrices for Freight Trips.

From the Fig. 11, it can be observed that freight traffic at outer cordons located in South and East (Badarpur, Gurgoan, Kalindi Kunj and GT Road Apsara Border) are significant compared to other locations. This result clearly indicating the fact that the there is an absence of bypasses in South and East. The new bypass roads come around the city of Delhi such as Kundli-Manesar-Palwal (KMP) Expressway (Western Peripheral Expressway) in West and North accommodating passing through traffic hence, there is less freight traffic entering or exiting from West and North. As there would be opening of Eastern Peripheral Expressway in near future, this passing through traffic in South and East would be reduced further.

5. Forecasting of Freight Trips from Freight Transport Demand Models

5.1. Estimation of Freight Trips in Future Years

The developed freight transport models are utilised to forecast the trips that going to be generated in the City of Delhi. As it was already discussed in Section 4.2 that the trip productions and attractions are depend on certain variables which are intern considered in equation development. The variables are:

- Population (*P*)
- Employment (*E*)
- Commercial Area (*C*)
- Industrial Area (*I*)

Out of all these variables, the population data over the years is available and limited data for the other variables namely employment available for the year 2021 which is related to Census Updation year in India. Using the growth factors for these variables, growth factors for other variables have been appropriately considered. From this exercise, the total trips productions and attractions for the year 2021 are estimated. The estimated trips for the year 2017 and 2021 are shown in the Fig. 13.

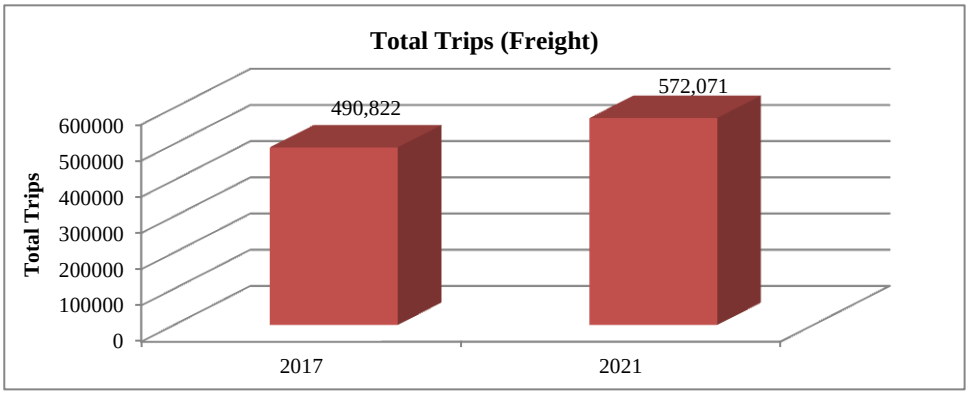


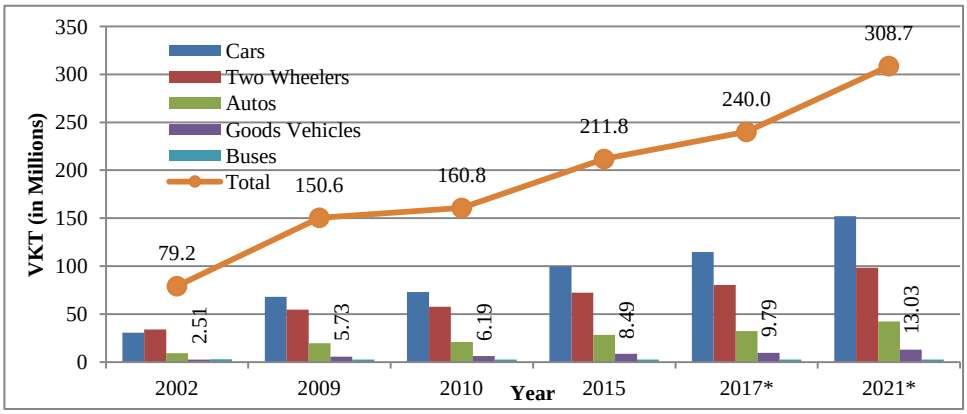
Fig. 13. Forecasted Total Freight Trips for the Year 2021 in Delhi.

From the Fig. 13, it can be seen that the forecasted trips have increased to about 572 thousands with a growth rate of 4% per annum.

Taking into account of the findings from the present study and inventory of the literature with the aim to arrive at a reasonably complete but manageable list of indicators to measure New Delhi's performance in the area of SCL, the list of indicators has been arrived as presented in Table 9 which also included suggested units and sources for measurement. In order to assess these parameters for city of Delhi, a survey can be undertaken among all the local authorities and policy makers, freight operators and experts.

5.2. Estimation of Traffic Loads on the Road Network

In 2002 and 2009, CRRI has conducted a study to estimate traffic loads in terms of vehicle kilometers travelled (VKT) on the road network of Delhi and accordingly projected for the years 2010 and 2015 (CRRI, 2009). Utilising this data, the time series projections have been made from the determined yearly growth factors for different vehicle types. The estimated VKT for 2017 and forecasted VKT for the year 2021 are presented in Fig. 14. From the Fig. 14, it can be observed that the estimated total traffic loads in terms of VKT are about 240 Millions and 300 Millions in 2017 and 2020 respectively. The VKT by freight vehicles are going to be about 10 Million and 13 Millions in 2017 and 2020 respectively which is having a share of about 4%. The growth of total VKT is increasing with 7% per annum growth whereas freight vehicles growth is about 8% per annum.



** Estimated in Present Study*

Fig. 14. Estimated Vehicle Kilometers Travelled /Day for different Vehicle Types for Different Years

6. Concluding Remarks

Understanding and forecasting freight movements is critical to plan for future transportation in terms of capacity augmentation, operation, preservation, safety and security, energy and economy investment needs. Many demand forecasting models and data sources are more appropriate for passenger transportation than for freight transportation in terms of understanding freight travel behaviour and forecasting freight movements. Creating better data and models is needed to enable planners to better predict freight movement and design better informed policies. In view of this, the present study have been conceptualised to study on urban logistics An extensive pilot study is carried out for the city of New Delhi, i.e. National Capital Territory of Delhi (NCTD), India has been selected as study area. By conducting extensive field surveys, metrics of city logistics, design of measurement system and data acquisition in the city of Delhi have been developed. In the present study, possible freight metrics from the various field studies have been measured and developed traditional four-stage freight travel demand model. The summary is given below:

- On a normal working day, a total of about 1.24 million vehicles enter and leave Delhi city which has grown with 3% per annum (about 1.02 million vehicles in 2009). The freight traffic forms about 10% of the total traffic with another 4% of traffic is composed of slow moving vehicles like bicycle, cycle rickshaws, animal carts etc.
- Maximum number of vehicles in the order of about 354 thousands entering and exiting through Rajokri Border followed by Ghazipur Border with an entry/ exit traffic volume of about 163 thousands and Kalindi Kunj Border with an entry/ exit traffic volume of about 126 thousands.
- A total of about 100 Thousand freight vehicles enter and leave Delhi city on a normal working day and about 21% of these freight vehicles are found to be passing through the city which was almost same in 2009. Though the total traffic increased, freight traffic remain stagnated at outer cordons because of new bypass roads come around the city of Delhi such as Noida-Greater Noida Expressway, Yamuna Expressway, Kundli-Manesar-Palwal (KMP) Expressway etc.
- The freight vehicle types namely Goods Auto (GA), Goods Van (GV), LT, HT and MT are found at entry and exit locations of outer cordons. In case of passing through freight traffic, HT has almost 50% share followed by MT and LT has share of about 18% each. Smaller Goods Vehicles (GA and GV) has a share of about 14% of passing through traffic. This can be attributed to the fact that the heavy vehicles travel long distances compared to light and small vehicles.
- From focal points studies within the city, it has been observed that maximum number of vehicles per day is in the order of about 8 thousands entering and exiting through Ghanta Ghar Sabzi Mandi followed by Azadpur Sabzi Mandi with an entry/ exit volume of about 7 thousands and Chandini Chowk Area with an entry/ exit volume of about 5 thousands. It has also been found that about 40% are consisting of Goods Auto (GA) and Goods Van (GV) in that. The vehicle types of LT, HT and MT are in the range of 24%, 11% and 8% respectively. The other freight vehicles are about 18%.

- The mid block traffic studies reveled that the total daily volume (24 hours) on Ring Road (Naraina) is almost 190 thousands with a peak volume of about 16 thousands (19:00 ~ 20:00 Hrs). The summary of traffic on all the mid block locations shows about 80% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 7% mainly consist of Goods Autos, LT, HT and MT.
- In the present study, freight transport demand model has been developed considering traditional approach of four-stage modelling (Freight Trip Generation, Freight Modal Split, Freight Trip Distribution and Freight Traffic Assignment).
- Accordingly, the total trips generated daily in the city of Delhi from all the zones are estimated to be about 500 thousands of freight trips. The final freight modal split for different freight vehicles namely GA, LT, HT and MT shows almost equal share varying between 22-25% where as GV has about 5% share. The Freight O-D Matrix estimated from Freight Trip Distribution adopting Gravity Model.
- The majority of freight trips are Internal - Internal (I-I) which is almost 80%. The Internal-External (I-E) and External-Internal (E-I) are almost same about 8% each and External-External (E-E) trips (passing through) are about 4%.
- The analysis of modal split of these freight trips shows that heavy freight vehicle share is about 26% in case of I-I Trips, about 43% in case of I-E Trips, about 53% in case of E-I Trips and about 61% in case of E-E Trips.
- The share of freight trips is only about 3% and passenger trips are about 97% in the city of Delhi. Though the share of freight trips is very insignificant, it is going to influence huge in traffic congestion, air pollution and road safety related issues of the city of Delhi.
- The freight trips are estimated to increase to about 572 thousands by the year 2021 with a growth rate of 4% per annum.
- The estimated traffic loads in terms of vehicle kilometers travelled (VKT) on the road network of Delhi for the year 2017 and forecasted VKT for the year 2021 are about 240 Millions and 300 Millions respectively. The VKT by freight vehicles are going to be about 10 Million and 13 Millions in 2017 and 2020 respectively which is having a share of about 4%. The growth of total VKT is increasing with 7% per annum growth whereas freight vehicles growth is about 8% per annum.

In the present study, four important priorities for the future have been identified, which could be part of a joint mission statement of the collective of stakeholders to achieve sustainable urban freight systems:

- ❖ Reduction of negative effects of urban freight transport while maintaining productivity.
- ❖ Identification of workable urban freight solutions including roadmaps towards data, tools and appropriate research.
- ❖ Increase of the knowledge base including data collection, models and scenarios.
- ❖ Collaboration with other stakeholders to realize solutions towards sustainability.

Acknowledgements

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Appendix

CSIR-Central Road Research Institute (CRRI), New Delhi

(in association with TNO, Netherlands and TU Delft, Netherlands)

EGACITY LOGISTICS: METRICS, TOOLS AND MEASURES FOR SUSTAINABILITY (MEGALOG)

Research Project Funded by

THE WORLD BANK IBRD • IDA | WORLD BANK GROUP

OUTER CORDON SURVEY / FOCAL POINT SURVEY (GOODS TERMINALS/ COMMERCIAL CENTRES)

OC/ FP

Location: _____ ***Interviewer Name:*** _____

Date: _____ ***Time:*** _____

1. Vehicle Details (a) Type: (1) LCV / (2) Normal Truck / (3) Tanker / (4) MAV / (5) Goods Auto / (6) Goods Van / (7) Others _____
   (b) Model Year_____
   (c) Fuel Used: (1) Petrol / (2) Diesel / (3) CNG / (4) LPG / (5) Propane
   (d) Registration Number: _____
   (e) Vehicle Ownership: (1) Government / (2) Pvt. Company/ (3) Personal / (4) Hired
   (f) Fuel Consumption (mileage) :_____*(km/ltr)*
2. Trip Details:
   (a) Origin of Trip: Destination of Trip:
   Place: _____ Place: _____
   State: _____ State: _____
   Outer Cordon Entry: _____ Outer Cordon Exit: _____
   (b) Distance of this Trip: _____ (*km*)
   (c) Distance of this Trip within the City: _____ (*km*)
   (d) Distance traveled in a day: _____ (*km*)
   (e) Time taken for this Trip: _____(*Hrs*)_____(*Mins*)
   (f) Time taken for this Trip within the City: _____(*Hrs*)_____(*Mins*)
   (g) Frequency of this Trip: (1) Daily/ (2) Bi-weekly/ (3) Tri-weekly/ (4) Weekly/ (5) Occasionally
   (h) Purpose of Entering the City (only for outer cordon): (1) Filling Fuel / (2) Loading (or) Unloading / (3) Passing through the city / (4) others _____
3. Commodity Detail: (a) Commodity Type:
   1. Fruits, Vegetables, Fish, Meat etc.
   2. Food Grains.
   3. Building Materials.
   4. Milk/Milk Products.
   5. Petroleum Products.
   6. Wood/Woods Items.
   7. Iron/Steel Products.
   8. Finished Products.
   9. Tyre /Rubber Products.
   10. Chemicals
   11. Medicines
   12. Glassware.
   13. Clothes.
   14. Sugar/ Jagery
   15. Paper Products.
   16. Water
   17. Others
   18. Empty

   (b) Weight: _____*Tonnes*