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# Assessment of network traffic congestion through Traffic Congestability Value (TCV): a new index

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**Abstract.** Traffic congestion is a major and growing problem in urban areas across the globe. It reduces the effective spatial interaction between different locations. To mitigate traffic congestion, not only the actual status of different routes needs to be known but also it is imperative to determine network congestion in different spatial zones associated with distinct land use classes. In the present paper, a new formula is proposed to quantify traffic congestion in the different spatial zones of a study area characterized by distinct land use classes. The proposed formula is termed the Traffic Congestability Value (TCV). The formula considers three major influencing factors: congestion index value, pedestrian movement and road surface conditions; since these parameters are significantly related to land use in a region. The different traffic congestion parameters, i.e. travel time, average speed and the proportion of time stopped, were collected in real time. Lower values of TCV correspond to a higher degree of congestion in the respective spatial zones and vice-versa and the results were validated in the field. TCV differs from the previous approaches to quantifying traffic congestion since it focuses on the causes of network congestion while in previous works the focus was generally on link flow congestion.

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## Contents:

## 1. Introduction

Major cities across the world are witnessing urbanization. The urbanization phenomenon indicates movements of people into urban areas from outside and this with an increasing population compel an increase in vehicles in cities and consequently there is direct pressure on traffic movement. Especially there is a huge increase in transport demand in Indian cities. Widespread congestion and delays are a common scenario across major cities in India (Singh et al., 2005; Pratap et al., 2011).

There are various reasons for the growing demand for transport but the most striking factor that needs to be addressed is surprisingly increasing vehicle ownership and use. Significantly this rise is faster than population growth (Gwilliam, 2010). Rao and Rao (2012) highlighted other significant factors that can be potential reasons for triggering urban traffic congestion. For example, causal factors can be categorized into two principal groups i.e. micro level and macro level. Primarily traffic congestion in a city is triggered at micro level it is; but macro level factors underlie. Micro level factors consist of movements of people at a single moment e.g. social and political gatherings. While on the other hand, macro level factors consist of land use patterns, infrastructure establishments, employment patterns, and regional economic dynamics. Moreover Boamah (2010) explained other reasons that are responsible for congestion i.e. traffic volume greater than capacity, accidents, road maintenance etc. Traffic congestion has several negative consequences ranging from increasing delays, influencing the economy since productive hours are lost in congested conditions and fuel consumption increasing air pollution.

Urban traffic congestion cannot have a single definition since it is both a physical as well as a relative phenomenon. However, it can be considered a situation where supply exceeds available road space. Both operational and user perspectives are needed to understand the behavior of congestion (Joint Transport Research Centre, 2007). A decrease in average speed, increase in travel time and vehicle queues are various facets, consequently there is a fall in land value in urban areas that are susceptible to it (Lee et al., 2008). In the past various policies were formulated and implemented to mitigate congestion. Expansion and establishment of new transport infrastructure to meet the challenges posed by its rise is a conventional approach. But there are others which were used for control, for example, discouragement of peak-period travel, incorporating a permit system to limit access to congested areas, and improvements to the road system to accommodate the same demand (Lindsey & Verhoef, 2000). Quingyu et al. (2007) insisted that external costs should be quantified as they are significant in the determination of congestion.

Earlier, several studies pertaining to the assessment and mitigation of urban traffic congestion were carried out from different perspectives. A few are directly related to the assessment of congestion (Triantis, 2011; Hamilton, 2012; Simecki, 2013; Mitsakis, 2014) while others are based on analyzing its impact on other aspects of the urban system such as the urban environment, infrastructure and mobility (Ryley, 2013; Jimenez, 2014). Investigations undertaken by Taylor et al., 1992 ; Anh, 2003; Koshak, 2006; Lee et al., 2008 ; Wen, 2008 ; Chen et al., 2009 ; Jian et al., 2011 focus on assessment and management of link traffic congestion. The main focus of these investigations is the usage of physical parameters i.e. a congestion indicator or technology to monitor and manage it. However the possible influence of network structure and its functional characteristics on congestion is overlooked in their studies. Investigations by Li & Tsukaguchi, 2005 and Menon, 2005, however, incorporated the network component. Both investigations considered the influence of the geometrical characteristics of the network on other sections of the urban system only. Further researchers (Rajagopalan & Yu, 2001; Uang & Hwang, 2003; Quingyu et al., 2007; Zhili et al., 2009; Godescu & Zurich, 2010) attempted to explain other aspects of congestion. For example, its relationship to pedestrian dynamics and the significance of congestion charges. However the scope of their investigation does not include the network structure component and hence the significance of network characteristics is not reflected in there. Furthermore, it is evident that pedestrian movements, in the absence of proper infrastructure, can disrupt traffic flow. In developing countries, the absence of an adequate infrastructure for pedestrian movement compels commuters to walk on the roads and, consequently, it affects their traffic capacity. Past investigations have not considered any variable to represent the randomness created by pedestrian movements in causing congestion. But these limitations were overcome by the studies of Sun and Zhang 2006; Xu and Sui, 2007; Oort and Nes, 2009; Liu and Ban, 2013 to some extent.

The investigation led by Xu and Sui, 2007 assessed the small world characteristics of spatial networks. However it does not establish a relationship between small world characteristics and congestion. Taylor et al. (1992) proposed a formula i.e. $(C-C_0)/ C_0$ where C is total travel time and $C_0$ is free flow time. If the value of $(C-C_0)/ C_0$ is greater than 2 then it signifies congested conditions whereas a value near zero shows a low level. Jian et al. (2011) investigated the reasons for the spatial-temporal evolution of congestion and floating car data, a geo-simulation platform and GIS technologies were used to carry out the study. Further, the status of congestion in different links was assessed using a correlation algorithm. Finally various measures were proposed to mitigate congestion. Lee et al. (2008) observed that one of the most significant reasons is the merging of roads. Therefore, the study focused on understanding the behavior of such congestion using a proposed fluid dynamic algorithm and kinematic wave theory. In the investigation, a dynamic traffic simulation tool was also developed for scenario planning and prediction. Koshak (2006) highlighted the challenges of monitoring and controlling traffic flows that the urban planners of the city of Makkah, Saudi Arabia face during the period of the Hajj. In the investigation, the potential of web-based geographic systems as a tool to spread awareness of traffic planning among urban planners and urban designers was demonstrated. Chen et al. (2009) employed the concept of mobile agent technology and multi-agent systems to develop a traffic management system to tackle uncertainty in a dynamic environment. The result of the investigation suggested that the use of mobile agent technology and multi-agent systems increased system flexibility.

Anh (2003) attempted to determine the causes and effects of traffic congestion in Hanoi. The system dynamic approach was applied to study the existing transportation system and provide long-term policies to alleviate traffic congestion. Wen (2008) developed an automatic traffic light control system to assess traffic status. It contains six sub-models; each one represents a route with three intersections. The model takes inter-arrival and inter-departure times as inputs to simulate the physical movement of the cars on road. It was found that the system is effective in controlling the flow of traffic in urban areas. Li & Tsukaguchi (2005) proposed a classification methodology to establish the relationship between pedestrian route choice behavior and network topology. The findings of the proposed investigation indicated that pedestrian route choice behavior can vary within the same network; it in fact depends upon the start and destination points. Menon (2005) demonstrated the use of a network analysis tool to determine the optimal route between two points on the basis of travel expense which can be either travel time or distance between two points. The results of the investigation provide information regarding direction of travel on the routes. Godescu and Zurich (2010) attempted to establish a very interesting relationship between efficient stock market dynamics, pedestrian route choice behavior and traffic control. Qualitative approaches were employed to prove the hypothesis. It was emphasized in the paper that qualitative approaches can be used for practical purposes. However, the authors suggested that qualitative approaches can be quantified on the basis of empirical observations. Zhili et al. (2009) highlighted the importance of charges to mitigate congestion. The paper predicted a scenario in the mega cities of China under congestion charges. It was observed that traffic conditions could improve with the implementation of such a charge. However, it was advised in the study that charges should be implemented according to local conditions. Rajagopalan and Yu (2001) proposed a model to make equipment choice decisions in a multi-product, multi-machine and single stage environment. Congestion effects were introduced into the model. The results showed that the model succeeded in providing solutions to industry-size problems.

Uang and Hwang (2003) conducted an investigation to analyze the differences in driving performance while using both traditional paper and electronic route maps. In the investigation, congestion information and map-scale sizes were included to investigate the impact on workload and the subjective feelings of drivers. Various parameters such as trip duration, driving speed, navigation errors and heart rates were identified as criteria to assess driving performance. The results of the research indicate that differences in performance depend upon the design characteristics of an electronic route map. Quingyu et al. (2007) first investigated the reasons for the evolution of traffic congestion. Consequently, external costs as a consequence were categorized into different classes i.e. extra travel time costs, environmental pollution costs, accident costs and fuel consumption costs. Finally each class was quantified to implement road congestion pricing. Xu and Sui (2007) investigated the emergence of small world characteristics in spatial networks using two network autocorrelation statistics i.e. Morgan's I and Getis-Ord's G. The study was undertaken for three transportation networks at different levels i.e. national, metropolitan and intra-city. The results indicate that the network structure and its dynamics are responsible for the evolution of small world characteristics. Further Oort and Nes (2009) highlighted that studies on the relationship between network structure and service regularity are rare. The proposed investigation established a quantitative relationship between network structure and service regularity. It was discovered that a direct influence of network structure on capacity efficiency exists. Consequently this may also affect operational costs. Liu and Ban (2013) assessed status of urban traffic congestion from a complex network perspective. Floating car data was used for the investigation and it was found that there is spatial-temporal variation in the distribution of traffic congestion. Internal mobile regularities of an urban system are responsible for the spatial temporal variations.

Sun and Zhang (2006) attempted to forecast traffic flow using Bayesian networks. In the transportation network, the traffic flows of adjacent links were considered to form a Bayesian network. A Gaussian Mixture Model consisting of joint probability distribution between the cause nodes and effect nodes was employed for traffic flow forecasting. The criterion of minimum mean square error was used for traffic flow forecasting. The significance of the study lies in its departure from conventional approaches to assess congestion. It considers information from adjacent links other than the current link.

Ranchi city, capital of Jharkhand State, India was chosen to carry out the present investigation. The study area is covered in the Survey of India topo sheet No. 73 E/7 with spatial extension from 23° 24' 06" N to 23° 25' 47" N and 85° 26' 57" E to 85° 27' 26" E. It is shown in the Fig. 1.

Most of the routes have mixed traffic. To make the situation worse, land use along the roads is random and movements of people along and across the roads is a common sight in the city. The impact of land use on congestion cannot be denied (IRC, 1990), consequently, almost all the routes in the area are vulnerable to point congestion. Economic growth compelled the establishment of a huge array of infrastructure in the city and thereby, attracting a swarming of people and traffic. However, the absence of transport infrastructure to accommodate the huge increase can be felt in any part of the area. There are other reasons for the traffic menace which cannot be ignored, such as a highly irregular street pattern, an absence of effective traffic management measures etc. The relationship between length of routes and congestion is very interesting: if the speed of a vehicle decreases due to some impedance, it can recover its average speed if route length is long enough. Otherwise, traffic flow will be prevented from recovering from any kind of shock. Ranchi faces a similar kind of problem because of its shorter road lengths.

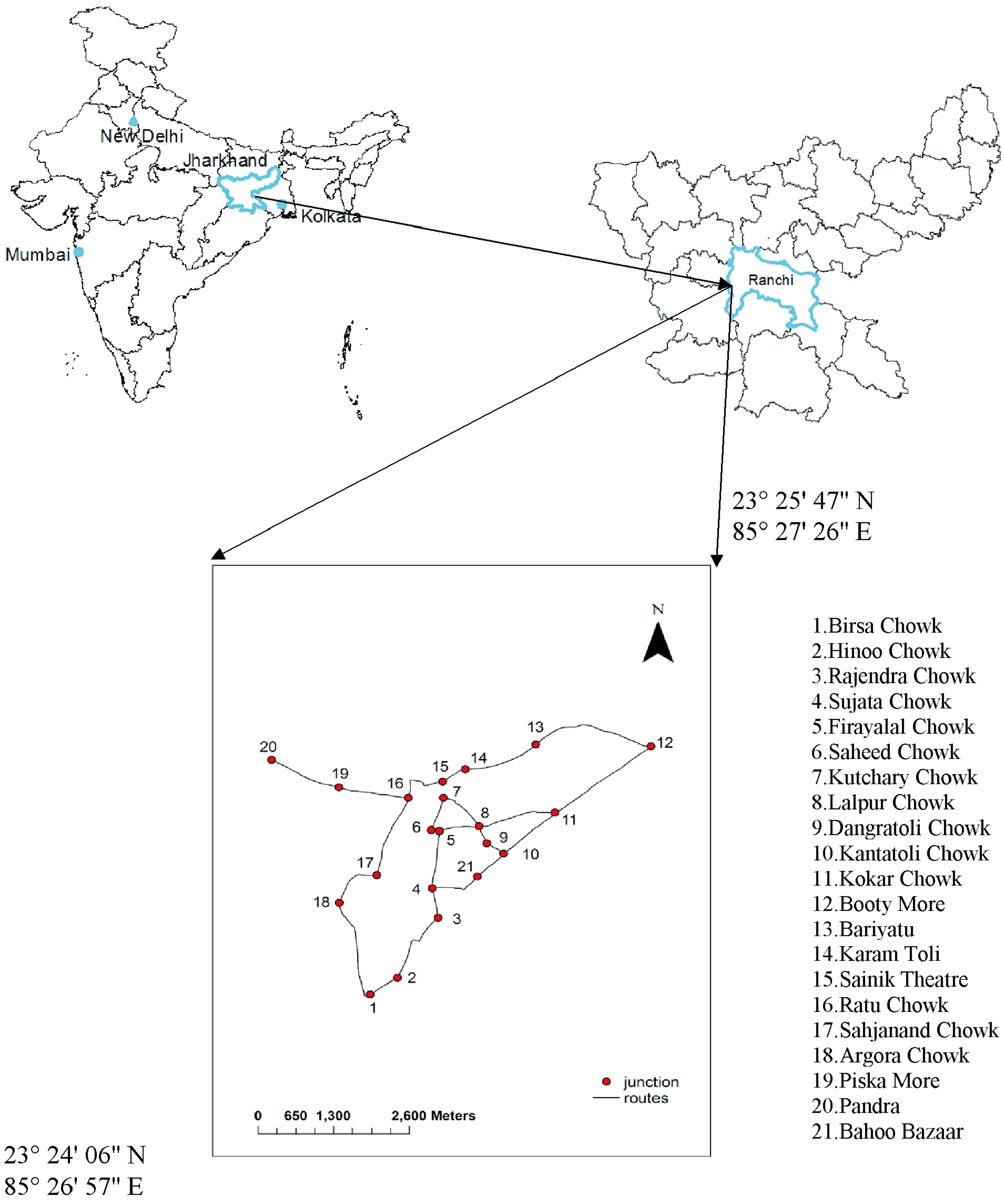

**Fig. 1.** Study area

*Source*: Authors

The present study differs from past investigations in its perception toward assessment of congestion. The objective of the research is to assess network congestion rather than link flow congestion. Determination of link flow congestion gives an idea of the status of traffic flow on a particular route. It signifies whether a balance between traffic capacity and volume exists or not. It considers local factors to quantify congestion and its influence is restricted to a certain route only. Besides establishing new infrastructure to accommodate a rising load, alleviation of congestion needs diversion of traffic flow from one route to another to lessen the demand on a particular route. The diversion is based on the intensity of congestion in different sections of the urban area. Instead of considering only link congestion, congestion in a cluster is considered which can be more representative in understanding the causes and consequences within and beyond a particular route. The proposed formula to quantify network congestion enables the status in different zones of the area to be assessed. Consequently, it can be used to identify the city locations where links are required to mitigate congestion. Further, the direction of traffic flow among zones can be determined.

## 2. Research methodology

The research methodology consists of five different parts for the assessment of network traffic congestion. The study began with the pre-processing of data i.e. geo-referencing and digitization of the road network map to make it suitable for further analysis. Then a detailed field survey was done to collect the physical congestion parameters i.e. Average Speed, Free Flow Time, Total Travel Time and Congestion Index Value (CIV). Moreover the impact of other attributes such as pedestrian movement and road surface conditions on different routes was assessed based on empirical observations. Having done pre-processing and data collection, a GIS traffic database was created, then a relationship was established among the variables that define network congestion. Finally the results obtained from the present research were validated in the field. A range of factors can affect traffic flow, and their characteristics can be geometrical or functional. Geometrical factors such as those related to traffic flow (Average Speed, Free Flow Time, Total Travel Time and Congestion Index Value) can be quantified easily. However it is not easy to quantify the functional characteristics of a factor such as pedestrian movement. Therefore both quantitative and qualitative perspectives were involved in the investigation.

## 3. Determination of the Traffic Congestability Value (TCV)

The assessment of network traffic congestion in the study area requires information regarding the status of traffic on different routes in the city, and the condition of road surfaces along the routes of the study area. Further the behavior of pedestrians on different routes needs to be assessed to determine the compound effect of these parameters on traffic congestion. Therefore the investigation began with a collection of traffic data, assessment of road surface conditions and pedestrian behavior in different parts of the study area. Then different parameters (criteria) were formulated to represent network congestion better. Finally different spatial zones were identified and network congestion was quantified for those zones.

### 3.1. Collection of traffic data

Rigorous field survey was done to assess the status of congestion, road surface conditions and the behavior of pedestrian movements on different routes (from Birsa Chowk to Booty More). The moving observer technique (Taylor et al., 1999) was used to collect various parameters, i.e. free flow time, total travel time etc., on different routes of the city. In the moving observer technique, we drove in real time to collect physical congestion parameters using GPS and stopwatches. The data was collected for different time intervals comprising a lean period (06:00 AM to 08:00 AM) and a peak period (02:00 PM to 05:00 PM). Collection of data at different time periods enables us to understand the spatial-temporal complexities of congestion. Then the status of traffic congestion, i.e. the congestion index value, was computed using the formula $(C-C_0) / C_0$ (Taylor et al., 1992). However, it is not feasible to quantify the condition of road surfaces and pedestrian behavior in different sections of the study area. Instead the assessment of these factors was made on the basis of empirical observations.

### 3.2. Assignment of congestion weights to different routes

Having determined the values of $(C-C_0) / C_0$, i.e. congestion index values for different routes of the city, a congestion weight is assigned to all routes on the basis of a relative weighting. The formula for relative weighting is as follows:

$$\text{Congestion weight} = f(CIV) = CIV_c / CIV_{max}.$$

Where
$CIV_c$: Congestion Index Value of current route.
$CIV_{max}$: Maximum Congestion Index Value.

The congestion weights for different routes are presented in the Table 1 where a weight approaching 1 represents congested conditions.

**Table 1.** Representation of congestion weights and values for Traffic Management Parameters (TMP) for different routes

| Route ID | Routes | Congestion Index Value (CIV) | Congestion weight | Pedestrian weight | Road surface weight | TMP |
|---|---|---|---|---|---|---|
| 1 | Birsachowk to Hinoochowk | 0.79 | 0.33 | 0.8 | 0.7 | 0.75 |
| 2 | Hinoochowk to Rajendrachowk | 1.06 | 0.44 | 0.7 | 0.7 | 0.70 |
| 3 | Rajendrachowk to Sujatachowk | 0.69 | 0.29 | 0.5 | 0.5 | 0.50 |
| 4 | Sujatachowk to Firayalalchowk | 2.41 | 1.00 | 0.2 | 0.1 | 0.15 |
| 5 | Firayalalchowk to Saheedchowk | 2.23 | 0.93 | 0.2 | 0.2 | 0.20 |
| 6 | Saheedchowk to Kutcharychowk | 0.60 | 0.25 | 0.7 | 0.7 | 0.70 |
| 7 | Kutcharychowk to Lalpurchowk | 1.45 | 0.60 | 0.5 | 0.6 | 0.55 |
| 8 | Lalpurchowk to Dangratolichowk | 0.77 | 0.32 | 0.7 | 0.7 | 0.70 |
| 9 | Dangratolichowk to Kantatolichowk | 1.38 | 0.57 | 0.5 | 0.5 | 0.50 |
| 10 | Kantatolichowk to Kokarchowk | 0.97 | 0.40 | 0.8 | 0.8 | 0.80 |
| 11 | Kokarchowk to Booty more | 0.25 | 0.10 | 0.9 | 0.9 | 0.90 |
| 12 | Booty more to Bariyatu | 0.09 | 0.04 | 0.8 | 0.9 | 0.85 |
| 13 | Bariyatu to Karamtoli | 0.23 | 0.10 | 0.8 | 0.7 | 0.75 |
| 14 | Karamtoli to Sainik theatre | 0.21 | 0.09 | 1 | 0.9 | 0.95 |
| 15 | Sainik theatre to Ratuchowk | 0.67 | 0.28 | 0.6 | 0.5 | 0.55 |
| 16 | Ratuchowk to Sahjanandchowk | 1.06 | 0.44 | 0.7 | 0.8 | 0.75 |
| 17 | Sahjanandchowk to Argorachowk | 0.17 | 0.07 | 0.9 | 0.9 | 0.90 |
| 18 | Argorachowk to Birsachowk | 0.14 | 0.06 | 0.9 | 0.9 | 0.90 |
| 19 | Ratuchowk to Piska | 2.37 | 0.98 | 0.1 | 0.1 | 0.10 |
| 20 | Piska to Pandra | 1.48 | 0.61 | 0.4 | 0.5 | 0.45 |
| 21 | Firayalalchowk to Lalpurchowk | 1.68 | 0.70 | 0.5 | 0.4 | 0.45 |
| 22 | Lalpurchowk to Kokarchowk | 1.23 | 0.51 | 0.5 | 0.4 | 0.45 |
| 23 | Sujatachowk to Bahoobajaar | 0.88 | 0.37 | 0.6 | 0.7 | 0.65 |
| 24 | Bahoobajaar to Kantatolichowk | 1.02 | 0.42 | 0.7 | 0.6 | 0.65 |

*Source*: Authors

### 3.3. Identification and quantification of the Traffic Management Parameter (TMP)

Irrespective of the transport infrastructure, i.e. an adequate number of routes to handle the traffic load, there are other factors which need to be considered to make traffic flow smooth. These factors could contribute to urban congestion. In the present investigation, the condition of road surfaces and pedestrian movement are seen as influencing parameters which have a direct impact over traffic flow. On the basis of empirical observations, knowledge-based weightings i.e. pedestrian weight and road surface weight (Table 1) are assigned to each and every route on a scale of 0 to 1 representing road surface conditions and pedestrian movements. A weight near 0 represents a worse situation whereas weight approaching 1 represents the best. Since both parameters, i.e. pedestrian movement and road surface conditions, can compound the degree of congestion, the mean of these weights is computed for all routes concerned and is termed the Traffic Management Parameter (TMP) (Table 1).

### 3.4. The creation of different spatial zones in the study area

As discussed in section 1, land use has a significant role in influencing traffic flow. Moreover there is significant variation in land use i.e. commercial, residential, industrial or mixed classes along the routes of the study area. Therefore different spatial zones are created on the basis of their land use characteristics. Here, a spatial zone does not correspond to some polygonic structure rather it consists of different routes (road network) having the same patterns of land use along them. The different spatial zones of the city are shown in Fig. 2.

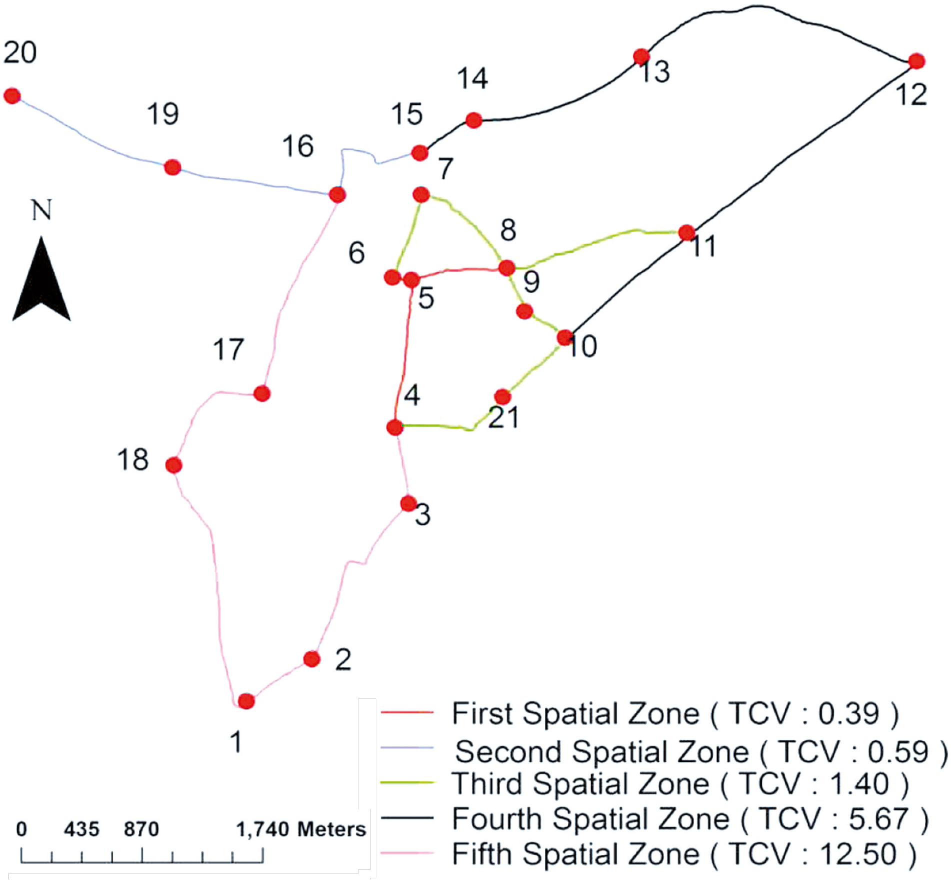

**Fig. 2.** Traffic Congestability Value (TCV) for different spatial zones

*Source*: Authors

### 3.5. Computation of influencing variables of the proposed formulae

For each and every spatial zone, the Mean Congestion Index Value (MCIV) (Table 2) and Mean Traffic Management Parameter (MTMP) (Table 2) are computed. The MCIV represents the traffic load in a particular zone and the value of MTMP indicates traffic managerial strategies. A higher value of MCIV represents congested condition whereas lower values of MTMP signify worse road surface conditions and pedestrian movements in a spatial zone.

**Table 2.** Traffic Congestability Value (TCV) of different zones in the study area

| Spatial zones | Routes | Mean Congestion Index Value ( MCIV) | Mean Traffic Management Parameter (MTMP) | Traffic Congestability Value (TCV) |
|---|---|---|---|---|
| 1 | Sujatachowk to Firayalalchowk<br>Firayalalchowk to Saheedchowk<br>Firayalalchowk to Lalpurchowk | 0.70 | 0.27 | 0.39 |
| 2 | Sainik theatre to Ratuchowk<br>Ratuchowk to Piska<br>Piska to Pandra | 0.63 | 0.37 | 0.59 |
| 3 | Saheedchowk to Kutcharychowk<br>Kutcharychowk to Lalpurchowk<br>Lalpurchowk to Dangratolichowk<br>Dangratolichowk to Kantatolichowk<br>Lalpurchowk to Kokarchowk<br>Sujatachowk to Bahoobajaar<br>Bahoobajaar to Kantatolichowk | 0.43 | 0.60 | 1.40 |
| 4 | Kantatolichowk to Kokarchowk<br>Kokarchowk to Booty more<br>Booty more to Bariyatu<br>Bariyatu to Karamtoli<br>Karamtoli to Sainik theatre | 0.15 | 0.85 | 5.67 |
| 5 | Ratuchowk to Sahjanandchowk<br>Sahjanandchowk to Argorachowk<br>Argorachowk to Birsachowk<br>Birsachowk to Hinoochowk<br>Hinoochowk to Rajendrachowk<br>Rajendrachowk to Sujatachowk | 0.06 | 0.75 | 12.50 |

*Source*: Authors

### 3.6. Substitution of variables in the formulae

Substituting the values of MCIV and MTMP in the formulae:

$$TCV = 1/MCIV * MTMP$$

Finally the TCV of different zones in the study area was computed. A lower value represents congested conditions in the zones. The value of Traffic Congestability Value (TCV) for different zones is presented in the Table 2.

## 4. Results and discussion

The Traffic Congestability Value (TCV) enables determination of network congestion in different zones. Previous research focused only on the causes of link flow congestion. Since TCV can be used to determine the congestion status in the different spatial zones of a study area, it can be used for effective monitoring and control of congestion. In addition, the determination of the spatio-temporal variation in the TCV would facilitate development of a suitable remedial strategy to alleviate congestion on a sustained basis. The computed values of the congestion index value (CIV) and the traffic management parameter (TMP) for different routes in the study area are presented on Table 1. It is obvious from Table 1 that route 4 has the highest congestion index value i.e. 2.41 followed by routes 19 and 5 with congestion index values of 2.37 and 2.23 respectively. However, the lowest TMP value is associated with route 19 signifying worse road surface conditions and pedestrian movements on the route. Thorough analysis of Table 1 indicates that routes having congested conditions have TMP values varying between 0.10 and 0.55. Route 14 has the highest TMP value, i.e. 0.95, indicating the least influence of road surface conditions and pedestrian movements in creating chaos in the flow of traffic. This observation is confirmed by the occurrence of a low value of CIV on route 14, i.e. 0.21 representing smooth traffic flows on this route segment. Having determined CIV and TMP values, the network congestion was quantified on different routes of the city. The results are presented in Table 2. The first spatial zone comprising routes 4, 5 and 21 is the most congested with a TCV of 0.39 followed by the second spatial zone (routes 6, 7, 8, 9, 22, 23 and 24) with 1.40 as TCV. The least congested zone is the fifth with a TCV of 12.50. It is also worth noting the relationships between the TCV, CIV and MTMP in a spatial zone. The most congested i.e. first spatial zone has the highest Mean Congestion Index Value (MCIV), i.e. 0.70, and the least value of the Mean Traffic Management Parameter (MTMP), i.e. 0.27.

## 5. Conclusions

In the present investigation, network congestion in different spatial zones is determined with the help of a new formula i.e. the Traffic Congestability Value. The lower its value, the higher is the congestion in that spatial zone and vice-versa. Effective transportation depends more on network congestion than link flow congestion. The TCV quantifies network congestion in a spatial zone, therefore it gives a more realistic view of the situation in a zone by considering the various influencing factors i.e. number of route segments, pedestrian movements and road surface conditions, and would therefore serve as a potential indicator for traffic management personnel to take appropriate measures to alleviate congestion.

The proposed TCV consists of variables representing both capacity and probable irregularities in a transportation network. For example, the number of routes represents the capacity of the transportation network to carry its load. While on the other hand, variables like pedestrian movements and road surface conditions were used to assess the internal regularities of the transportation network. Generally, variables pertaining to the representation of the capacity of a transportation network remain the same across different areas. However the nature of internal regularities in a system may differ and therefore variables representing them may be considered according to study area characteristics. Thus there is no change required in the concept of TCV and it can be applied for assessment of network congestion for different areas.

The results of the research clearly indicate that the First and Second Spatial Zones are the most congested with TCV values 0.39 and 0.59 respectively. Several measures can be taken to control congestion in these zones. For example, in the first zone, functional activities along roads must be discouraged. There is a heterogeneous pattern of commercial activities in this zone; further heterogeneity in commercial activities should be prevented. Moreover, in this zone especially, mixed traffic must not be allowed so that flow can be effectively regulated. The same factors mentioned before are also prevalent in the second zone. However, there is one serious concern here regarding mounting congestion, i.e. the presence of fault intolerant nodes (nodes no. 19 & 20). Therefore, the huge load on route 19 cannot be redistributed and hence it affects traffic flows on all the surrounding routes. There are other measures that should be adopted to mitigate congestion for the whole area such as the installation of automatic traffic signals and arrangements for adequate parking space. Since the present area witnesses random movements of vehicles, implementation of charges at peak hours according to type of vehicle will be very significant in controlling congestion.

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