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A case study of Delhi

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Assessment of urban freight travel characteristics - A case study of Delhi

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

[a] *Senior 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 transport data has been exhaustively collected to assess the urban freight characteristics of Delhi. For this purpose, the field surveys namely outer cordon traffic surveys at 10 locations and focal point survey at 20 locations within the city have been conducted. The results can make a good database to understand the freight characteristics of a city and it would be highly useful in developing freight travel demand models and also evaluate appropriate freight related transport policies for their effective implementation on the urban road network by the policy makers and concerned authorities.

Keywords: Urban Freight; Delhi City; Outer Cordon; Focal Point; 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 driven by the growth in the manufacturing, retail, Fast-moving consumer goods (FMCG) or consumer packaged goods (CPG) and e-commerce sectors which have large freight transport requirements across the country which is generally done by road transportation. 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 on an average compared to 25 days in developing countries (TCI and IIM, 2016). The delays could range from five per cent of time taken in a journey to a high of 25%. The average speed of trucks on Indian roads is about 20 km/ hour and a truck in India can cover only 250-300 km a day compared to 700-800 km in developed countries such as the US and Europe. Moreover, on an average, total trip expenses increases about 15% due to the delays at check-posts and on-road for filling in forms required by various government departments, checking of documents and physical checking of the vehicles, drivers and consignments by Regional Transport Offices and traffic police, and collecting highway toll and taxes. 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. There is increasing recognition in India that transport infrastructure could become a serious bottleneck for future economic growth. The need is recognized for collaboration amongst stakeholders to identify optimal policies and pursue a rapid deployment of improvements.

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 assess the freight travel characteristics in an urban area. 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 the metrics for measurement of sustainability city logistics 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 and 4 respectively. The freight vehicular and travel characteristics of Delhi is discussed in Section 5. In this section, the network level freight estimations in terms of vehicle kilometers travelled (VKT) for future years are also discussed. Section 6 includes the proposed metrics for sustainable city logistics for the city of Delhi. Finally, Section 7 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

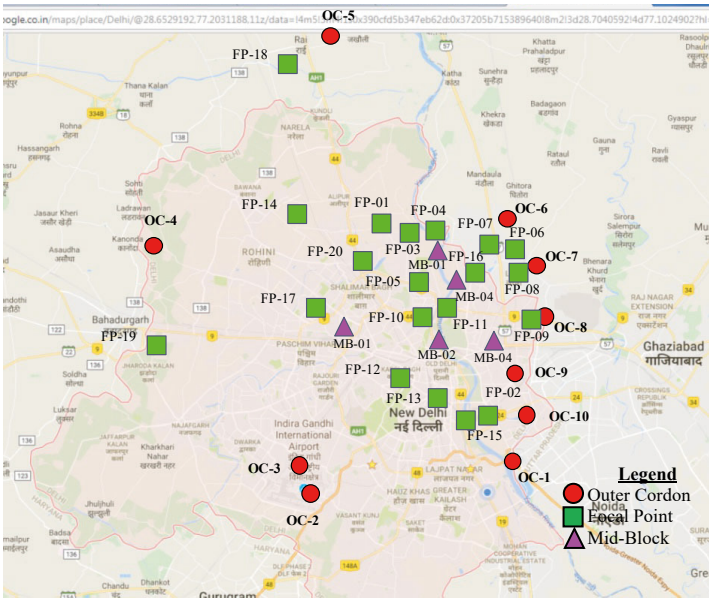


Fig. 1. Selected Study Area of National Capital Territory of Delhi (NCTD) and Survey Locations (Source: Google Maps)

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.

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

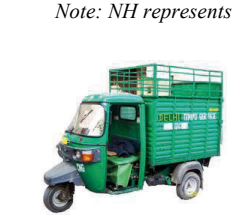
Apart from the classified traffic volume count that has been conducted at these 10 outer cordon locations, interview survey also carried out to collect the travel behaviour of the freight vehicles that are entering and exiting Delhi through these locations. The survey has been carried out using predesigned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

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		
			Entering Delhi	Exiting Delhi	Total
1	OC-1	Badarpur Border (NH -2)	441	459	900
2	OC -2	Aya Nagar Border (Mehrauli - Gurgaon Road)	285	130	415
3	OC -3	Rajokri Border (Delhi-Gurgoan Expressway NH-8)	983	208	1,191
4	OC -4	Tikri Border (NH-10)	946	54	1,000
5	OC -5	Singhu Border (NH-1)	580	176	756
6	OC -6	Loni Border	342	422	764
7	OC -7	Apsara Border (G.T. Road at Shahadara)	830	170	1,000
8	OC -8	NH-24 Bypass (Ghazipur)	428	335	763
9	OC -9	Chilla Border (Mayur Vihar - Noida Link Road)	521	246	767
10	OC -10	Kalindi Kunj Border (Sarita Vihar - Noida Road)	482	353	835
				Total	8,391

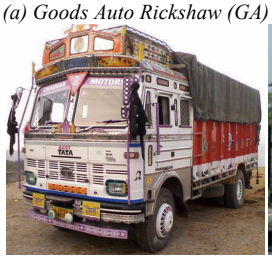
Note: NH represents National Highway



(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. Selected Vehicles Types Considered under Freight Transport in the Present Study

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. 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 at Outer Cordons

3.1. Freight Traffic Volume

The collected traffic data has been analysed in terms of hourly vehicular traffic distribution and traffic composition for all the locations and a typical hourly distribution of traffic volume and traffic composition at Rajokri Border (NH-8) on Delhi-Gurgoan Expressway is shown in Fig. 3. From the Fig. 3, it can be seen that the total daily volume (24 hours) entering and exiting Delhi through Rajokri Border is in the order of 354 thousands and the peak hour is occurring in the evening between 18:00 and 19:00 Hrs with a peak volume of about 24 thousands. It can also be inferred from the analysis that about 95% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 4% mainly consist of Goods Autos (GA), LT, HT and MT.

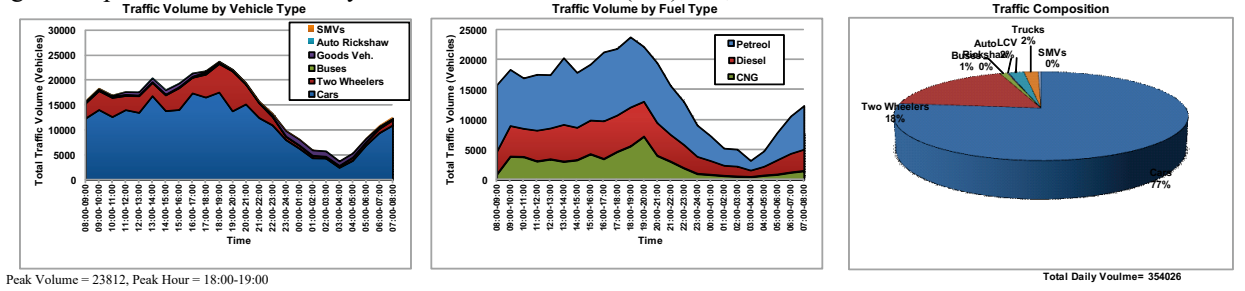


Fig. 3. Hourly Distribution of Classified Traffic Volume and Traffic Composition at Rajokri Border (Delhi-Gurgoan Expressway)

The summary of all the 10 outer cordon locations is presented in Table 3 and traffic composition is presented in Fig. 4. From the Table 3, it can be observed that 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 volume of about 163 thousands and Kalindi Kunj Border with an entry/ exit volume of about 126 thousands. From Fig. 4, it can be inferred that about 85% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 8% mainly consist of GA, LT, HT and MT.

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. 5. 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. 5. 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).

Table 3. Summary of Classified Traffic Volume (24 hours) at Different Outer Cordons of Delhi

S. No	Outer Cordon	Cars	Auto	Buses	TW	GA & GV	LT	HT	MT	SMV	Total
1	Badarpur Border	47520 (51.1%)	15825 (4.2%)	2685 (2.1%)	26380 (28.5%)	3753 (2.8%)	3754 (2.8%)	5369 (3.2%)	6221 (3.3%)	7033 (1.9%)	118540 (100%)
2	Arjun Garh (Aya Nagar Border)	55356 (67.3%)	78 (0.1%)	578 (0.7%)	24403 (29.7%)	357 (0.4%)	163 (0.2%)	128 (0.2%)	240 (0.3%)	934 (1.1%)	82237 (100%)
3	Rajokari Border	271571 (76.7%)	642 (0.2%)	3353 (0.9%)	63353 (17.9%)	2838 (0.8%)	4369 (1.2%)	3616 (1%)	2966 (0.8%)	1318 (0.4%)	354026 (100%)
4	Tikri Border	25861 (46.9%)	2281 (4.1%)	1101 (2%)	17657 (32%)	1542 (2.8%)	2176 (3.9%)	1190 (2.2%)	1058 (1.9%)	2262 (4.1%)	55128 (100%)
5	Singhu Border	44993 (59.2%)	1487 (2%)	1532 (2%)	13829 (18.2%)	3304 (4.3%)	3085 (4.1%)	2812 (3.7%)	3319 (4.4%)	1700 (2.2%)	76061 (100%)
6	Loni Border	8818 (12.3%)	21370 (29.9%)	558 (0.8%)	32100 (44.9%)	254 (0.4%)	664 (0.9%)	555 (0.8%)	123 (0.2%)	7122 (10%)	71564 (100%)
7	Apsara Border (Dilshad Garden)	38704 (45.6%)	4880 (5.8%)	3208 (3.8%)	30116 (35.5%)	1603 (1.9%)	1551 (1.8%)	1185 (1.4%)	625 (0.7%)	2972 (3.5%)	84844 (100%)
8	Ghazipur Border	86229 (52.8%)	9567 (5.9%)	4196 (2.6%)	35486 (21.7%)	6688 (4.1%)	2474 (1.5%)	5932 (3.6%)	5388 (3.3%)	7259 (4.4%)	163219 (100%)
9	Chilla Boarder	66110 (64.6%)	3425 (3.3%)	2557 (2.5%)	24088 (23.5%)	1803 (1.8%)	1679 (1.6%)	1723 (1.7%)	708 (0.7%)	240 (0.2%)	102333 (100%)
10	Kalindi Kunj Border	64404 (51.1%)	5237 (4.2%)	2634 (2.1%)	35957 (28.5%)	3589 (2.8%)	3539 (2.8%)	4088 (3.2%)	4153 (3.3%)	2358 (1.9%)	125959 (100%)
	Total	709566 (57.5%)	64792 (5.3%)	22402 (1.8%)	303369 (24.6%)	25731 (2.1%)	23454 (1.9%)	26598 (2.2%)	24801 (2%)	33198 (2.7%)	1233911 (100%)

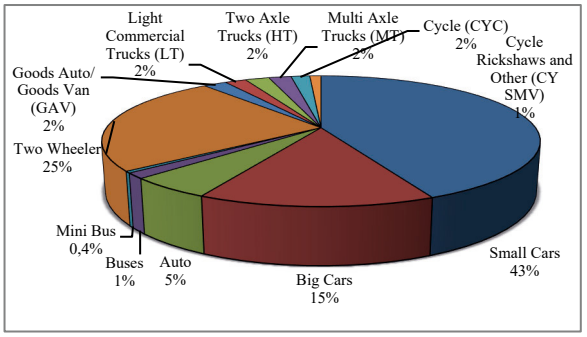


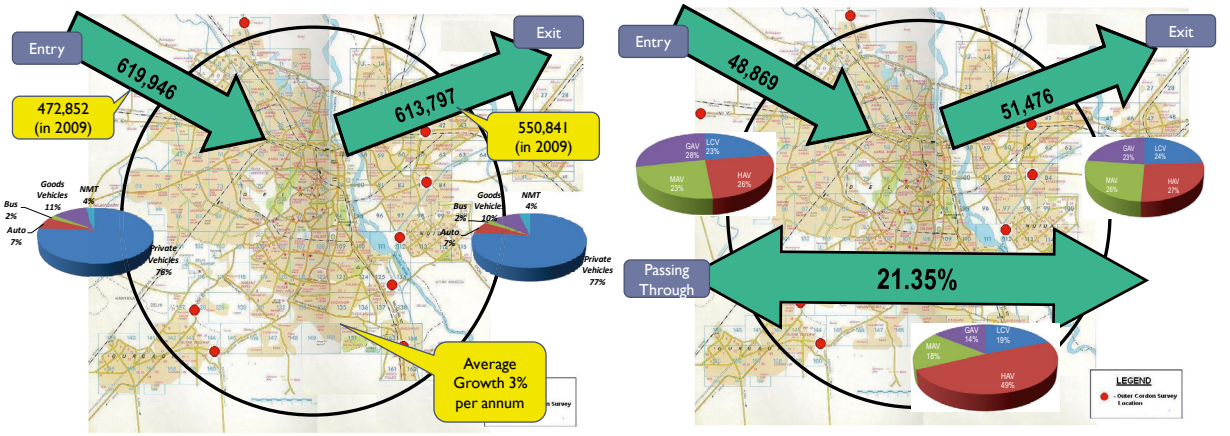
Fig. 4. Traffic Composition at Different Outer Cordons of Delhi

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.

4. Freight Traffic Characteristics in the Urban Area

4.1. Freight Traffic Volume at Focal Points

The collected freight traffic data has been analysed in terms of hourly vehicular traffic distribution and traffic composition at all the locations. A typical hourly distribution of traffic volume and traffic composition at Azadpur



(a) Total Traffic (b) Freight Traffic

Fig. 5. Pattern of Total External Traffic at Outer Cordons of Delhi

Sabzi Mandi is shown in Fig. 6. From the Fig. 6, it can be observed that the total daily volume (24 hours) entering and exiting Azadpur Sabzi Mandi is in the order of about 7 thousands and the peak hour is occurring in the midnight between 23:00 and 24:00 Hrs with a peak volume of about 575 freight vehicles. From the Fig. 6, it can also be inferred that about 26% are consisting of Goods Autos and Goods Vans, LT is about 23% and HT and MT are 21% each. It can also be observed that Slow Moving Vehicles (SMVs) are about 9%.

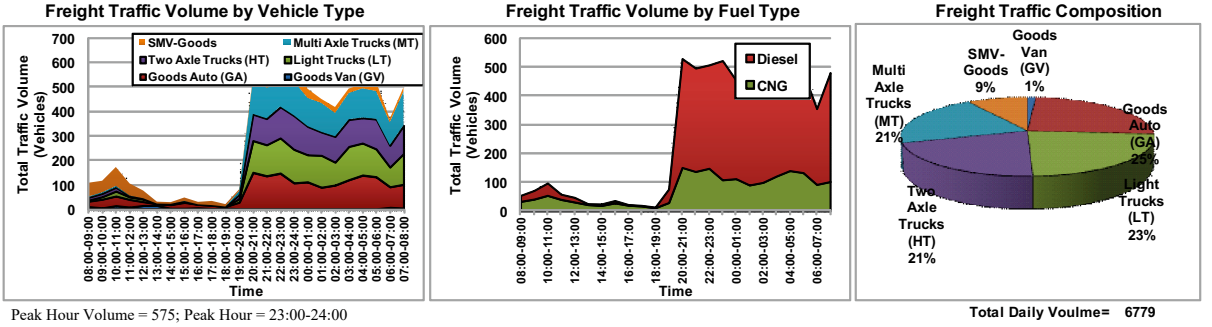


Fig. 6. Hourly Distribution of Classified Freight Traffic Volume and Traffic Composition Azadpur Sabzi Mandi

The summary of all the focal points is presented in Table 4 and traffic composition is presented in Fig. 7. From the Table 6, it can be observed that maximum number of vehicles per day 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. From Fig. 7, 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%.

Table 4. Summary of Classified Freight Traffic Volume (24 hours) at Different Focal Points of Delhi

S. No	FP Code	Name of the Focal Point	GV	GA	LT	HT	MT	Hand Cart	Animal Cart	Cycle Rickshaw	E Rickshaw	Total
1	FP-01	Azadpur Sabzi Mandi	82	1645	1571	1408	1416	420		186	51	6779
2	FP-02	Okhla Sabzi Mandi	92	177	270	193	92	1		67	4	896
3	FP-03	Arya Pura Sabzi Mandi	483	1838	926	42	73	105		55	402	3924
4	FP-04	Ghanta Ghar Sabzi Mandi	452	3587	2478	912	553	0				7982
5	FP-05	Old Delhi Sabzi Mandi	155	706	603	212	242	595		0	0	2513
6	FP-06	Shahdara Sabzi Mandi	19	899	536	575	148	646				2823
7	FP-07	Mandawali Sabzi Mandi	32	200	106	196	25	8				567
8	FP-08	Shahdara	64	309	223	50	16	439				1101
9	FP-09	Gazipur	82	190	436	112	116	0		17	129	1082
10	FP-10	Connaught Place	126	85	269	71	38				15	604
11	FP-11	Chandni Chowk,	106	1062	248	119	28	1278	275	771	637	4524
12	FP-12	Sarojini Nagar	44	172	119	19	0					354
13	FP-13	Lajpat Nagar	246	204	195	68	45	190				948
14	FP-14	Pitampura	77	267	170	34	17	370				935
15	FP-15	Nehru Place*	197	304	39	13	0	29				582
16	FP-16	Gandhi Nagar*	215	599	462	119	68	22				1485
17	FP-17	Rajouri Garden	116	301	361	25	22	91		0		916
18	FP-18	Narela	49	248	301	165	243	0	0		37	1043
19	FP-19	Najafgarh	145	201	343	190	119					998
20	FP-20	Keshopur	61	780	564	190	126	1114	0	0		2835

** 12-Hour*

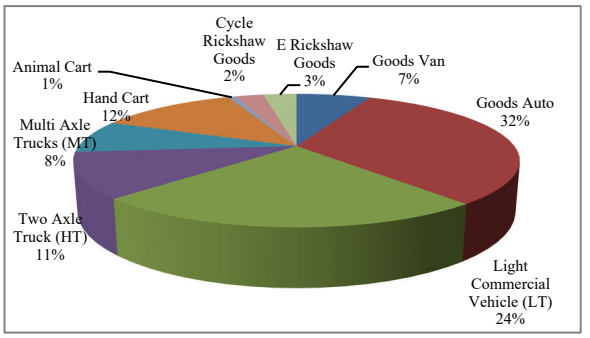


Fig. 7. Freight Traffic Composition at Different Focal Points of Delhi

4.2. 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 collected. The collected traffic data has been analysed in terms of hourly vehicular traffic distribution and traffic composition at all these locations. A typical hourly distribution of traffic volume and traffic composition at Ring Road (Naraina) is shown in Fig. 8. From Fig. 8, it can be observed that the total daily volume (24 hours) on Ring Road (Naraina) is almost 190 thousands and the peak hour is occurring in the evening between 19:00 and 20:00 Hrs with a peak volume of about 16 thousands. From Fig. 8, it can be inferred that about

80% are consisting of private vehicles mainly cars and two wheelers. The freight transport is about 12% mainly consist of Goods Autos, LT, HT and MT. The summary of traffic on all the mid block locations is presented in Table 5 and traffic composition is presented in Fig. 9. From the Fig. 9, 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.

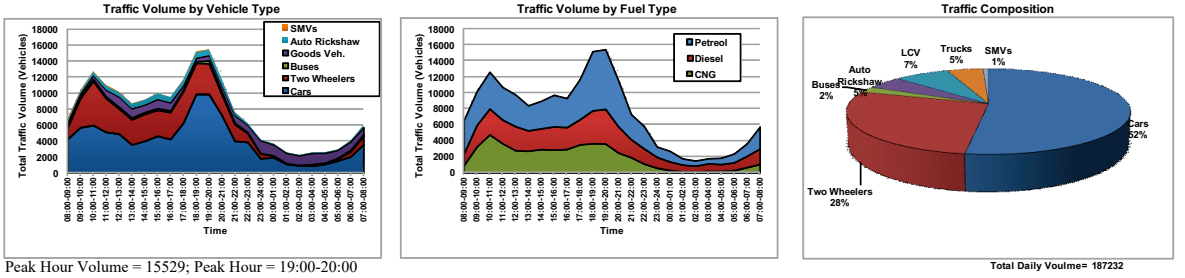


Fig. 8. Hourly Distribution of Classified Traffic Volume and Traffic Composition at Naraina on Ring Road

Table 5. Summary of Classified Traffic Volume (24 hours) at Different Mid Block Locations of Delhi

S. No	Mid-Block	Cars	Auto	Buses	TW	GA & GV	LT	HT	MT	SMV	Total
1	Ring Road (Rajghat)	51858 (37.5%)	25270 (18.3%)	1536 (1.1%)	49073 (35.5%)	4586 (3.3%)	1394 (1%)	1178 (0.9%)	1211 (0.9%)	2202 (1.6%)	138308 (100%)
2	Connaught Place (Regal Cinema)	28694 (45.1%)	13350 (21%)	4125 (6.5%)	16424 (25.8%)	227 (0.4%)	130 (0.2%)	69 (0.1%)	14 (0%)	603 (0.9%)	63636 (100%)
3	Ring Road (Naraina)	97773 (52.2%)	9235 (4.9%)	4092 (2.2%)	51717 (27.6%)	7807 (4.2%)	6086 (3.3%)	5428 (2.9%)	3725 (2%)	1369 (0.7%)	187232 (100%)
4	ITO Bridge	95755 (54.5%)	15571 (8.9%)	3875 (2.2%)	53246 (30.3%)	1457 (0.8%)	1647 (0.9%)	1536 (0.9%)	417 (0.2%)	2124 (1.2%)	175628 (100%)
5	NH-24 Bypass	81886 (56.7%)	11265 (7.8%)	5735 (4%)	29399 (20.3%)	2792 (1.9%)	4504 (3.1%)	4324 (3%)	3629 (2.5%)	973 (0.7%)	144507 (100%)

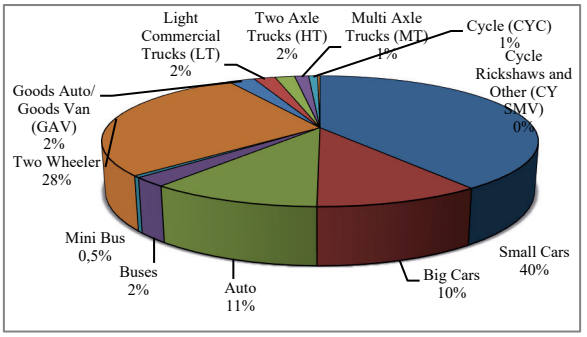


Fig. 9. Traffic Composition at Different Mid Block Locations of Delhi

5. Freight Vehicular and Travel Characteristics

5.1. Age Distribution

A total of 8,391 freight vehicles at 10 outer cordon locations and 10,091 freight vehicles at 20 focal points (within city) were intercepted and interviewed. Through the roadside interviews, age of the vehicles were recorded along with other important travel characteristics and analysed for all the sampled vehicles. From the model year (manufacturing) of vehicle data, the age of vehicle has been determined and age distribution is developed for different freight vehicle types at outer cordons and within city. Fig. 10 present the distribution of vehicles as per the

year of manufacture, as obtained at outer cordon points and focal points. From the Fig. 10, it can be found that the mean age of freight vehicles is almost same at outer cordons and within the city varying between 4.5 and 5.0 years and the share of 10 year and more old vehicles within the city is ranging from 1 to 6% and 5 to 9% at outer cordons as shown in Table 6.

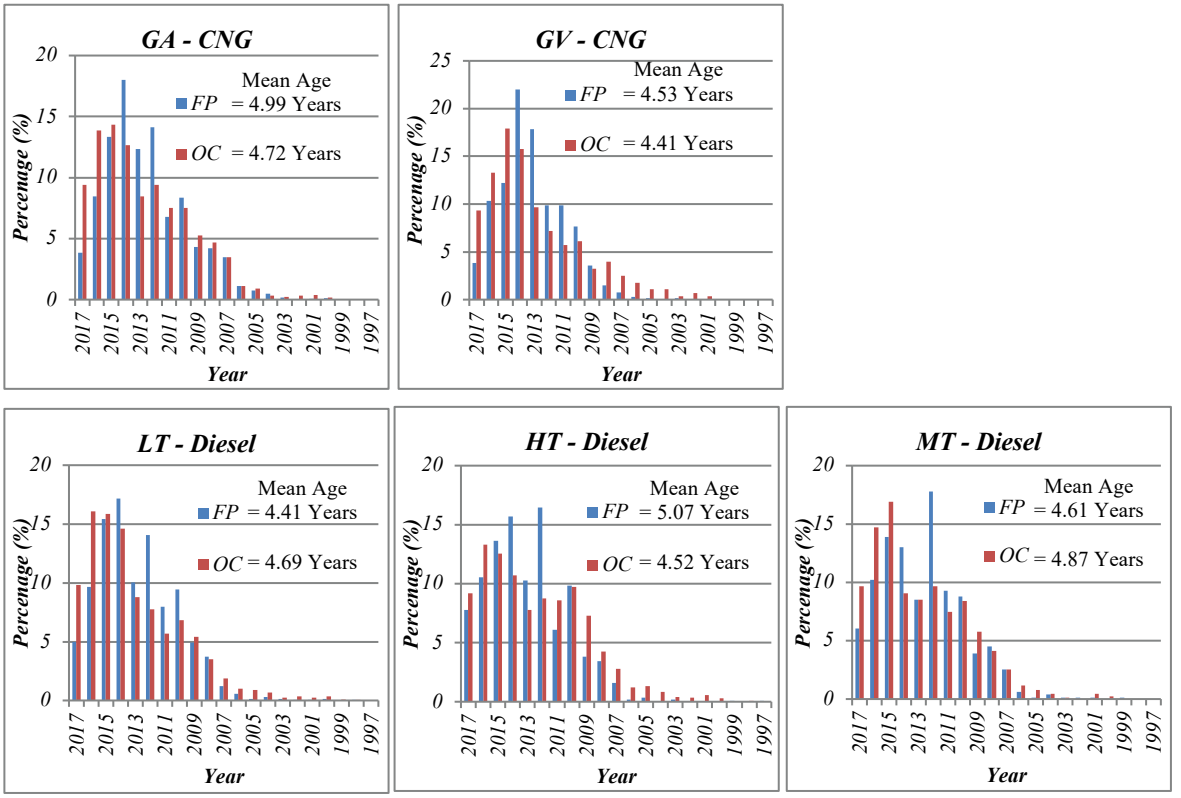


Fig. 10. Age Distribution of Different Freight Vehicles at Outer Cordons and Focal Points (within City) in Delhi

Table 6. Share of 10 Year and More Old Vehicles within the City and at Outer Cordons

S. No	Location	Age	LT	HT	MT	GA	GV
1	Outer Cordons	1 - 10 Years	94.3%	92.1%	94.3%	93.1%	92.1%
2		More Than 10 Years	5.7%	7.9%	5.7%	6.9%	7.9%
3	Within the City	1 - 10 Years	97.4%	97.6%	95.9%	93.8%	98.7%
4		More Than 10 Years	2.6%	2.4%	4.1%	6.2%	1.3%

5.2. Fuel Used

In case of freight vehicles, two types of fuels are mainly used. They are Diesel and Compressed Natural Gas (CNG). The fuel usage distribution of different freight vehicles at outer cordons and within the city is shown in Fig. 11. From Fig. 11, it can be seen that Heavy Vehicles mostly use Diesel where as Goods Auto and Goods Van almost use CNG as fuel. In case of LT, about 45% and 75% use Diesel as fuel at outer cordons and within city respectively.

5.3. Ownership of Freight Vehicle

The ownership of different freight vehicles at outer cordons and within the city has been analysed and shown in Fig. 12. From the Fig. 12, it can be seen that private company vehicles are high in case of heavy vehicles (HT and

MT) at outer cordons and within the city. The private vehicle share is almost same for light vehicles (LT, GA and GV) within the city whereas it is higher at outer cordons.

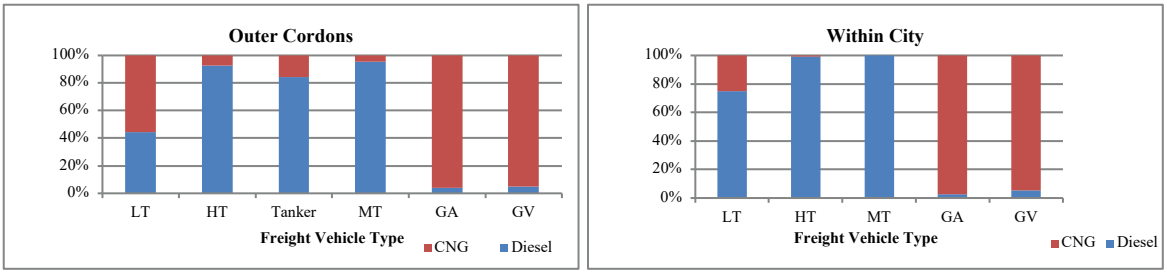


Fig. 11. Fuel Usage Age Distribution of Freight Vehicles at Outer Cordons and within the City of Delhi

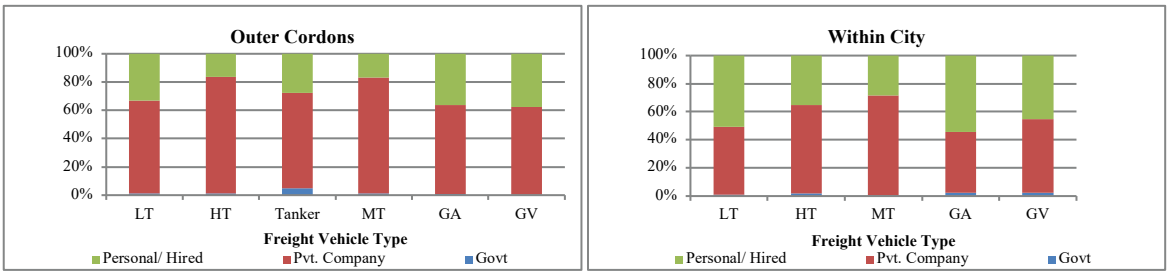


Fig. 12. Ownership Distribution of Freight Vehicles at Outer Cordons and within the City of Delhi

5.4. Fuel Efficiency

The mileage (fuel efficiency in terms of km/litre) data of different freight vehicles has been analysed and shown in Fig. 13. From the Fig. 13, it can be observed that light vehicles (LT, GA and GV) have higher fuel efficiency which are mostly run on CNG. Heavy freight vehicles have fuel efficiency about 6.5 and 4.8 km/litre for HT and MT respectively. Light vehicles namely LT has about 11 km/litre, where as GA and GV has more than 14 km/litre.

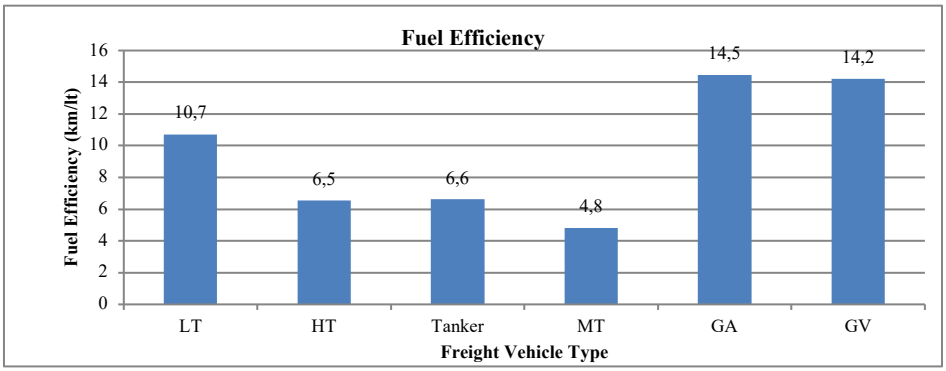


Fig. 13. Fuel Efficiency of Different Freight Vehicles

5.5. Distance Travelled

The distance travelled data in terms of km/trip, km inside city and km/day of different freight vehicles has been analysed and shown in Fig. 14. From the Fig. 14, it can be observed that average trip distance of MT is about 228 km and for HT, it is about 112 km, whereas vehicle type LT has about 70 km and smaller vehicles are having a trip

distance of about 50 km. All these vehicle types travels about 20-25 km within the city. And it can also be observed that the maximum average distance travelled in a day by these vehicle types is about 200 km. This clearly indicate that these freight vehicles face lot of congestion and other problems to travel more distances in a day experiencing lot of delays and increased operating costs.

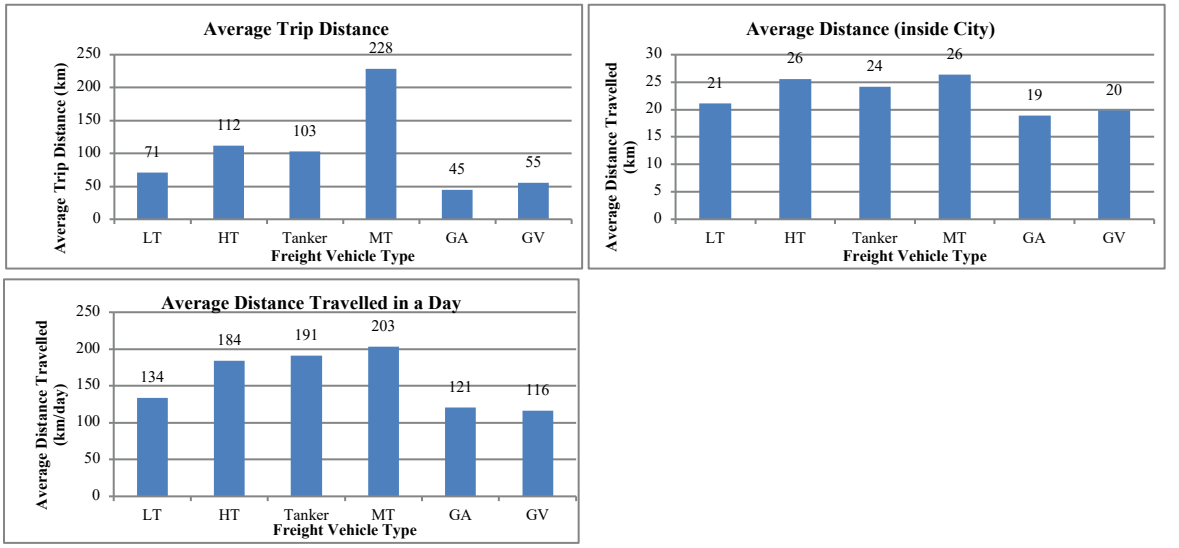


Fig. 14. Distance Travelled by Different Freight Vehicles

5.6. Frequency of Trips

The frequency of trips data of different freight vehicles has been analysed and shown in Fig. 15. From the Fig. 15, it can be observed that Light Vehicles are having more daily trips and Heavy Vehicles are more in Occasional trips.

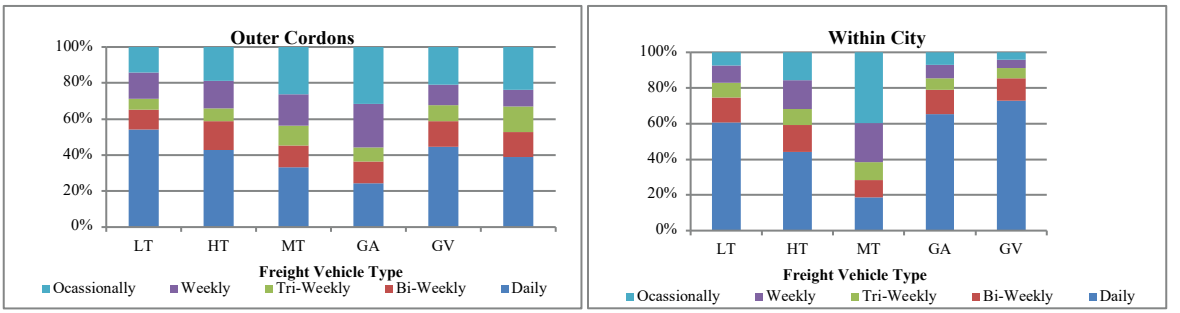


Fig.15. Frequency Distribution of Freight Vehicles at Outer Cordons and within the City of Delhi

5.7. Weight Carried

The weight carried by different freight vehicles has been analysed and shown in Fig. 16. From the Fig. 16, it can be observed that MT Vehicles are carrying average weight more than 13 tonne where as HT vehicle is carrying average loads of 5-6 tonne. The LT is carrying average weight about 2 tonne and smaller vehicles like GA and GV are carrying less than a tonne. Further, an analysis has been carried out to assess the share of empty vehicles and the result is also presented in Fig. 16. From Fig. 16, it can be seen that the 10-20% vehicles are running empty on the road network of Delhi. Further the total weight carried by these freight vehicles on the entire road network of Delhi has been estimated from average distance travelled and weight carried in a day which comes to be about 2.480 Million Metric Tonne (MMT) per day.

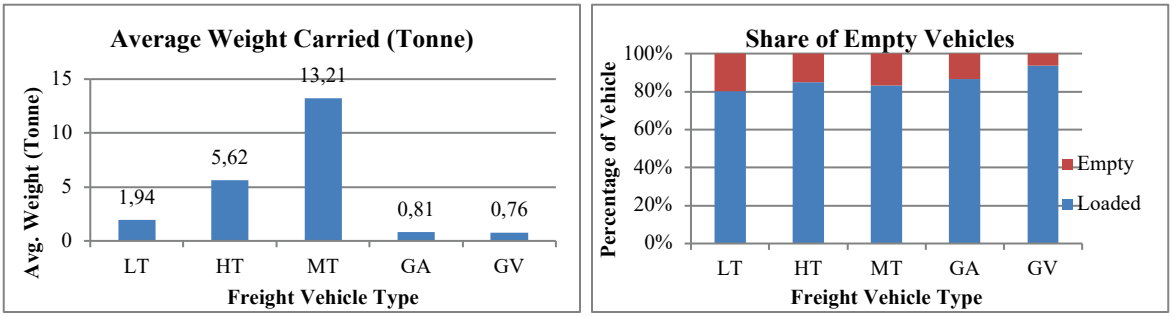


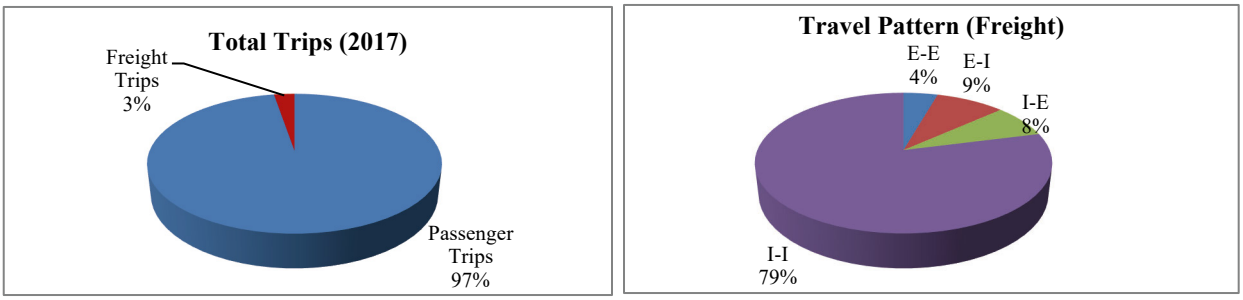
Fig.16: Average Weight Carried and Share of Empty Vehicles in Different Freight Vehicles

5.8. 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. 17 (a). From the Fig. 17, 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. 17 (b). From the Fig. 17 (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. 17: Share and Pattern of Freight Trips in Delhi

The modal split of these freight trips has been analysed and presented in Fig. 18. From the Fig. 18, 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.

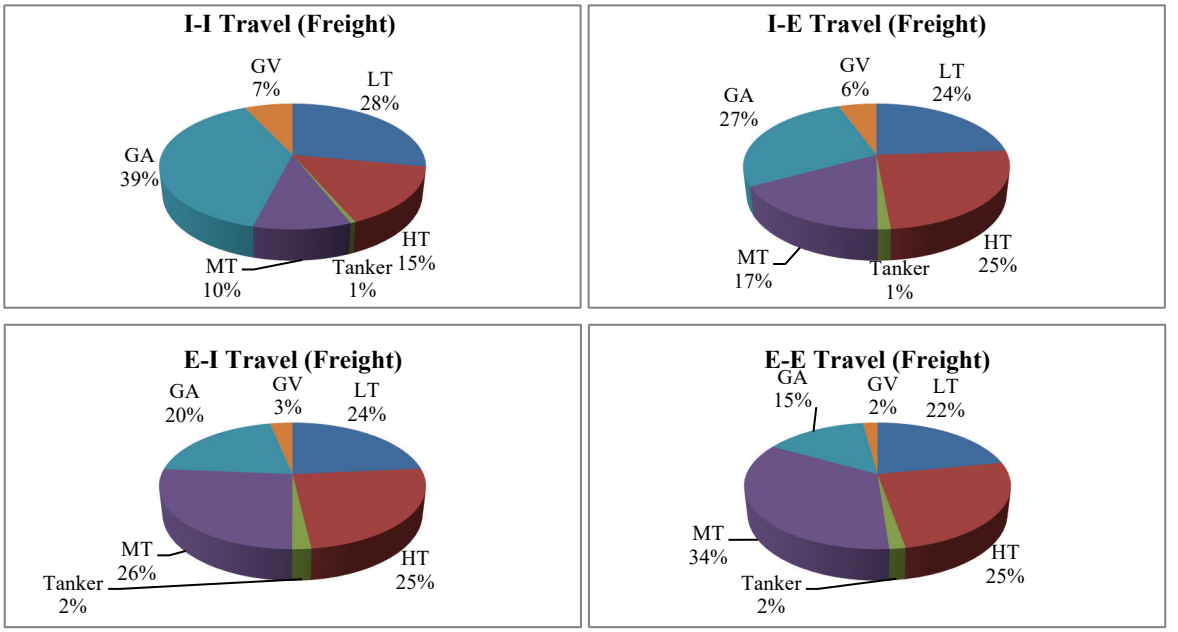
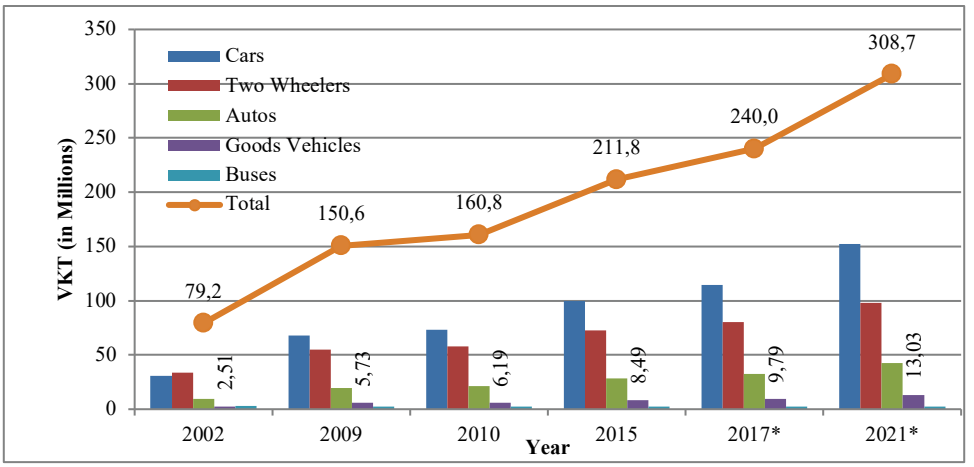


Fig. 18. Freight Modal Split for Different Types of Trips in Delhi

5.9. 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 projections have been made from the growth factors for all the vehicle types. The estimated VKT for 2017 and forecasted VKT for the year 2021 are presented in Fig. 19. From the Fig. 19, 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. 19. Estimated Vehicle Kilometers Travelled /Day for different Vehicle Types for Different Years

6. Proposed Metrics for Sustainable City Logistics (SCL)

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 7 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.

Table 7. List of Indicators to Measure New Delhi's Performance in the area of Sustainable City Logistics (SCL)

Category	Indicator	Parameter [unit]
Economic - General transport system	Level of road infrastructure	Road infrastructure density [lane-kms/km^2]
	Availability of intermodal transport access	No. of intermodal hubs according to type (rail, inland waterway, air) [#]
	Cost of congestion	Average congestion delay [veh-hours/year]
	Road quality	Percentage of road undergoing maintenance per year [%]
	Financial health	Transport budget [RP]
Economic – logistics service quality	Level of service for roads	Mean speed of freight vehicles [km/h]
	Reliability of travel time	% trips deviating from mean travel time
	Costs of transport services/ Total costs of delivery	Mean costs (fixed and running costs) per deliveries
	Accessibility for freight vehicles	Percentage of accessible roads per vehicle category [%]
Environmental	Greenhouse gasses	Well to wheels GHG emissions for UFT [ton-CO_2eq/year]
	Energy efficiency	Total energy used according to freight traffic volume [MJ/ton-km]
	Air pollution	Total emissions of air pollutants (PM10, NOx) [kg/year]
	Urban area used for UFT	Percentage of urban area used for UFT out of total city area
Social	Traffic safety	Injuries and fatalities involving freight vehicles [#]
	Jobs	Employment in city logistics (#)

7. 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 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.
- The mean age of different freight vehicles is almost same at outer cordons and within the city varying between 4.5 and 5.0 years and the share of 10 year and more old vehicles within the city is ranging from 1 to 6% and 5 to 9% at outer cordons.
- The fuel usage distribution of different freight vehicles at outer cordons and within the city results shows that Heavy Vehicles (HT and MT) mostly use Diesel where as Goods Auto and Goods Van almost use CNG as fuel. In case of LT, about 45% and 75% use Diesel as fuel at outer cordons and within city respectively.
- The ownership of different freight vehicles at outer cordons and within the city has been analysed and found that private company freight vehicles are high in case of heavy vehicles (HT and MT) at outer cordons and within the city. The private company and personal freight vehicle share is almost same for light vehicles (LT, GA and GV) within the city whereas private company freight vehicle share is higher at outer cordons.
- The mileage (fuel efficiency in terms of km/litre) of different freight vehicles has been observed that light vehicles (LT, GA and GV) have higher fuel efficiency which are mostly run on CNG. Heavy freight vehicles have fuel efficiency about 6.5 and 4.8 km/litre for HT and MT respectively. Light vehicles namely LT has about 11 km/litre, where as GA and GV has more than 14 km/kg of CNG.
- The freight vehicle types travels about 20-25 km within the city and the maximum average distance travelled in a day by these freight vehicle types is about 200 km. This clearly indicate that these freight vehicles face lot of congestion and other problems to travel more distances in a day experiencing lot of delays and increased operating costs.
- The frequency of trips of different freight vehicles analysis shows that Light Vehicles are having more daily trips and Heavy Vehicles are more in Occasional trips.
- From the results of weight carried by different freight vehicles, it has been observed that MT Vehicles are carrying average weight more than 13 tonne where as HT vehicle is carrying average load of 5-6 tonne. The LT is carrying average weight about 2 tonne and smaller vehicles like GA and GV are carrying less than a tonne.
- The share of empty vehicles is about 10-20% across different freight vehicle types. Further the total weight carried by these freight vehicles on the entire road network of Delhi has been estimated to be about 2.480 Million Metric Tonne (MMT) per day.
- In the present study, 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 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.
- Taking into account the findings from present study and the inventory of the literature, a list of indicators to measure New Delhi's performance in the area of SCL has been proposed.

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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References

TCI, IIM Calcutta, 2016. Operational Efficiency of Freight Transportation by Road in India, Joint Study Report, Transport Corporation of India (TCI) and Indian Institute of Management Calcutta, 3rd Edition, 2016.

Census, 2011. Census of India, Government of India.

Delhi Air Pollution: Real-time Air Quality Index, 2017. http://aqicn.org/city/delhi/

Air Now, 2017. https://airnow.gov/index.cfm?action=aqibasics.aqi

MoUD, 2016. Decongesting Traffic in Delhi, Report of the High Powered Committee, Ministry of Urban Development, Govt. of India, June 2016.

CRRI, 2009. Urban Road Traffic and Air Pollution in Delhi, Central Road Research Institute (CRRI), Final Report, Society of Indian Automobile Manufactures (SIAM), 2009.

Gupta, S., 2017. Role of Non -Motorized Transport in Distribution of Goods in the Metropolitan City of Delhi. Transportation Research Procedia, Elsevier Publishers, Vol. 25, pp. 978–984.

Nilanjana De-Bakshi, Nomesh B. Bolia, Geetam Tiwari and Jose Holguin-Veras, 2017. Urban Freight in Delhi: Characteristics and Mobility Restrictions. VREF Research Brief 8 (RB08-2017), Volvo Research and Educational Foundations (VREF).

CRRI, 2017. Development and Application of Technologies for Sustainable Transportation (SUSTRANS). Central Road Research Institute (CRRI), 12th Five Year Plan Project, Transportation Module, Final Report, Planning Commission 2017.

CRRI, TU-Delft, TNO, 2018. Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG). CSIR-CRRI, New Delhi in association with TU-Delft, The Netherlands and TNO, The Netherlands, Final Report, The World Bank Group, May 2018.