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traffic congestion; congestion identification; congestion speed

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IDENTIFICATION OF TRAFFIC CONGESTION ON URBAN ARTERIALS FOR HETEROGENEOUS TRAFFIC

Summary. With the rapid growth of urban traffic, the gap between traffic demand and supply is increasing by the day, and traffic congestion has become a part of urban Indian life. The following aspects have become important for transportation planners and managers: identification of the frequently congested road sections, estimating their influence on the entire road network, and improving the connectivity and accessibility of the whole road network. Identification of congestion metric is the first step in such endeavour as it would be of help in selecting appropriate remedial measures. This paper presents some insights on how to identify the traffic congestion and establish the congestion thresholds on urban arterials. Stream speed emerges as one of the candidate metrics in identifying congestion on urban arterials. Further, speed studies conducted on an interrupted heterogeneous mix of vehicles plying Delhi urban arterials is also presented.

IDENTIFICACIÓN DE LA CONGESTIÓN DEL TRÁFICO EN LAS ZONAS URBANAS PARA EL TRÁFICO ARTERIALS HETEROGÉNEOS

Resumen. Con el rápido crecimiento del tráfico urbano, la brecha entre la demanda y la oferta de tráfico está aumentando día a día, y la congestión del tráfico se ha convertido en una parte de la vida de los indios urbanos. Los siguientes aspectos se han convertido en importantes para los planificadores y gestores de transporte: identificación de los tramos de carretera congestionada frecuentemente, estimar su influencia en toda la red de carreteras y la mejora de la conectividad y accesibilidad de toda la red de carreteras. Identificación de métricas de congestión es el primer paso en esa tarea, ya que sería de gran ayuda en la selección de medidas correctivas adecuadas. Este trabajo presenta algunas ideas sobre cómo identificar la congestión del tráfico y establecer los umbrales de la congestión urbana arterials. Velocidad de flujo emerge como uno de los candidatos en la identificación de métricas de congestión en arterials urbano. Además, los estudios efectuados sobre la velocidad se interrumpa una mezcla heterogénea de vehículos que recorren Delhi arterials urbano también es presentado.

1. INTRODUCTION

Traffic congestion has been one of the major issues that most metropolises face, and thus many measures have been adopted to mitigate congestion. It is believed that identification of congestion characteristics is the first step for such efforts since it is an essential guidance for selecting appropriate measures. Congestion—both in perception and in reality—affects the movement of people and freight and is deeply tied to the history of high levels of accessibility and mobility. Traffic congestion wastes time and energy, causes pollution and stress, decreases productivity and imposes costs on society.

The two principal categories of causes of congestion are (a) micro-level factors (e.g. those relating to traffic on the road) and (b) macro-level factors that relate to overall demand for road use. Congestion is “triggered” at the “micro” level (e.g. on the road) and “driven” at the “macro” level by factors that contribute to the incidence of congestion and its severity. The micro level factors include many people and freight wanting to move at the same time and too many vehicles for limited road space and intersection capacity. Some factors that cause many trips to be delayed through a variety of traffic congestion problems are events that are irregular, but frequent—accidents, vehicle breakdowns, poorly timed traffic signals—and special events like mass social gatherings, political rallies, etc., and bad weather conditions. The essential macro level factors useful in identifying the demand for road use are land-use patterns, employment patterns, income levels, car ownership trends, infrastructure investment, regional economic dynamics, etc. There are several studies which have tried to identify congestion [1-4], and some of them also relate demand to the availability of the facilities [5].

However, there seems to be limited experience on a metric that can define the urban traffic congestion [6-7]. Thus, this paper tries to identify congestion metric(s) that can be used for quantification and mitigation.

The rest of the paper is presented in five sections. Section 2 presents a review of existing practices in identifying urban traffic congestion. Section 3 describes the case study details. Details on speed as the identified metric of congestion are discussed in Section 4. Section 5 elaborates on various hypothesis tests on the speed measurements. Lastly, the summary and recommendations are presented in Section 6.

2. LITERATURE REVIEW

2.1. Identification of the congestion measurement metrics

Congestion can generally be defined as excess demand for road travel. Supply of road travel infrastructure is not sufficient to meet demand levels to a given level of service. As a consequence, travel speeds fall and delays are explained. This general definition of congestion implies that it can be measured in various ways. Average speed, flow/density, delay and travel time variability can be used to measure the level of congestion [6].

2.1.1. Travel time and delay

Congestion is travel time or a delay in excess of that normally incurred under light or free-flow travel conditions [1]. Unacceptable congestion is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of the day. The regional council of governments in Tulsa, Oklahoma, defines congestion as travel time or delay in excess of that normally incurred under light or free-flow travel conditions [2]. Congestion is the presence of delays along a physical pathway due to the presence of other users [3].

2.1.2. Volume

In Cape Cod, Massachusetts, a traffic congestion indicator is used to track average annual daily bridge crossings over the Sagamore and Bourne bridges. This very simple measure was chosen for this island community since it is appropriate and easy to measure, and since historic data are available to monitor long-term trends. Congestion usually relates to an excess of vehicles on a portion of a roadway at a particular time, resulting in speeds that are sometimes much slower than normal or “free flow” speeds.

2.1.3. LOS

Michigan defines freeway congestion in terms of LOS F, when the volume/capacity ratio is greater than one.

2.1.4. Demand/Capacity related

Congestion prevents traffic from moving freely, quickly and/or predictably [4]. When the vehicular volume on a transportation facility (street or highway) exceeds the capacity of that facility, the result is a state of congestion [5]. Traffic congestion occurs when travel demand exceeds the existing road system capacity [8]. Congestion is a condition in which the number of vehicles attempting to use a roadway at any time exceeds the ability of the roadway to carry the load at generally acceptable service levels [9].

2.1.5. Speed

The prevailing traffic speed at any section of a roadway affects the quality of traffic at the time. Whereas excessive speeds affect the severity of road traffic accidents, crawling speeds in the urban environment is also indicative of congestion. Congestion is a function of a reduction in speeds, which is the direct cause of loss of time and leads to increased vehicle operating costs and emissions of air pollutants and increase in Green House Gas (GHGs) emissions. Therefore, the setting of a threshold that is directly related to travel speeds is most appropriate. This is in contrast to the traditionally planned use of LOS, which compares volumes with capacity and does not explicitly account for speed. A speed-based threshold accounts for the impact of congestion in a better way than a threshold based on capacity.

3. STUDY AREA

The National Capital Territory (NCT) of Delhi is spread over an area of 1,484 km^2, of which 783 km^2 is designated as rural and 700 km^2 as urban. The road network in Delhi is 33,198 km as of March 2012, having 1922 km of road length per 100 km^2; Delhi has the highest road densities in India. Road network accounts for about 21% of the total area, which is nearly double the national average of 12 to 15 % for urban areas. The reasons that can be adduced for these conditions are the ever-increasing number of vehicles in Delhi, close to 7.45 million (Economic Survey of Delhi, 2012-13). Inner Ring Road, one of the principal arterials, is selected for the study. Inner Ring Road is an around 55 km long circular road that surrounds important locations of the city and is in fact one of the longest roads in Delhi. It starts from the Interstate Bus Terminal (ISBT) at Kashmiri Gate and touches Delhi Gate, ITO, Ashram, AIIMS, Dhaulakuan and Naraina in one semi-circle. On the other half, it passes through Raja Garden, Punjabi Bagh, Azadpur and Delhi University before ending at ISBT. This road is divided into 27 road segments for data collection and analysis purposes. These three roads are studied in this study and shown in Fig. 1.

4. IDENTIFICATION OF TRAFFIC CONGESTION-SPEED

Identification of traffic congestion threshold is very important for traffic congestion analysis. This threshold is identified based on various criteria observed from field data. The procedure for identification is explained in detail in the next sections.

4.1. Free speed data analysis

Free speed data collected across different vehicle types at various locations on the Ring Road has been critically examined. The observed average free stream speed on the study corridor is 48.7 km/h. Here it may be noted that the stream speed is matching with the modelled free speed of the stream. This speed is a key input for identification of the Level of Service (LOS) on the corridor.

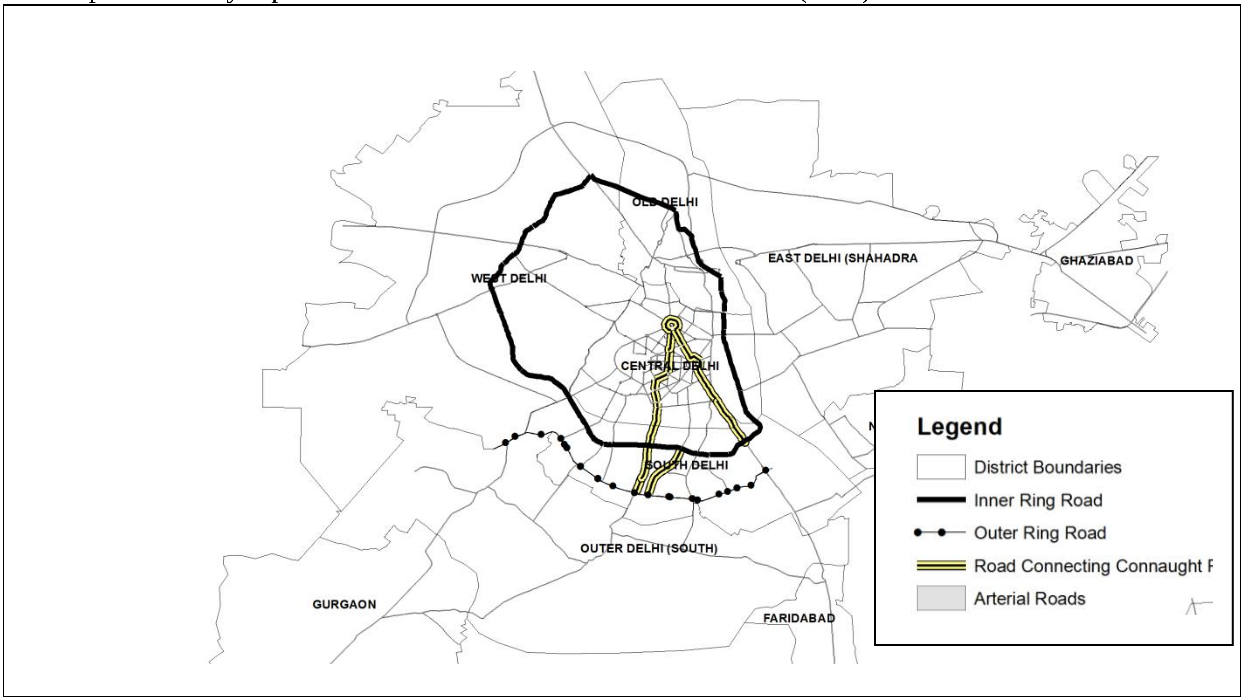


Fig. 1. Corridors selected for study
Fig. 1. Los corredores seleccionados para el estudio

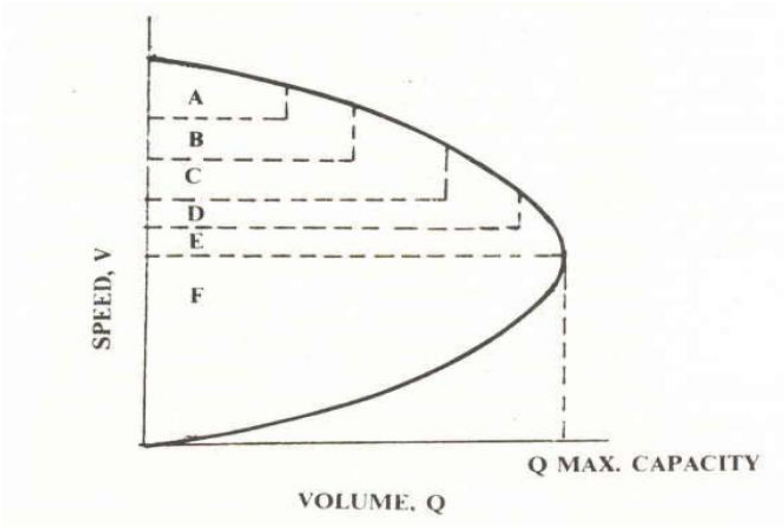
4.1.1. Levels of service and free flow

Capacity standards are normally fixed in relation to the Level of Service (LOS) adopted for the design. Level of service is defined as a qualitative measure describing operational conditions of the traffic stream and its perception by drivers and passengers. Level of Service definition generally describes these conditions in terms of factors such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort, convenience and safety. Six levels of services are recognized commonly, designated from A to F, with Level of Service A representing the best operating conditions (i.e., free flow), and Level of Service F the worst (i.e., forced or breakdown flow). Fig.2 shows the various levels of service in the form of indicative volume-flow relationship for urban conditions. Each of the levels can be described broadly in Tab. 1 [10-11]. It may, however, be noted that HCM 2010 does not prescribe a similar speed-flow curve (Fig. 3).

The Level of service F is termed as the forced flow; service flow rates at LOS C or D shall be deployed for most design or planning efforts to ensure an acceptable operating service for facility users (HCM 2010). As per HCM, the acceptable operating speed of the facility is 19.48 km/h; hence, this speed 19.48 km/h can be designated as congestion speed.

4.2. Stream speeds

The traffic stream includes a combination of driver and vehicle behaviour. The driver or human behaviour being non-uniform, traffic stream is also non-uniform in nature. It is influenced not only by the individual characteristics of both vehicle and human but also by the way a group of such units interacts with each other. Thus, the flow of traffic through a street of defined characteristics will vary both by location and time corresponding to the changes in the human behaviour.



Speed volume curve showing levels of service [11]

Different Levels of Services and Percentage of free flows [10-11]			
Level of Service	**Description**	**% of Free-flow Speed (HCM 2000 & IRC 106)**	**% of Free-flow Speed (HCM 2010)**
A	Primarily free-flow operations at average travel speeds; vehicles are completely unimpeded in their ability to manoeuvre within the traffic stream.	90	85
B	Reasonably unimpeded operations at average travel speeds, the ability to manoeuvre within the traffic stream is only slightly restricted.	70	67-85
C	Describes stable operations; however, the ability to manoeuvre and change lanes in midblock locations may be more restricted than at LOS B, and longer queues.	50	50-67
D	LOS D borders on a range in which small increases in flow may cause substantial increases in delay and decreases in travel speed.	40	40-50
E	Operations are caused by a combination of adverse progression	33	30-40
F	characterized by urban street flow at extremely low speeds	25-33	<30

Fig. 2. Different levels of services and respective free flows
Fig. 2. Diferentes niveles de servicios y sus respectivos flujos libres

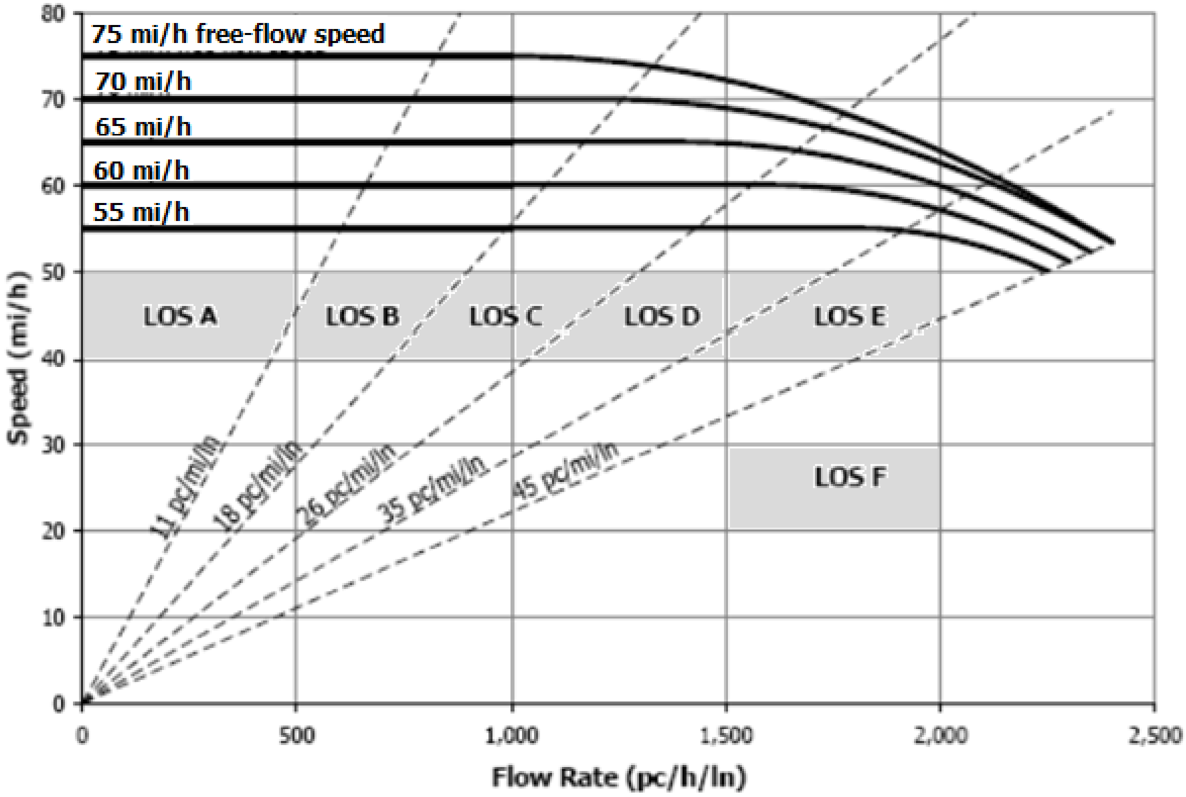


Fig. 3. Speed Flow Curve on basic freeway segments as per HCM 2010
Fig. 3. Curva de flujo de velocidad en autopista básicas segmentos como por HCM 2010

The traffic stream itself is having some characteristics on which the behaviour can be predicted. These characteristics can be classified as speed, flow and density. Speed is considered as a quality measurement of travel as the drivers and passengers will be concerned more about the speed of the journey than the design aspects of the traffic.

The speeds are calculated as per the guidelines of IRC: 106- 1990 for various level of service and summarized inTable 1

.

Table 1

Level of Service and Observed Speed on Study Corridor

LOS	% Free Speed	Speed
A	90	43.83
B	70	34.09
C	50	24.35
D	40	19.48
E	33	16.07
F	33	16.07

From the speed flow (q-k) diagram **(**Fig. 4**),** it is observed that the parabolic curve started deteriorating at the speed 30 km/h, then the congested branch starts; hence, the speed of 30 km/h can be defined as congestion speed. This speed is the one at which transition from free to congested state occurs.

4.2.1. Stream speeds prior to peak periods

An attempt was made to find out the minimum speed (i.e., 15th percentile speed) when there is no congestion situation; hence, the data was collected prior to peak hours at various locations. Using the speed data collected at various locations, cumulative percentile graphs were prepared for all the sections and one such typical cumulative percentile graph is depicted in Fig. 5. This analysis shows the 15th percentile speed, which is the minimum observed speed from surveys and is found to vary from 19 km/h to 22 km/h based on observation from all the locations in the study.

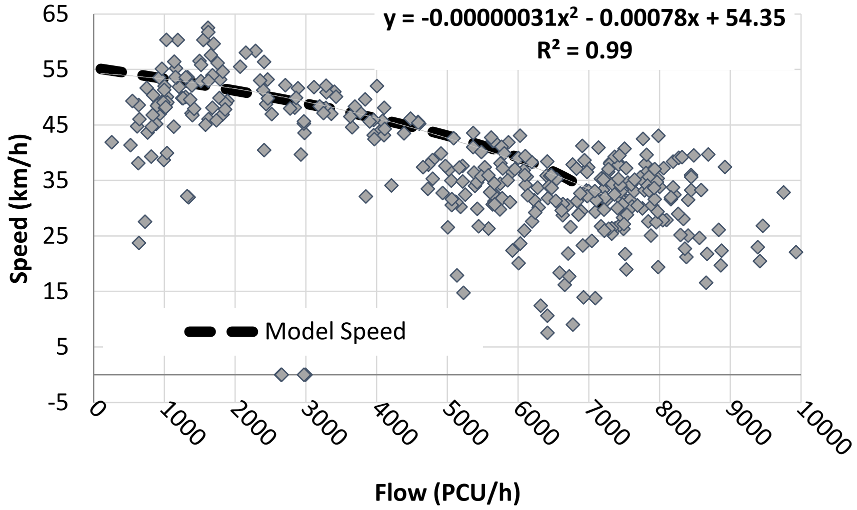


Fig. 4. Speed flow relationship
Fig. 4. Relación de flujo velocidad

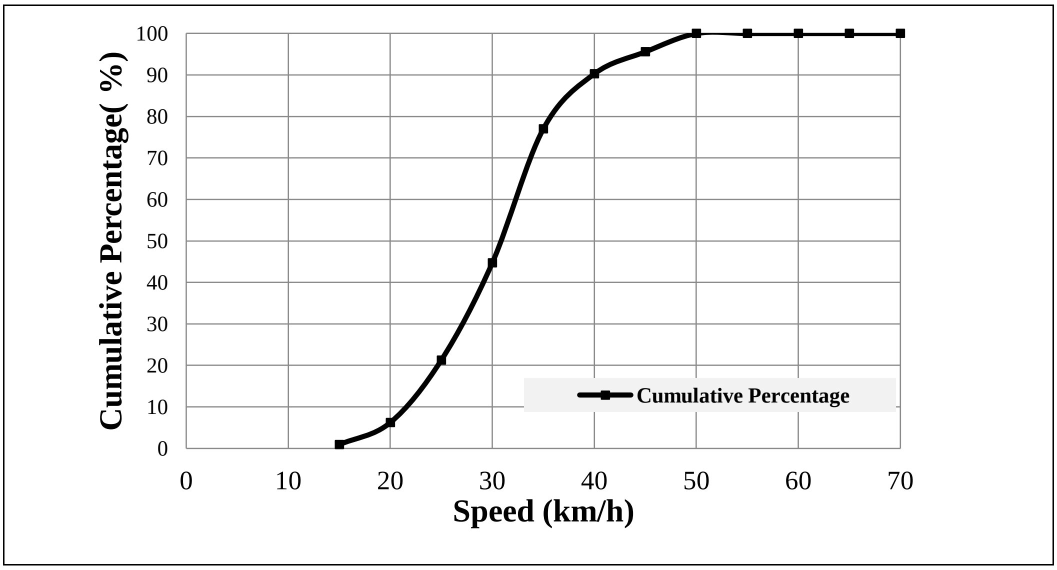


Fig. 5. Cumulative speed distribution graph at LID 16
Fig. 5. Gráfico de distribución de velocidad acumulativa en TAPA 16

4.3. Congestion stream speed

To estimate the congestion stream speed, studies were carried as mentioned in section 4.2. Traffic volume and speed studies were carried out at various locations where recurrent congestion (bottlenecks) occurs. The time of the survey is selected in such a way that the traffic stream characteristics changes from free-flowing to congested regimes. The weighted average congestion speeds from unstable flow to congestion was observed to vary between 18.13 km/h and 22.39 km/h.

A typical cumulative speed profile graph is shown in Fig. 6. It can be inferred that almost all the vehicles are travelling below the stream speed, i.e. 30 km/h, changing from unstable to congested state and resulting in stop and go conditions. It is interesting to note that the above unstable phenomenon was also observed in the stream flow macro level model presented in section 4.2. It was also observed that the 50th percentile speed is 19 km/h, and the slope of the curve is observed to vary from the 50th percentile to 100 percentile is steep [11].

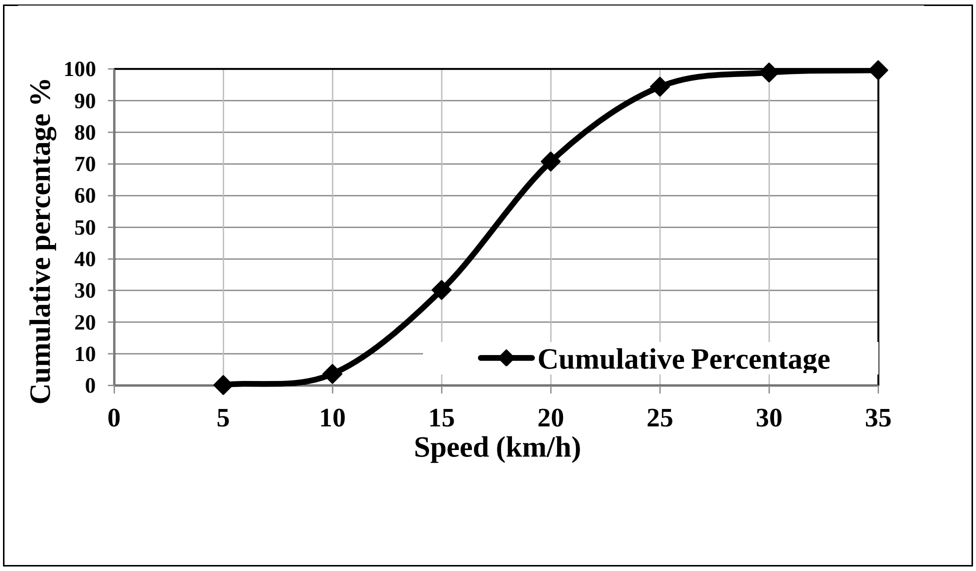


Fig. 6. Cumulative Speed profile at LID 33 under congestion state
Fig. 6. Perfil de velocidad acumulativa en TAPA 33 bajo estado de congestión

5. HYPOTHESIS TESTING FOR CONGESTION SPEED

Different field surveys were conducted to find out the free speed, stream and congestion speed. The analysis has been carried out separately and the results are discussed in previous sections. A summary of the different speeds is presented in Tab. 2.

After the analysis of the observed data, congestion speed can be defined as the 19 km/h for the urban arterials considered in this study. In the discussions that follow, testing of hypotheses was done to see whether the defined congestion speed is the value where the all vehicles lose their identity.
The congestion speed identified by various criteria should be validated by some hypotheses. Hence, the following hypotheses were formulated to test the definition of congestion speed.

5.1. Hypothesis 1

"The Standard Deviation (SD) of speeds of individual modes is high from the stream speed in the congestion state". The stream speeds are computed by taking the average of all the modes. To test this hypothesis, standard deviation of speed by different modes are calculated considering congested and free-flow conditions.

The standard deviations were calculated for the congested regime and the free-flow regime at various locations and the time duration is identified after assessing the stream speed. Fig. 7 shows the standard deviation of speed before and after congestion regime. Fig. 8 shows the variation in standard deviation at free-flow regime.

Result:

Fig. 7 (b) shows that there is less number of variations of SD in the congested state (speeds around 19 km/h) for different modes. The variations are more pronounced in the free-flow state (

Fig. 8) and the post-congestion state of the traffic as shown in

Fig. 7 (b). Thus, the null hypothesis is rejected. Hence, the deviations of speed around the 19 km/h value are less for all modes and this could be identified as threshold speed at the onset of congestion.

Table 2

Summary of the Speed Studies

S. No.	Description	Speed (km/h)	Remarks
1	Average free speed observed on study corridor from field surveys data	48.7	Free speeds calculated individual sites and averaged for corridor
2	Acceptable operating speed of the facility (HCM 2000)	19.48	LOS D (40% of free speed)
3	Minimum speed range (15th percentile speed) observed prior to morning, afternoon and evening peaks at various locations	19 – 22	Since the variation is small the lower value of 19 km/h can be taken as minimum speed on corridor
4	Congestion speed observed from speed-flow model	30	Aggregate level speed flow graph is developed for entire corridor
5	Speed (98 percentile) observed in the congestion state	30	This speed is same as the fundamental diagram congestion speed
6	50th percentile speed observed in congested state	19	This speed can be termed as the congestion speed
7	Speed at LOS E	16.05	33% of free speed

5.2. Hypothesis 2

"The speed variation amongst different modes at congestion is more than ten percent of the mean speed". The mean speeds of different modes at the time of congestion are checked for the variability; once the congestion sets in different mode speeds may not deviate significantly. To check this hypothesis, the mean speed of different modes are calculated and compared with the stream speed, which is equal to the congestion speed. The average speeds for individual modes were calculated and percentage difference with the stream speed is compared. Fig. 9 shows the variation of the speed of individual modes with respect to the stream speed.

Result:

Fig. 9 shows the stream speed and percentage mean speed variations. It can be observed from the graph that the variation of speed at congestion state (i.e., speed at 19 km/h) is less than 10%. Hence, the hypothesis is REJECTED. Thus, it can be concluded that the congestion speed for the corridor chosen is 19 km/h.

6. SUMMARY AND RECOMMENDATIONS

The term congestion is frequently used by road users and transport planners; it is often understood but not formally defined. In this study an attempt has been made to identify the congestion thresholds for urban arterials. If the congestion definition is clear then the identification and mitigation would be easy. The major findings of the study are:

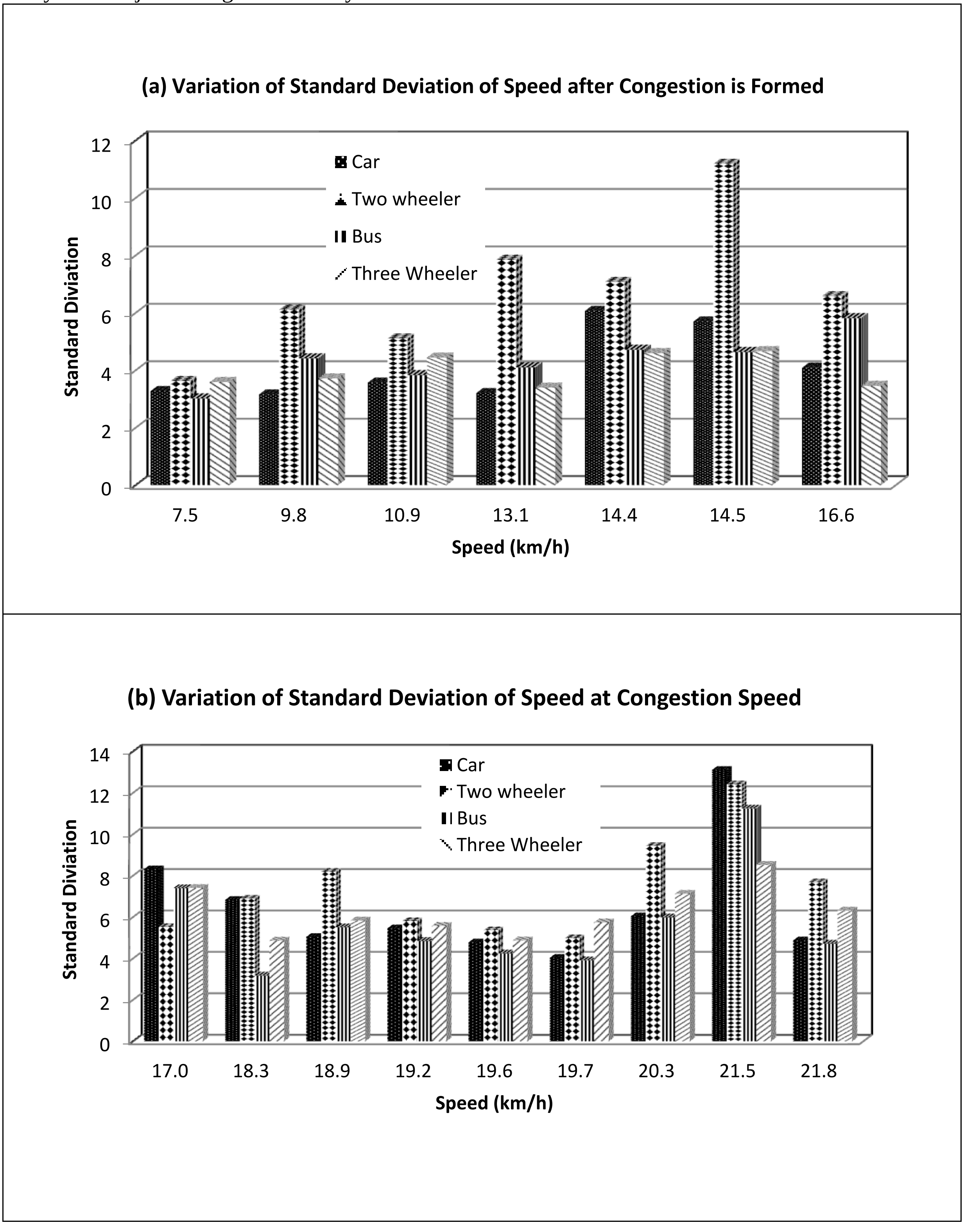


Fig. 7. Variation of standard deviation of speed at congestion
Fig. 7. Variación de la desviación estándar de la velocidad a la congestión

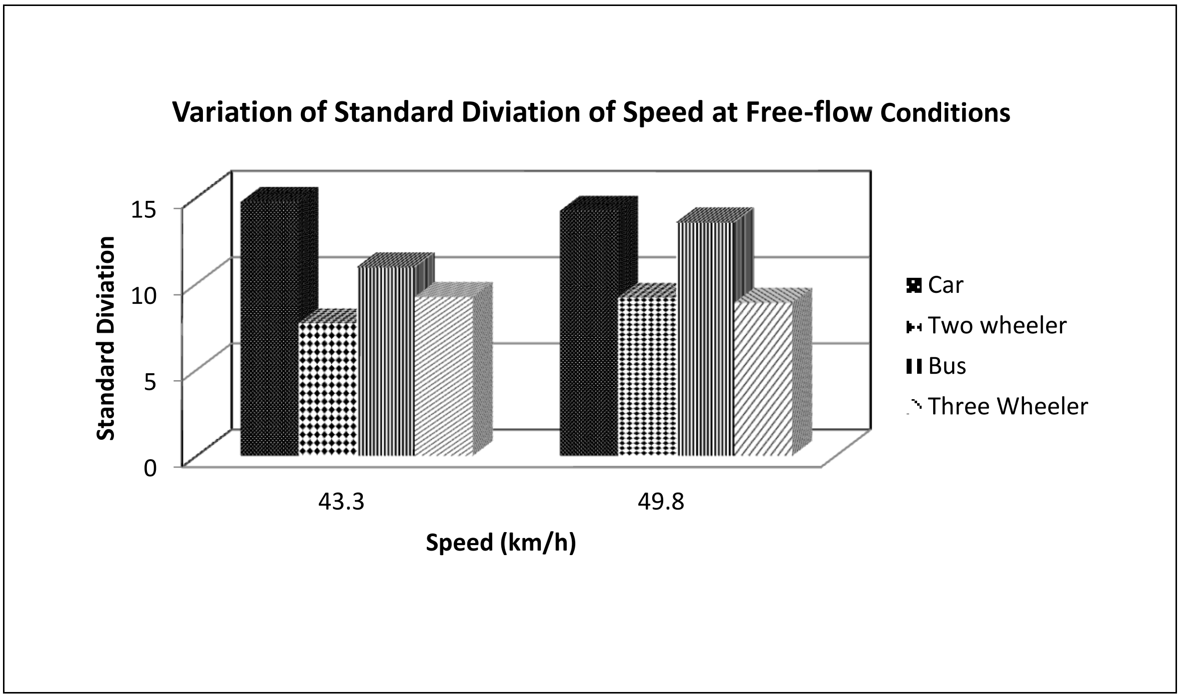


Fig. 8. Variation of standard deviation of speed at free-flow conditions
Fig. 8. Variación de la desviación estándar de la velocidad en condiciones de flujo libre de la

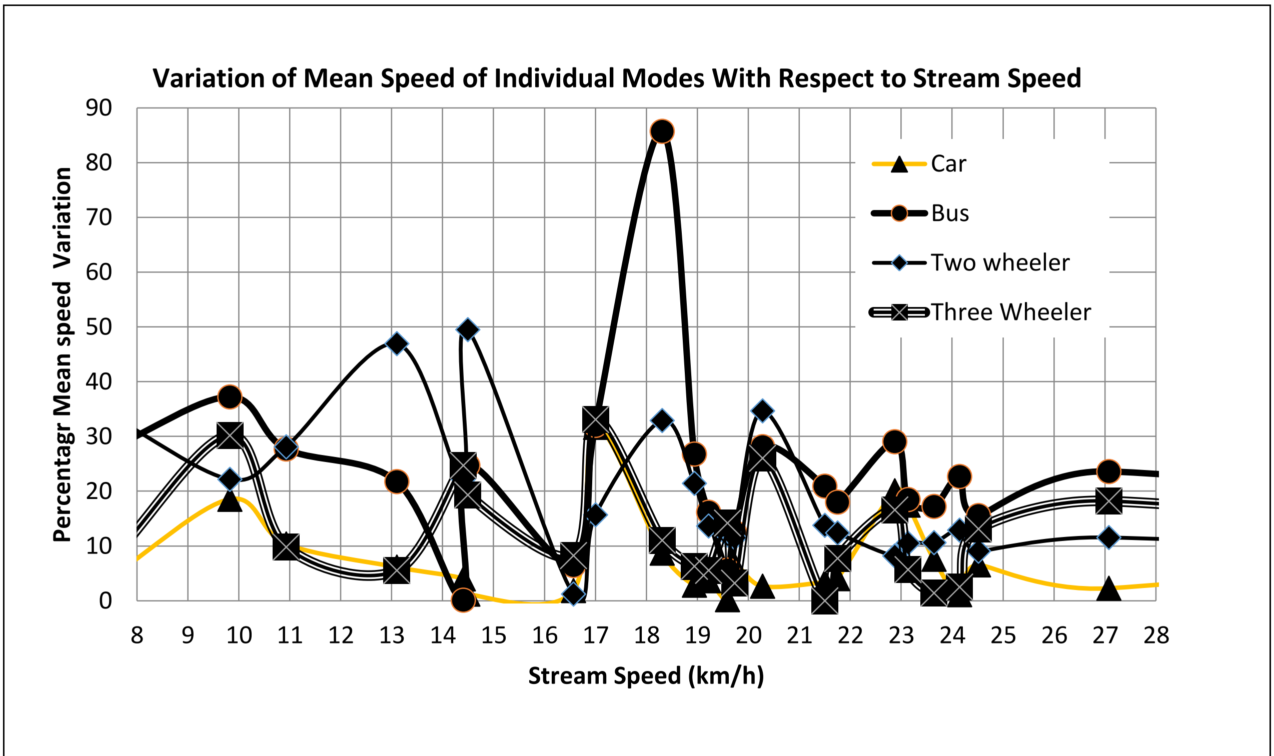


Fig. 9. Variation of mean speed of individual modes
Fig. 9. Variación de la velocidad media de los distintos modos

1. Definition of congestion speed is a complicated phenomenon for heterogeneous traffic; only spot speed techniques are not enough; the congestion defined based on free speed is differing by other analysis.

2. The free speed observed on these corridors is 57km/h as per the HCM; if any section is having a speed of 28km/h then that section can be termed as a severely congested section.
3. The stream speeds observed at normal condition are varying from 27km/h to 33km/h at this speed the streams are observed moving smoothly.
4. Congestion stream speeds are observed as 18km/h to 22 km/h; in a congestion state 50 percentile vehicles are running below the speed of 19km/h.
5. The speed observed by the floating car method shows all modes almost losing their identity at the stream speed of 19km/h.
6. From all the results the congestion speed can be defined as 19km/h for this corridor.

Further detailed studies are needed to establish the stability of speed as a congestion metric under varied traffic, road infrastructure and land-use characteristics. This would help in accepting speed or identifying another metric as one of the reliable congestion indices.

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