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WEIGHTING RESPONSIBLE FACTORS FOR TRAFFIC CONGESTION IN SMALL CITIES IN INDIA BY ANALYTICAL HIERARCHY PROCESS METHOD

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Abstract

Introduction : It's critical to recognise that improvement is occurring gradually on a global Traffic congestion cause serious concerns for urbanites all over the world. However, most studies related to traffic congestion have been limited to large metropolitan cities only. But for sustainable urban development traffic congestion issues faced by small cities must be discussed. Hence, this study has been carried out with the purpose to identify and prioritize the significant factors responsible for traffic congestion in small cities (population less than 500,000) in India. Prioritization of factors and sub-factors responsible for traffic congestion will be helpful in knowing the commuters' perspectives about traffic congestion issues and useful in developing mitigating strategies to curb the congestion problem in resource-deprived small cities in India. Further, the analysis of significant factors causing traffic congestion could be beneficial to ease traffic congestion, in terms of planning, operation, and management and may increase behavioural corrections of drivers and pedestrians. For this research study, various responsible factors for traffic congestion have been identified by reviewing the past literature and then their relative role in traffic congestion has been determined by prioritizing them through Analytical Hierarchy Process (AHP) method, a multi-criteria decision-making tool (MCDM). A total of fifteen factors, considered responsible for traffic congestion, have been identified and further classified under four key factors: Socioeconomic, Technical, Human, and Random. In order to conduct pair-wise comparisons of various factors and sub-factors relevant to the study, commuters from four small cities in Bihar, India, were surveyed. The AHP-based traffic model results found technical factors (0.32) as the most responsible factors which cause traffic congestion in the study area followed by human (0.27), random (0.23), and socioeconomic (0.19) factors. Moreover, the global weight of sub-factors revealed poor transport infrastructure, irresponsible behavior of the drivers, increased informal transport operators, special events, and accidents as the top five sub-factors responsible for traffic congestion in the study area than other sub-factors.

Keywords: Analytical Hierarchy Process; Multi-Criteria Decision Making; Traffic; Congestion; Small Cities; India.

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Introduction

One of the major issues encountered by urban residents worldwide is traffic congestion. (Bharadwaj et al., 2017; Falcocchio & Levinson, 2015; Wang et al., 2017). It results from more vehicles using a specific section of road at one time than the capacity of the road network (Vencataya et al., 2018; Raheem et al., 2015). Congestion in traffic is also seen as a disruption of the regular flow of traffic due to the high density of vehicles which lengthens the travel time (Afrin & Yodo, 2020; Systematics, 2005). It is perceived as an increase in travel expenses as a result of a disruption in the usual flow of traffic.

Moreover, it is seen as an increase in a road user's expenses due to a disturbance in normal traffic flow (Bull, 2003; Litman, 2007). Congestion in traffic results in a waste of time, money, and energy and is notoriously accountable for air and noise pollution hence put a negative impact on sustainable transport practices.

In US cities, on average, drivers 'lost' 51 hours sitting in traffic in the year 2022 which was 15 hours increase from the preceding year (INRIX, 2022). Congestion in traffic made London infamously responsible for emitting an additional 2.2 mega tonnes of CO_2 in the same year (TomTom Traffic Index, 2022). On average, during peak traffic times, commuters in four Indian metro cities exhaust 1.5 hours more on their daily travel than their counterparts in other Asian cities, costing the economy more than $22bn annually (BCG, 2018).

The societal, environmental, and economic well-being of any country is negatively affected by traffic congestion (Fattah, 2022; Samal et al., 2020; Ackaah, 2019). It produces serious issues for daily commuters, slows down the crucial movement of supply chain delivery personnel (Weisbrod & Fitzroy, 2011), and is a big obstacle in the uninterrupted movement of emergency vehicles, such as police vans, fire brigades, and ambulances (Deepa et al., 2021; Nellore & Hancke, 2016). Moreover, it poses a major bottleneck in sustainable global transport systems and consequently a huge threat to the growth of any country (Fattah, 2022). This phenomenon is expected to aggravate in the future owing to exponential growth in population and urbanization all over the world (Zhang, 2016; Samal, 2020).

The spatial movement of humans is continuously heading toward urban pastures. According to Revision of World Urbanization Prospects, 2018, presently more than 50% of the world's population lives in urban areas, and by 2050, this percentage is expected to rise up to 68%. But their congregation would not be in large metropolitan regions only (UN report, 2018). Today, small cities occupy nearly fifty percent of the urban land in low-income countries and this share is foreseen as increasing in the upcoming decades (World City Report, 2022). Hence, small cities, especially of the global south, are prone to facing several consequent issues. Traffic congestion is one of them.

India is one of the major emerging nations the of global south (Shaban et al., 2020). Presently, near about thirty percent of its urban population resides in small cities (populations less than 500,000) (Census of India, 2011, Tiwari & Phillip, 2021). An exponential increase in the population of these cities is expected to take place over the next two decades (Tiwari & Phillip, 2021). Hence, small cities in India are more vulnerable to traffic congestion than metros (Abhishek, 2020). Six of the 20 slowest cities in India do not appear on the global list of the top 100 cities by population, which provides a clear indication of the intensity of traffic congestion in smaller cities. (Abhishek, 2020). Further, owing to their less developed transportation infrastructure (Singh et al., 2016; World Bank 2018; Abhishek, 2020), lack of financial resources (Pucher et al., 2004, Ahluwalia, 2019), and poor urban governance

(Ahluwalia,2019**)** the situation is becoming worse.

Most studies in the past pertaining to traffic congestion in India have been limited to large metropolitans only. But the focus of new research should certainly be on smaller developing cities if sustainable urban development is to be achieved (Pojani & Stead, 2015). Hence, this study aims to identify, categorize, and prioritize the significant factors responsible for traffic congestion in small cities (population less than 500,000) in India. For this research study, a three-level hierarchical traffic model, containing responsible factors and related sub-factors, has been developed. The Analytic Hierarchy Process (AHP), a multi-criteria decision-making technique (MCDM), has been utilized to prioritize these factors. The analysis of significant factors causing traffic congestion could be beneficial to ease traffic congestion, in terms of planning, operation, and management and may increase behavioral corrections of drivers and pedestrians. Further, to ease the congestion problem, the ranking of defined criteria could assist decision-makers in focusing on highlighted critical factors causing traffic clogs on a priority basis. Hence, the study has been carried out to attend the research questions mentioned below:

- What are the factors and sub-factors responsible for traffic congestion in small cities in India?
- What is the prioritization of these factors and sub-factors according to their severity in traffic congestion?
- What are the steps to be taken to minimize the traffic congestion issues?

The study has unfolded in the following manner: a review of related works has been done in section two, materials and methods have been discussed in section three, results and discussion have been deliberated in section four, and the last section has been devoted to conclusions.

2. Review of literature

2.1 Traffic congestion

Bull et al. (2003) examined the negative effect caused by traffic congestion and the multidisciplinary efforts required to keep it under control through the development of appropriate policies & methods. Aftabuzzaman (2007) critically reviewed the measure of traffic congestion and proposed a framework for measuring congestion relief due to public transport. Alam & Ahmad (2013) studied urban transport systems and congestion in some Asian cities and discussed about respective mitigating policies. They also discussed the transport policies of the Indian government and examined the probable causes that fail to bring the desired impact on reducing traffic congestion. Bandyopadhyaya & Bandyopadhyaya (2021) identified key factors for the management of parking areas to reduce traffic clogs in India. Bao et al. (2022) investigated the effect of built environments on traffic behaviour in smaller urban areas in China.

2.2 Factors responsible for traffic congestion

Some of the past studies divided traffic congestion factors into recurrent and non-recurrent factors (Anbaroglu et al., 2014, Varaiya, 2007). Excess travel demand, inadequate traffic capacity, and poor signal control (Han and May, 1989; Anbaroglu et al., 2014) have been categorized as recurrent factors whereas vehicle breakdown, special events (e.g., strikes, religious or social procession), accidents, engineering works or poor weather are considered as non- recurrent factors for congestion in traffic (Kwon et al., 2006).

Rao and Rao (2012) argued that micro-level factors, increased travel demand, poor road network, vehicle breakdowns, inefficient traffic signals, accidents, special events like social gatherings, processions, unfriendly weather conditions, etc., are basically triggering factors for traffic congestion but its intensity is fuelled by macro-level factors like land-use patterns, traffic infrastructure, car ownership level, regional economic capacity, etc. Jain et al. (2012) found that poor traffic management around small critical areas leads to congestion. Mahmud et al. (2012) found limited resources for the expansion of transport infrastructure as a cause of traffic congestion. Uwadiegwu (2013) identified and divided traffic congestion factors into four categories: physical, technical, land use, and human as responsible for traffic congestion in Nigeria. Computation of variables loadings for determining the relevant factors have been done by Relative Factor Index (RFI) and recommended some management measures to improve terminal facilities, traffic-related education, proper land use, and required training of traffic personnel. Chakrabartty & Gupta (2014) studied the traffic congestion problem faced by one of the metropolitans in India and found poor synchronization between mobility demand and road space availability reason behind extreme congestion in Kolkata. Chow et al. (2014) assessed traffic congestion issues in central London, UK. They further identified and characterized different causes through linear regression analysis. On the basis of a case study, they observed that 15 % of traffic congestion occurs because of nonrecurrent factors Bian et al. (2016) evaluated, classified, and analyzed traffic congestion factors prevalent in China. Lizbetin & Bartuska (2017) opined that the increased number of cars and disproportionate increase in traffic volumes led the traffic congestion. Further, they studied human factors contributing to congestion format on urban roads. Vencataya et al., (2018) assessed the traffic congestion factors and their subsequent effect on the society, economy, and individuals in Mauritius. Authors found that population growth, economic development, poor road network, unforeseen circumstances, inefficient public transport services, and an excessive number of vehicles as significant factors responsible for congestion in traffic which severely affect individuals, society, and the economy. Nwaigwe et al., (2019) analyzed the causes of traffic congestion and its negative effects in Nigeria. The prime causes of the congestion discussed were: lane indiscipline, poor road network, high traffic density, inefficient traffic management, poor traffic infrastructure, and delayed removal of broken-down vehicles. They opined that sustainable policy measures can improve the required intra-urban mobility. Noor et al. (2021) have assessed the pattern of traffic congestion in an emerging city in Bangladesh. They discovered that a rapid expansion in automobiles, poor public transport, the behaviour of pedestrians, road occupancy, and lax traffic law enforcement as the prime reasons for traffic congestion in the CBD areas.

2.3 Analytic Hierarchy Process (AHP) method

The analytical hierarchy process is an important multi-criteria decision-making technique (MCDM) expounded by Thomas A Saaty. Although it is used for solving intricate MCDM problems, owing to its flexible nature different researchers have been applying it in several fields for ranking or prioritizing, allocation, selection, and many more (Singh 2013, Gupta, 2017).

Berrittella et al. (2007) evaluated transport policies to assess the impact of Climate Change and found that environmental-friendly transport modes promoting tax policies as the noblest policy. Jain et al. (2014) used AHP to prioritize reliability, comfort, safety, and cost, for encouraging commuters to shift from private to public transport systems in the capital city of India. Hao et al. (2017) integrated the fuzzy analytic hierarchy process and gray correlation techniques to evaluate the severity of traffic congestion and proposed a hybrid decision-making model for the same. Farooq et al. (2021) studied frequent lane-changing behaviour and prioritized the causative factors and sub-factors by integrating Analytical Hierarchy Process – Best Worst Method methods. Ortega et al. (2020) evaluated six key criteria and 19 sub-criteria using Best Worst Method (BWM) to estimate the location of the Park &Ride system facilities to reduce city traffic. Kadkhodaei & Shad (2018) compared and evaluated control measures for traffic congestion using AHP. Barić & Džambo (2021) evaluated level crossing design in an urban area of Croatia by applying the AHP method for finding weights for six criteria and 15 sub-criteria. Alkharabsheh et al. (2021) assessed public transportation systems of urban areas with an integrated approach of multi-criteria decision-making and grey theory. Naeem & Abbas (2021) applied a computational model for MCDM for discussing problems related to traffic congestion.

By reviewing the pertaining literature, the author of the present study found there is no study in the past that prioritize the factors responsible for congestion in traffic in small cities in India using the Analytical Hierarchy Process method.

Hence the present study has been conducted with the aim to prioritize factors causing traffic congestion in small cities in India. The AHP method has been used to determine the weightage assigned to the factors given by commuters. A field survey in the state of Bihar, India, was organized to collect responses about commuters' perceptions regarding the severity of the factors and sub-factors accountable for congestion in traffic in the study area.

3. Materials and Methods

This section includes the components and materials used to conduct the study, including a detailed view of how the survey was performed and a detailed description of the method used.

3.1 Questionnaire Survey

For this research study four small cities of Bihar, the third largest state in India with 1,17,58,000 urban population (Census, 2011), had been judgementally selected.They are Sitamarhi, Samastipur, Purnia, and West Champaran. As per census 2011, all these selected cities have a population of less than 5000,000. Apart from their own population growth, people from peripheral rural areas commute to these cities to meet their educational, medical, recreational, shopping, and work-related needs. Consequently, owing to poor transport infrastructure, these cities are witnessing a poor synchronization between travel demand and related supply. Moreover, a sharp increase in vehicle ownership and use, too many informal transport operators, lack of public transport, and inadequate traffic management are some of the common factors that cause traffic congestion in these cities.

The data had been collected by developing a questionnaire containing a nine-point Saaty scale (Saaty, 1980) to evaluate the severity of factors and sub-factors responsible for traffic congestion. On the basis of the review done for the study, 15 factors have been identified that may cause traffic congestion. These 15 factors have been further categorized under four main factors: Socioeconomic, Technical, Human, and Random (Table 3.2). Consequently, prioritization of these key factors and respective sub-factors, on the basis of their severity for traffic congestion, had been done. The Analytical Hierarchy Process technique has been used for prioritization purposes as this method was found suitable to prioritize factors because the number of factors and corresponding sub-factors is less than or equal to four. Based on the review of the pertinent literature, a structured questionnaire was developed consisting of two sections. The first section consists of the personal details of the respondents such as age, gender, occupational status, area of residence, type of owned vehicle, and purpose of travel (Table 3.1). The second section was comprised of five tables. Pairwise comparisons of the main factors: Socio-economic, Technical, Human, and Random, had been done in the first table. Further, pairwise comparisons of sub-factors with respect to their respective main factor have been performed in the remaining tables.

Data has been collected from the commuters, selected on a convenience basis, through offline mode as well as through a popular video conferencing app. The questionnaire was written in Hindi with an English translation. Owing to the complexities of the questionnaire proper training had been given to the investigators for effectively administering the questionnaire. Proper explanation of factors and sub-factors has been done at length to the respondents prior to filling up the form. Data collection was done from February to March 2023. A total of 80 questionnaires were administered; 52 of them were found usable for analysis.

Table 3.1: Characteristics of sampled respondents

Variables	Frequency	Percentage
N	52	100
Age (years)		
18- 35	20	38
36-62	25	49
62 above	07	13
Gender		
Male	35	67
Female	17	33
Education level		
Below matriculation	14	27
Above matriculation	38	73
Working status		
Employed	46	89
Unemployed	06	11

3.2 Traffic Congestion Model

In this research study, a three-level hierarchical traffic congestion model consisting of responsible factors and their sub-factors has been developed, as presented in Figure 3.1. The first level comprises goal, second level consists of four key factors related to traffic congestion, such as socio-economic (Sun

& Land,2022), technical (Uwadiegwu, 2013), human (Lizbetin & Bartuska, 2017; Uwadiegwu,2013)), and random (Kwon et al., 2006). For level 3, these main factors were further distributed into 15 sub-factors. In past studies (Table 3.2), many researchers had considered these factors as responsible for traffic congestion.

Table 3.2: Conceptual framework

Responsible factors	Related Studies	Code
Socio-economic Factor		**SE**
Population growth	The world's population growth has resulted in increasingly congested roads (Jain et al., 2018, Nwaigwe et al.,2019; Lu et al, 2021).	PG
Increased vehicle ownership	Economic growth and urbanization have a consequent effect on increased mobility demand and vehicle ownership. (Bandyopadhyaya & Bandyopadhyaya, 2021, Shaban, 2020, Mishra, 2019, Nwaigwe et al. 2019, Pojani & Stead 2017, Alam & Ahmad, 2013; Pucher et al., 2004; Hao et al., 2017; Kaur & Roy, 2020).	IVO
Improved mobility of rural population	People from peripheral rural areas commute to nearby cities to meet their educational, medical, recreational, shopping, and work-related needs. (Feikie et al., 2018).	IMRP
Rapid urbanization	As a result of rapid urbanization, most Asian cities are confronting several challenging issues like Urban congestion. (Nwaigwe et al.,2019; Mishra, 2018; Alam & Ahmed, 2013; Rana, 2011; Davidich et al., 2021)	RU
Technical Factor		**T**
Poor transport infrastructure	Congestion occurs when traffic volume approaches the capacity of the road (Lizbetin & Bartuska, 2017). Inadequate planning of road networks and other roadway resources leads to traffic congestion (Pucher et al., 2004; Singh et al.; Kiunsi, 2013). 2016). Poor transportation infrastructure caused traffic congestion (Mahmud et al., 2012). The expansion in Indian urban road space is disproportionate to the private motor vehicles plying in Indian cities (Mishra, 2019). Cities in India suffer from a severe lack of public transport infrastructure (Pucher et al., 2004; Mishra, 2019).	PTI
Increased informal transport operator	The presence of too many informal operators in the public transport system plays a critical role in traffic congestion (Alam & Ahmad, 2013; Nwaigwe et al.,2019; Shaban, 2020; Ukpata &Etika, 2012; Noor, 2021).	IITO
Poor traffic management (Management of speed, signal, parking, rule etc)	To a large extent, a poor city's traffic management system, particularly traffic signals and their settings at junctions, contributes to congestion. (Lizbetin & Bartuska, 2017; Singh et al. 2016; Ukpata &Etika, 2012). Poor traffic management is one of the contributors to traffic congestion (Kiunsi, 2013).	PTM

Human Factor		**H**
Irresponsible behaviour of drivers	Human driving behaviour is exceedingly complicated, with nonlinearity, uncertainty, randomness, and other inherent human features (Wang & Chen, 2014). The picking up and dropping passengers off passengers from any point leads to traffic congestion (Mahmud et al.,2012; Agyapong & Ojo, 2018). Haphazard parking practice by bus/auto drivers and overtaking tendency causes traffic congestion (Mahmud et al.,2012). Commercial vehicle drivers are notorious for being harsh, irresponsible, always in a hurry, and rudely disobeying traffic restrictions. (Balogun et al., 2012).	IBD
Road/ footpath encroachment	Road and footpath encroachment happens due to illegal occupancy by the vendors leads to traffic congestion (Pucher et al., 2004; Alam & Ahmad, 2013; Uwadiegwu, 2013).	R&FE
Poor car-pooling Practice	Poor car-pooling practice reduces vehicle utilization and declines road use efficiency, raising traffic flow and aggravating traffic congestion (Sun & Lu, 2022). The high demand for automotive mobility during peak hours and low private car occupancy rates, causes traffic congestion in several urban areas (Agatz et al., 2012). Ride-sharing reduces travel time and parking demand (Agatz et al., 2012).	PCPP
Less active travel	Owing to the probable health risk due to air pollution and risk of injury posed by and motor vehicles there is a poor tendency towards walking and cycling (Aldred,2019; Winters et al. 2017 **cite it**).	LAT
Random Factor		**R**
Accidents	Congestion is highly related to the accident rate, particularly in towns and cities of developing countries (Pucher et al., 2004; Nwaigwe et al.,2019; Lizbetin & Bartuska, 2017)	A
Special events (Strikes, VIP movement, procession, etc.)	Planned special events play a key role for delays in transportation (Kwoczek et al., 2014). Special events like sport games and strikes are responsible for nonrecurrent congestion (Kwoczek et al., 2014). Special events like religious procession cause traffic congestion in several parts of north India (Kaur & Roy, 2020).	SE
Bad Weather	Bad weather like rain reduces traffic flow rate and travel speed on the roadway (Chung, 2012; Nwaigwe et al.,2019; Ukpata &Etika, 2012)	BW

Vehicle Breakdown	When a vehicle breaks down, the already narrow road becomes much more congested. (Chaw et al., 2014; Nwaigwe et al.,2019).	VB

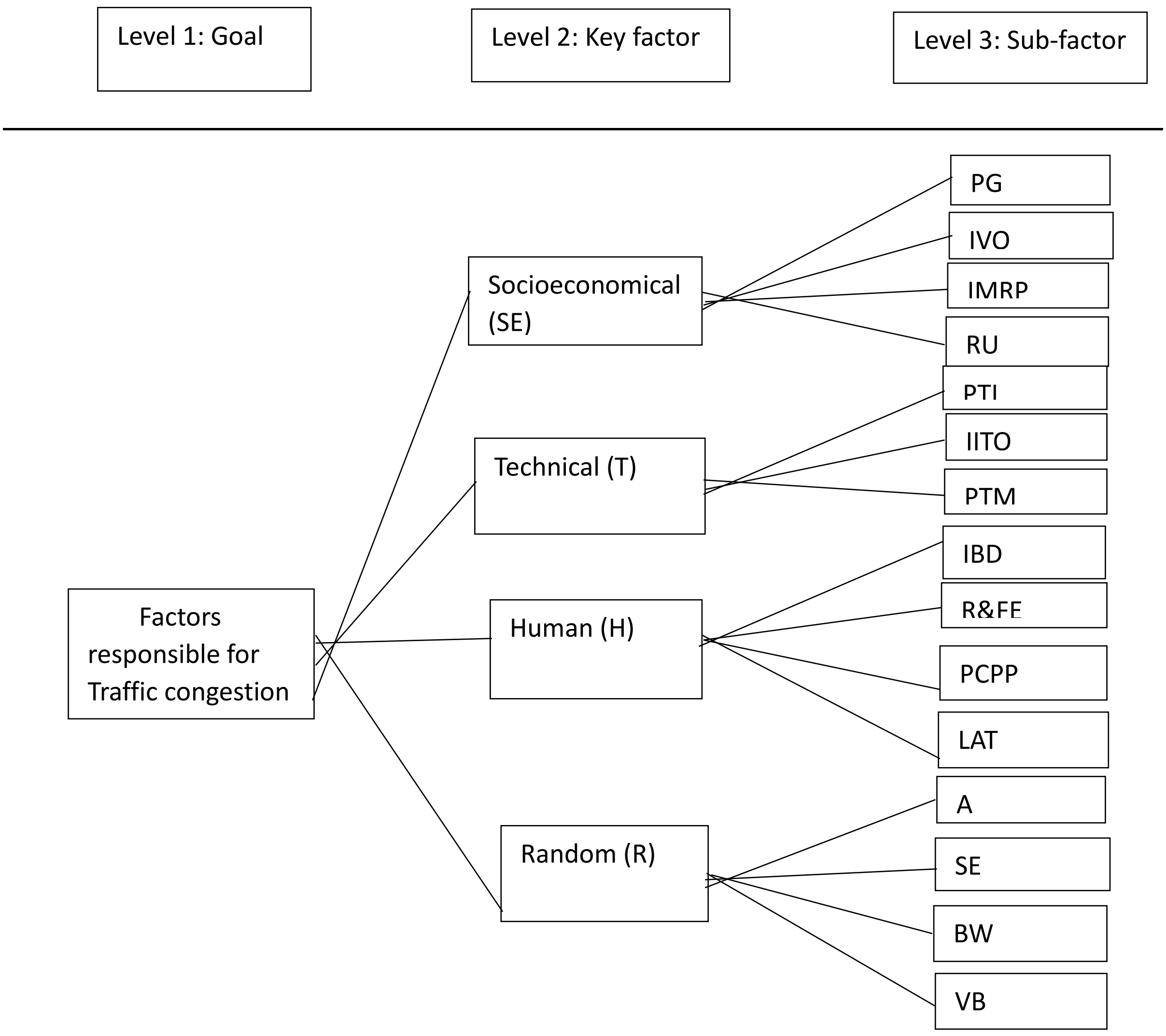

Figure 3.1: Three-level hierarchical structure of factors responsible for traffic congestion (Traffic Congestion Model)

3.3 Analytical Hierarchy Process

AHP is a multi-criteria-decision making technique, developed by Thomas A Saaty, used for making decisions problems. It is used by different researchers in several fields including, allocation, selection, planning, and prioritizing showing its multi-dimensional applicability (Singh 2013, Gupta, 2017). It is a powerful multicriteria method that can simply be adjusted to different numbers of attributes, criteria, sub-criteria, and alternatives. According to this approach, an MCDM problem is divided into three levels: the goal (objective), the criteria, and the alternatives (Saaty, 1980). Further, it evaluates the criteria's priority, compares the alternatives belonging to each criterion, and ranks these alternatives (Gupta et al. 2017; Douligeris and Pereira, 1994). According to Saaty (1980), the judgments are characterized by "how much more one element dominates another with respect to a given attribute". The followings are the steps to implementing AHP:

Step 1: Formulation of the problem and construction of the AHP model

In the first stage, a suitable hierarchical AHP model is created by taking a goal at the very first level. Subsequently, criteria or factors, sub-criteria or sub-factors, and alternatives are incorporated at the second and third level respectively.

Step 2: Collection of data from the respondents or experts

In the second step, the pair-wise comparisons data corresponding to underlined factors and sub-factors, on a nine-point scale (Saaty,1980) (Table 3.3.1), from the respondents is collected.

Table 3.3.1: Scale of relative importance

Intensity of Importance	Definition
1	Equal Importance
3	Moderate importance
5	Strong Importance
7	Very strong importance
9	Extremely strong importance
2,4,6	Intermediate values (For comparison between the above values)

Step 3: Determination of the normalized weights

The third step determines the normalized weights of each factor and sub-factor. It is done by following the steps below:

Pair-wise comparison matrix construction

To identify which factor predominates another and by how much, pair-wise comparisons are carried out by using the scale of relative importance table (Table 3.3.1).

In case of ith factor is dominating jth factor, the obtained integer is inserted in the comparison matrix corresponding to ith row and jth column, and further jth row and ith column of the same matrix is filled by its reciprocal. If the two factors under comparison are considered to be equally important, both positions receive the value 1. Consequently, comparison matrices C = [Cij] is developed by reciprocating the elements (i.e., cij=1/cji; i; j=1; 2; ... n). The size of each comparison matrix (n×n) is determined by how many factors (n) are being compared

Aggregation of comparison matrices

The data obtained from all the respondents on the pair-wise comparisons of various factors and sub-factors are aggregated by applying geometric mean method to obtain the aggregated responses for every single entry of the comparison matrices (Saaty, 1989; Forman and Peniwati, 1998). A matrix A = [aij] containing aggregated responses is developed for each factor, where aij (geometric mean) is calculated as:

$$a_{ij} = \left(\prod_{j=1}^{N} c_{ij}\right)^{1/N} \quad (1)$$

Determination of relative weights

The construction of a normalized matrix, denoted by N, is done for determining factor's and sub-factor's weights or ranks by using the undermentioned formula:

$$N = [n_i],$$

$$\text{Where, } nij = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

The average of the elements of each row of the normalized matrix N is then used to calculate the factors' priority (weights). The weight vector, order n x 1, is denoted as $W = [w_i]$

$$\text{Where, } \quad w_i = \frac{\sum_{j=1}^{n} n_{ij}}{n} \quad (3)$$

Consistency check for comparison matrix for the results.

By calculating the consistency levels of the comparison matrices using the consistency ratio (CR), it is possible to assess the estimated weight vector's validity. The level of inconsistency of comparison matrix A is regarded as acceptable if CR is <= 0.10, consequently, the priorities results can be accepted (Saaty, 1980). The CR value greater than 0.10 negates the possibility to accept the ranking results. For the matrix A to be consistent:

$$AW = nW \quad (4)$$

Equation (3) corresponds to Eigenvalue problem associated with the assumption that the largest Eigen value λ_{max} is greater than or equal to n (Saaty, 1980). The comparison matrix A is considered more consistent if the value of λ_{max} is closer to n.The Consistency ratio (CR) is calculated by following the steps below:

- Calculate λ_{max} by using equation (5)

$$AW = \lambda_{max}W \quad (5)$$

- The formula for CR is given as:

$$CR = \frac{CI}{RI} \quad (6)$$

$$\text{where, Consistency Index (CI)} = \frac{\lambda max - n}{n-1} \quad (7)$$

The value of Random Index (RI) is obtained corresponding to the different number of criteria (n) (Table 3.3.2).

Table 3.3.2: Random index table (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58	1.56

Calculation of global weights.

The formula shown in equation (3) is used to obtain the local weights of main factors and sub-factors. The global weights of the main factors are assumed to be equal to their local weights. Whereas, the calculation of the global weight of a sub-factor is done by multiplying the local weight of that sub-factor with the global weight of the corresponding main factor.

4. Result and discussion

MS EXCEL has been used for analyzing pair-wise comparisons data pertaining to various factors and sub-factors. The geometric mean of these responses was calculated using equation (1). Table 4.1 exhibits the information regarding comparison matrices of main factors, their corresponding weights as well as consistency tests whereas tables 4.2 to 4.5 contain the aforementioned information pertaining to subfactors within technical, human. Random and socioeconomic factors respectively. From these tables, it is evident that all CR values are less than the allowed value of 0.10, which shows the comparison matrices are consistent, and therefore, the obtained weights (ranking) can be accepted. Finally, the last table (Table 4.6) contains global weights as well as ranking of the 15 sub-factors taken under study.

Table 4.1 shows that among the four key factors, commuters found the technical factors (0.32) as the most responsible factors which cause traffic congestion in the study area followed by human (0.27), random (0.23), and socioeconomic (0.19) factors. Poor transport infrastructure, inadequate public transport, and poor traffic management have a dubious role in traffic congestion. The findings are in support with (Pucher et al., 2004; Singh et al.; Kiunsi, 2013, Mahmud et al., 2012, Lizbetin & Bartuska, 2017; Mishra, 2019). human factors (0.32) are the second-ranked responsible factor for traffic congestion. These findings imply that irresponsible behavior by drivers, road and footpath encroachment, poor carpooling practice, and less active travel significantly contribute in traffic congestion. These findings are consistence with those of (Agatz et al., 2012; Mahmud et al.,2012; Wang & Chen, 2014; Agyapong & Ojo, 2018; Pucher et al., 2004; Alam & Ahmad, 2013; Uwadiegwu, 2013).

Random factors are found to be the third most critical factor responsible for traffic congestion in small cities in India. The findings exhibit the unavoidable role of random factors like weather, vehicle breakdown, accidents, and special events, like VIP movements, strikes, religious, social or political processions, etc., in traffic congestion. Many authors (Pucher et al., 2004; Kwoczek et al., 2014; Kwoczek et al., 2014; Nwaigwe et al.,2019; Lizbetin & Bartuska, 2017; Kaur & Roy, 2020) opined the same view in their respective studies.

Socioeconomic factors are found to be the least responsible factors (as observed in the present study) for traffic congestion. The findings suggest that, however, there is notable growth in population (Lu et al, 2021), urbanization (Davidich et al., 2021), vehicle ownership (Hao et al., 2017), and rural mobility (Feikie et al., 2018) but if the severity of other three factors i.e., technical, human, and random, are kept under control than the effect of socioeconomic factors in traffic congestion may be reduced.

Table 4.1: Consistency test for main factors

Factor	SE	T	H	R	Weight	Test of consistency
SE	1.00	0.79	0.55	0.63	0.19	λmax=4.115 CI =0.38 RI =0.90 CR=0.43
T	1.26	1.00	0.91	1.00	0.32	
H	1.83	1.10	1.00	2.47	0.27	
R	1.59	1.00	0.41	1.00	0.23	

Table 4.2 exhibits the weights of sub-factors corresponding to technical factors. The findings indicate that commuters perceived poor traffic management (0.528) as the most important sub-factor responsible for traffic congestion followed by poor transport infrastructure (0.27) and increased informal transport operators (0.20). Efficient traffic management systems like signals, parking facilities, traffic personnel, traffic rules, etc., play a crucial role in mitigating traffic congestion. Poor traffic management, a usual phenomenon of small cities, owing to lack of resources, negligence in transport policy implementation, etc., makes the whole traffic scenario grave and wild and hence highly responsible for traffic congestion. Improved transportation infrastructure also has an influential role in reducing congestion in traffic. A city with poor transport infrastructure witnesses more traffic congestion, compared to cities with good efficiencies in this regard. The too many informal transport operators sub-factor carries low weightage as compared to the other two sub-factors of technical factors. This implies that if a city has a good traffic management system and transport infrastructure, the role of excess informal transport operators in aggravating traffic congestion can be consequently reduced. The findings are in consensus with that of (Lizbetin & Bartuska, 2017; Singh et al. 2016; Kiunsi, 2013; Ukpata &Etika, 2012) who argue that poor traffic management is one of the significant contributors to traffic congestion.

Table 4.2: Consistency test for sub-factors under technical factors

Sub-factor	PTI	PTM	IITO	Weight	Test of consistency
PTI	1.00	0.63	1.08	0.27	λmax=3.048 CI = 0.024 RI = 0.58 CR= 0.042
PTM	1.59	1.00	3.30	0.528	
IITO	0.93	0.30	1.00	0.202	

Within human factors (Table 4.3), irresponsible behavior of drivers (0.353) is understood as the top-most sub-factor responsible for traffic congestion, followed by road and footpath encroachment (0.296), poor carpooling practice (0.234) and less active travel (0.15). This indicates that irresponsible behavior of the drivers such as picking up & dropping off passengers from any point, overtaking practices, and reckless driving, found as the most causative sub-factor for traffic congestion. Further, road and footpath encroachment which mainly happens due to illegal occupancy by the vendors annoyingly reduces the capacity of the already narrowed road of small cities and hence its own role in traffic congestion. Poor carpooling practice and less active travel, found as less responsible for traffic congestion by the commuters, as compared to the first two ranked factors within human factors. It may be because, owing to safety reasons and societal constraints, people living in small cities have less inclination towards carpooling practices. Further, encroached footpaths and irresponsible driving behaviour greatly discourage commuters from opting for active travel practices. These findings are consistence with those of (Wang & Chen, 2014; Mahmud et al., 2012; Agyapong & Ojo, 2018; Balogun et al., 2012) who also opined that irresponsible behaviour of drivers such as, harsh driving, picking up and dropping passengers off passengers in a haphazard manner and rudely obeying traffic restriction greatly exacerbates traffic congestion problem.

Table 4.3: Consistency test for sub-factors under human factors

Sub-factor	LAT	R&FE	IBD	PCPP	weight	Test of consistency
LAT	1.00	0.78	0.39	0.47	0.15	λmax=4.248 CI = 0.083 RI = 0.90 CR= 0.092
R&FE	1.53	1.00	0.76	1.97	0.296	
IBD	1.69	1.23	1.00	2.26	0.353	
PCPP	1.32	1.45	0.42	1.00	0.234	

Among four sub-factors of random factors (Table 4.4), commuters are found to perceive special events (0.362) as a sub-factor which is the most responsible for traffic congestion followed by accident (0.354), Vehicle breakdown (0.291) and weather (0.177). Special events like strikes, socio-religious-political processions, and engineering work compel traffic movements painfully slow on the highly densified road of small cities. Roads can also be blocked due to accidents and consecutive protests against them hence causing traffic jams. If any vehicle breaks down then it also fuels the traffic congestion. Bad weather has been found as less responsible for traffic congestion as there is a tendency to be stayed at home by non-commuters of small cities in case of extreme weather conditions and hence lessen the congestion issues. The findings are in support of those of (Kwoczek et al., 2014; Kaur & Roy, 2020) who argued that special events although cause nonrecurrent congestion but critically affect traffic movement.

Table 4.4: Consistency test for sub-factors under random factors

Sub-factor	A	VB	BW	SE	weight	Test of consistency
A	1.00	1.51	1.64	1.42	0.354	λmax=4.215 CI = 0.072 RI = 0.90 CR= 0.079
VB	0.69	1.00	1.34	1.59	0.291	
BW	0.46	0.71	1.00	0.48	0.177	
SE	0.28	1.54	2.31	1.00	0.362	

Within the socioeconomic factor (Table 4.5) commuters perceived increased vehicle ownership (0.31) to be the most responsible sub-factor for traffic congestion than improved mobility of rural population (0.29), rapid urbanization (0.24) and population growth (0.15). Increased rate of vehicle ownership put too much pressure on the narrow roads of small cities and hence highly intensifies the congestion issues. Enhanced village road infrastructure in India has facilitated the movement of rural population to nearby cities for healthcare, education, shopping, and recreation purpose. Hence improved mobility of the rural population, mainly during the day-time, plays a role in traffic congestion. Rapid urbanization and population growth have been found to be less important than increased vehicle ownership and improved mobility of rural population. It may be because these unavoidable factors can effectively be managed by paying due attention to other traffic-related issues. The findings are in accordance with those of (Bandyopadhyaya & Bandyopadhyaya, 2021; Mishra, 2019, Nwaigwe et al. 2019; Pojani & Stead 2017; Alam & Ahmad, 2013; Pucher et al., 2004; Hao et al., 2017; Kaur & Roy, 2020) who argued that due to the speedy development of the economy there is an exponential increase in motor vehicle ownership, especially in developing countries, and hence severely responsible for traffic congestion.

Table 4.5: Consistency test for sub-factors under socioeconomic factors

Sub-factors	PG	IVO	IMRP	RU	Weight	Test of consistency
PG	1.00	0.64	0.45	0.59	0.15	λmax=4.164 CI =0.055 RI =0.90 CR=0.061
IVO	1.45	1.00	0.82	2.27	0.31	
IMRP	1.76	1.19	1.00	1.04	0.29	
RU	1.45	1.32	0.53	1	0.24	

The global weights of 15 sub-factors responsible for traffic congestion in the small cities in India and their associated ranks are shown in Table 4.6 which reveals that poor transport infrastructure, irresponsible behavior of the drivers, increased informal transport operators, special events, and accidents are the first five sub-factors that create congestion in traffic. Hence, effective and timely action is required by transport policy-making and implementing bodies for mitigating traffic congestion issues in small cities in India.

Table 4.6: Global weights of sub-factors and corresponding ranks

Sub-factors	Global weight	Rank
PTM	0.169	1
IBD	0.095	2
IITO	0.086	3
SE	0.083	4
A	0.081	5
R&FE	0.079	6
VB	0.067	7
PTI	0.064	8
IVO	0.063	9
PCPP	0.059	10
IMRP	0.055	11
RU	0.045	12
W	0.041	13
LAT	0.040	14
PG	0.029	15

5. Conclusion

Traffic congestion is a predicament that severely degrades the quality of urban life across the world. However, much attention had been given in the past to mitigate this problem but most of them are centered around metropolitan areas of both developed and emerging countries. In India, owing to exponential growth in population and economy, small cities have become immensely prone to traffic congestion. The present research study put an effort to identify and categorize different factors responsible for traffic congestion in small cities in India. Further, these factors have been prioritized on the basis of their severity in traffic congestion by means of analytical hierarchy process method. The categorization and prioritization of factors will be helpful in knowing the commuters' perspectives on traffic congestion issues and will help transport policymakers in developing mitigating strategies to curb the congestion problem in resource-deprived small cities in India. Technical factors have emerged as the most responsible factor for traffic congestion among small city commuters. It is followed by human, random, and socioeconomic factors. Moreover, commuters of the study area perceived poor transport infrastructure, irresponsible behavior of the drivers, increased informal transport operators, special events, and accidents as the top-most five sub-factors aggravating congestion in the traffic.

5.1 Theoretical contributions

This present research aims to provide advisable guidance by analyzing the factors that commuters count to be responsible for traffic congestion in small cities in India. The results of the AHP-based analysis of respective priorities of these factors show the contribution level of each factor in traffic congestion issues. Although prior studies have used the AHP method for dealing with several transport-related problems e.g., transport infrastructure, transport policy, transport project, etc., this method has not been used to evaluate the degree of severity various of factors and sub-factors in traffic congestion.

The novelty of the study lies in the interdisciplinary selection of factors and sub-factors in the hierarchy structure of the AHP model. Moreover, the study has also incorporated those sub-factors which are more relevant for the commuters of small cities in India like, improved mobility of rural population within socioeconomic factors, less active travel, and road and footpath encroachments within human factors.

5.2 Real-world applications

In brief, the findings of the present study indicate that there is an unavoidable need to take proper initiatives by all transport stakeholders to address the traffic congestion issues in small cities in India.

The transport policy-making and implementing bodies should focus on strengthening the small city transport management system by installing traffic signals and allotting appropriate parking places in the CBD area. Proper implementation of traffic rules should be ensured by traffic personnel. Drivers, of both public and private vehicles, should develop a tendency to adhere to the traffic rules. An efficient public transport system will curtail the prevalence of informal transport operators hence transport authorities should give due attention in this regard. Moreover, rapid and timely action should be taken by traffic personnel to efficiently handle the congestion issues emerging due to special events and accidents as and when required.

5.3 Limitation and scope

In the present research extraction of factors responsible for traffic congestion and corresponding sub-factors has been done by reviewing the relevant studies. Although proper care has been given by the researcher to accrue all the significant factors for the study, there may be a potential to construct more inclusive hierarchy of factors for future study as there may be city-specific congestion issues in small cities in India. Another limitation is arising from the AHP-based rating scale used for the study which is conceptual in nature. There are chances of getting biased responses while making pairwise comparisons of different factors. Therefore, relative scores to different factors should be carefully done. Further, there may be interrelationships among factors and sub-factors such as poor traffic management and irresponsible behavior of the drivers; road and footpath encroachment and less active travel, etc., and the AHP method does not take into account these interrelationships hence posing a limitation of the present study. This phenomenon is better handled by the ANP (Analytical Network Process) method. Therefore, there is a scope to broaden this study by considering other area-specific factors responsible for traffic congestion to be analysed using ANP in the improved model.

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