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Modeling of traffic congestion on urban road network using fuzzy inference system

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ABSTRACT : *Traffic congestion is a complex issue which most of metro cities are experiencing. The degree of congestion on urban links is not always measured & treated uniformly as it is not well defined phenomenon. The traditionalapproaches are unable to represent realistic& true traffic condition and leads to deviation in congestion measurement because of various factors such as imprecision of the measurement, the traveller's perception of acceptability, variation in sample data, and the analyst's uncertainty about causal relations. To overcome this, fuzzy inference approach is proposed in which, three input parameter i.e. speed reduction rate, proportion of time traveling at very low speed (below 5 kmph) compared with total travel time and traffic volume to roadway capacity ratio are combined to get single output in term of congestion index. The proposed model is demonstrated by considering real time traffic data on major road network of Nagpur city, India. This study allows the process to combine different measures and also to incorporate the uncertainty in the individual measures so that the composite picture of congestion can be reproduced with greater accuracy & low error margin.*

Keywords: *traffic congestion; fuzzy inference system, speed reduction rate, low speed rate, v/c ratio*

I. INTRODUCTION

The tremendous rise in number of vehicles is variably accompanied by ever increasing volume of traffic and intense traffic congestion on roads. Almost every city in India is facing acute traffic problem in regards to delay, congestion, pollution, accidents, parking etc. These problems contribute not only loss of precious manpower but also results in additional fuel consumption, development of mental stress and overall feel bad environment for the driver. Since traffic congestion has been one of the major issues that most of the metropolises are facing, a system for measuring the severity of traffic congestion is needed.Such a measure provides the foundation for traffic engineers and policy makers to identify problems and determines the effectiveness of mitigation strategies. In addition, a consistent and uniform measure will allow comparison of traffic conditions at different locations, so that priorities for improvementscan be developed, which helps the public to understand the trafficconditions objectively.

The roadway traffic congestion is one of the most confusing tasks, as it is very difficult to conceive of single value that will describe all of traveller's concern about congestion.Several measures of traffic congestion are suggested by various researchers in their studies which can be broadly categorized into four groups: (i) basic measures, (ii) ratio measures, (iii) level of service and (iv) indices. Each measure has individual advantages & limitations and isunable to define traffic congestion uniformly. It is found necessary to develop a process which will combine various independent traffic congestion measurement methodsand measure it into single index form. Thus a new approach is proposed to estimate the road traffic congestion using fuzzy techniques. In this paper the fuzzy inference system is used to measure the degree of congestion on major arterial road network by using the traffic flow information such as speed reduction rate, proportion of delay time within total travel time, traffic volume and roadway capacity information. The fuzzy logic is well known to be suitable for handling problems that are nonlinear in nature such as human feelings. Road congestion is a subjective quantity, because it comes from the feelings of vehicle driver and decision makers which may be different for different drivers or decision makers. In the same road conditions, some may feel that the road is heavily congested, while some others may feel that the road is only slightly congested. This is the problem of mismatching data interpretation due to different user's perception. With the help of fuzzy sets, the vagueness and uncertainties of the real world is handled in smooth manner.

The research paper is organized as follows; second section describes the state of art literature. The third section describes the proposed method to measure congestion based on fuzzy inference system. Section fourdeals with information about study area and field work adopted to collect relevant data. Thesection fivedescribes the application and features of proposed fuzzy model. In section six, demonstration of model on real-world problem and their consequent results are discussed. Last the conclusion and outlook towards future research work is presented in section eight.

II. LITERATURE REVIEW

Though congestion is the fundamental concern in dealing with any transportation problem, the degree of congestion on urban arterial roadways is not always measured and treated uniformly, mainly because congestion is not a very well-defined phenomenon.Amudapuram Mohan Rao&KalagaRamchachandraRao [1] and MdAftabuzzaman [2] have carried out systematic and detailed review of traffic congestion in their paper covering the existing practises in different countries, the contributions by individuals and prevailing methodologies for measurement of the congestion along with critical review of the methods. Many definitions have been proposed to describe traffic congestion on roadways in urban areas. However, there is no universally accepted definition of traffic congestion. As perRothenberg [3], congestion is a condition in which 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. While Downs [4] definesthe congestion as the situation when traffic is moving at speeds below the designed capacity of a roadway, Bovy and Salomon [5] found Congestion as state of traffic flow on a transportation facility characterized by high densities and low speeds, relative to some chosen reference state. Weisbrodet al. [6] described traffic congestion is a condition of traffic delay (when the flow of traffic is slowed below reasonable speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle those. Lomax et al. [7] defined traffic congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.

KhaledHamad&Shiya Kikuchi [8] has developed new approach to measure congestion on arterial roadways using fuzzy inference method by usingtwo independently treated measures i.e. average travel speed and the proportion of time travelling at very low speed rate within the total travel time as input for fuzzy inference to have single congestion index as outcome.NilanchalPatel&AlokBhushanMukherjee [9] in their study conducted at Ranchi, India demonstrated that application of the fuzzy concept and knowledge-based congestion weights can provide better realistic status of the congestion in the field as compared to traditionally used congestion index value of the influencing parameters. R.Narayanan et al.[10] conducted study for quantifying congestion using fuzzy logic, in which measurable quantities such as Speed and Inter Vehicular Distance were consider as two input parameters for fuzzy model and result found to be more appropriate compared to present system of defining congestion using v/c ratio.Hari Shankar et al. [11] evaluated the road traffic congestion of Dehradun city in India from traffic flow information using fuzzy techniques. Three different approaches namely Sugeno, Mamdani models which are manually tuned techniques, and an Adaptive Neuro-Fuzzy Inference System (ANFIS) which an automated model decides the ranges and parameters of the membership functions using grid partition technique, based on fuzzy logic. PanitaPongapaibooletal.[12] evaluated level of road traffic congestion using manually tuned fuzzy logic and adaptive neuro-fuzzy technique and compared measuring accuracy of output obtained by both the methods.

III. MEASURE OF CONGESTION BASED ON FUZZY INFERENCE SYSTEM

The various congestion measures used in practice have individual advantages and limitations. Since the congestion is a phenomenon which is caused by many factors and perceived in different ways the efforts are needed to incorporate more than one measure. Similarly while measuring the traffic congestion, one of the important element of the process i.e. traveller’s perception of what is acceptable and unacceptable is required to be incorporated. As this boundary is not well defined and differs among each traveller and travel circumstances. Considering the facts and limitation of present congestion measurement methods, a process is proposed that uses fuzzy inference system which allows the vague boundary of a set and identify solution for problem involving ambiguity and uncertainty. The procedure consists of computing the values of the input parameters, classifying the input values into different groups, defining different states of congestion, and finally determining the congestion index.

3.1 Input Parameters

The proposed procedure considers three measures of congestion that are observed and then combines them into a single measure using fuzzy inference. The three measures are speed reductionrate, proportion of time traveling at very low speed (below 5 kmph) compared with total travel time and traffic volume to roadway capacity ratio. Initially all these three measures are computedseparately on the basis of field data collected and then, they are combined according to a set of fuzzy inference rules. The three inputs as a composite represent the traffic condition, making use of average speed, variation of speed within travel and volume to capacity ratio represents the traveller’s sense of frustration and irritation.

Speed reduction rate is the rate of reduction in speed of vehicle caused by congestion. It provides a way to compare the amount of congestion on different routes for non-peak and peak condition.

Speed reduction rate= $\frac{(NonPeakFlowSpeed \quad - PeakFlowSpeed \ )}{NonPeakFlowSpeed}$ **(1)**

This value is between 0 and 1, 0 being the best condition, when the Peak flow speed is larger than or equal to the Non-Peak flow speed, and 1 being the worst condition, when Peak flow speed is near to 0.

The very-low-speed rate is computed on the basis of the proportion of time traveling at very low speed compared with the total travel time.

Very-low-speed rate= $\frac{Timespentindelay}{Totaltraveltime}$ **(2)**

This value is between 0 and 1, 0 being the best condition (least congestion), with no delay, and 1 being the worst condition, with most of the travel time spent in delayed conditions. Delay is defined as the total travel time at a speed less than 5kmph.

The volume to capacity ratio of each traffic link during peak flow condition is computed. The volume is calculated in terms of Passenger car unit/hour, while capacity of roadway is considered as per IRC 106:1990 recommendation [13].

V/C Ratio= $\frac{Volume \ of ve hiclesinpeak \ \ hour}{Capacityofroadway}$ **(3)**

This value is between 0 and 3, a value near 0 being the best condition, when v/c ratiois minimum and 3 being the worst condition when very large volume of vehicles are moving on road compared to its capacity.

3.2Classification of Observed Values

After computing three mentioned input parameters from real-world data, each value is fuzzified. Fuzzification means mapping the value to a class of conditions defined by a natural language to which the traveller can relate, such as “high congestion.” Each of the natural-language classes is considered as a fuzzy set, which has vague boundaries.

For speed reduction rate, the calculated value is translated into one of six natural-language-based classes from very good (near 0) to very bad (near 1). The six categories are designated A to F, for ease of designation: A is the best, and F, the worst. The correspondence between the values and the fuzzy sets is based on the HCM 2000 [14] definition of LOS for urban and suburban arterials. The membership functions corresponding to each of these classes are shown in Figure 1, in where a value of speed reduction rate is given, the degree to which this value is compatible with a class is given in the membership function. It is possible that one value could correspond to more than one class.

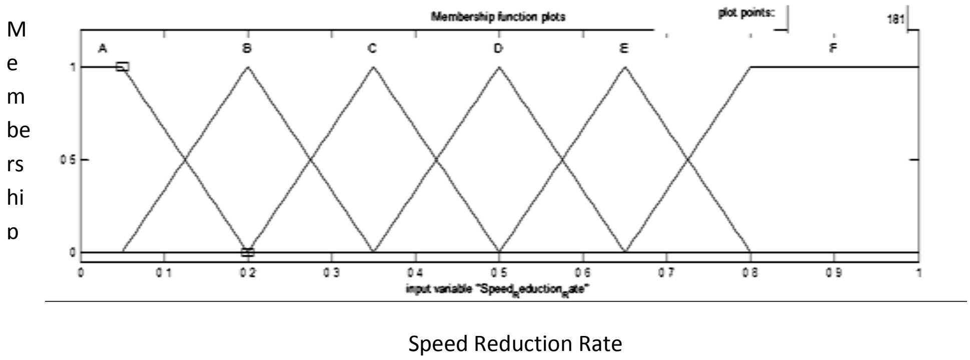

Figure 1: Membership Function for Speed Reduction Rate

Similarly, the values of very-low-speed rate are categorized into three groups that are identifiable to travellers: “low,” “moderate,” and “high,” where “low” indicates that the proportion of travel time at very low speeds (less than 5 kmph) is minir` ıd thus the condition is very good. The membership functions of the three classes are shown in Figure 2.

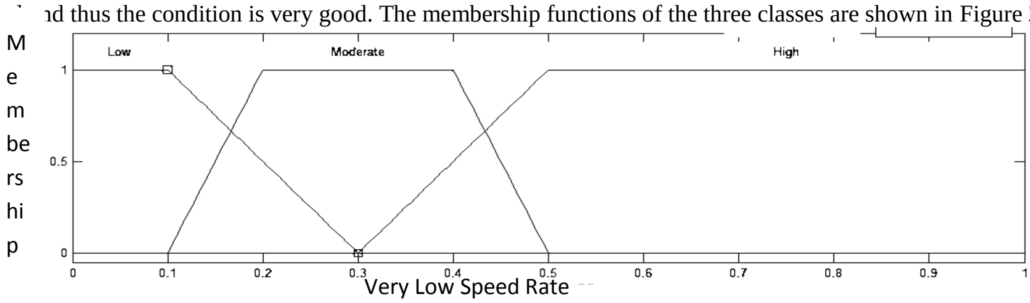

Figure 2: Membership Function for Very Low Speed Rate

For v/c ratio, the values classified into three groups that can be realize by travellers: “low,” “medium,” and “high,” where “low” indicates that the ratio of vehicles travelling on road to standard roadway capacity is minimal and thus the condition is very good. The membership functions of the three classes are shown in Fig.3.

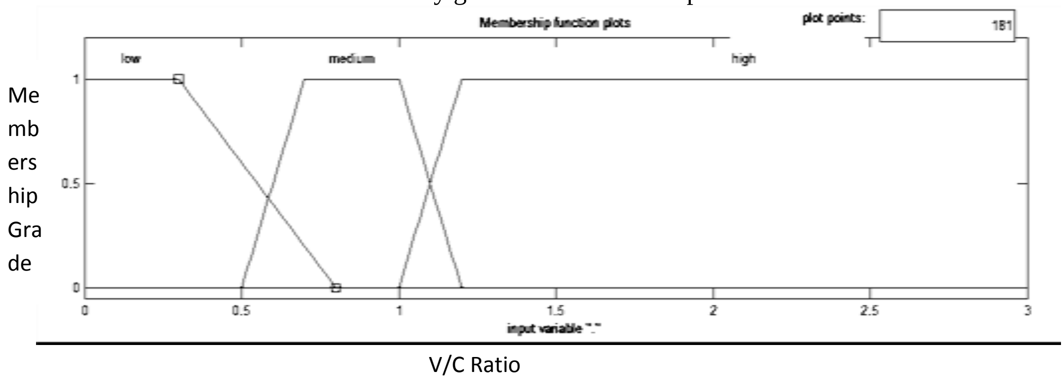

Figure 3: Membership Function for V/C Ratio

3.3 Output Parameter

The quantification of congestion in terms of “congestion index” is the output of the process, is categorized into four classes: “low,” “moderate,” “high,” and “very high.” Their membership functions are shown in Figure4, in which the x-axis is a scale between 0 and 1, where 0, is very good, and 1 is very bad. The four classes of congestion condition are defined on the basis of this scale. The boundaries of the classes are rather vague, and hence each class is designated with a natural-language term, which is useful in expressing the prevailing situation.

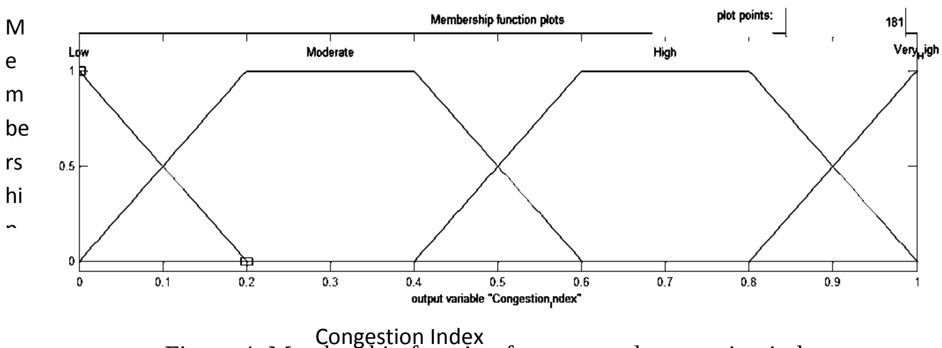

Figure 4: Membership function for proposed congestion index

3.4 Rules

The task of combining three inputs (i.e. Speed reduction rate, very-low-speed rate and v/c ratio) and deriving a natural-language-based congestion measure is performed using a fuzzy rule which are manually designed are of the following type:

Rule: IF (speed reduction rate is P) AND (the very-low-speed rate is Q) AND (v/c ratio is R), THEN (Congestion is S)

WhereP,Q,R and S each represent the degree of congestion as defined in Figures 1, 2, 3, and 4. The part of the rule following IF is called the antecedent, and the part following THEN is called the consequent. The two rules corresponding to the extreme conditions are as follows:

IF speed reduction rate is “high” AND the very-low-speed rate is “high” AND v/c ratio is “high”, THEN congestion is “very high.”

IF speed reduction rate is “low” AND the very-low-speed rate is “low” AND v/c ratio is “low”, THEN congestion is “low.”

As much as 54 no. of rules between these three extremes are possible using combinations of different classes in the speed reduction rate, very-low-speed rate and v/c ratio. Out of these, 38 no. of possible rules areexecuted in this process to get desired output.

IV. SELECTION OF THE STUDY AREA AND FIELD WORK FOR DATA COLLECTION

Nagpur is the fast growing multimodal centre of India and second capital of Maharashtra state with population exceeding 25 lacks situated almost in the centre of country. The city has coordinal point’s 21^0 09’ north latitude and 79^0 05’ east longitudes with altitude over 312.42 m above mean sea level. The city is spreaded over the metropolitan area of 217.56 km^2. In recent years, many major projects such as Multi-Modal International Cargo

Hub and Airport at Nagpur (MIHAN), IT Industries, and Premier educational institutes like IIM, IIIT and AIIMS are introduced in the city, which will lead heavy flow of people from all over the country. It is estimated that population of city will be about 40 lakhs by 2021. As far as the link flow is considered, most of the routes are congested because traffic volume is much higher than the capacity of the road. Nagpur is experiencing the several traffic problems as most of cities of India are facing such as non-uniformity of roadway features, encroachment on roads, abutting land-use pattern and resulting pedestrian activities, poor lane discipline, improper bus stop location, uncontrolled on-street parking, heterogeneity of traffic etc. resulting into traffic congestion on major road network of the city. The severity of this congestion reaches to highest level during morning and evening peak hours.

The field work is carried out invariably under perfect weather condition on normal working day in the month of January-February 2014. Field work is carried out in two parts: (a) travel time study and (b) traffic volume count.For conducting travel time study, the test car technique is adopted. Test car was run on traffic links in peak hours and non- peak hours. The average speed, travel time and distance between intersections, and total time traveling at speed less than or equal to 5kmph. was observed and tabulated. The timing of field work was from 9.30 am to 11.30 am during morning peak hour and 5.30 pm to 7.30 pm during evening peak hours. Test car was made to run on road network between 7 am to 9 am and 12 noon to 5 pm to record travel time in non-peak hours. During the study, the test car was run at speed which in the opinion of driver is the representative of average speed of all the vehicles in stream of flow at the time of run.

The traffic volume data is collected manually by team of experts during the peak hours of the day. Number of vehicles passing over the links was noted and all vehicles moving on street are converted into common unit termed as “Passenger Car Unit” (PCU). Considering equivalent PCU of different vehicle, the volume of traffic during peak hour is calculated in PCU/Hour. The capacity of each link is considered as referred by IRC 106:1990. [13]

V. APPLICATION OF FUZZY INFERENCE SYSTEM FOR COMPUTING CONGESTION INDEX

The manually tuned Mamdani-type fuzzy inference system is used to compute the traffic congestion. MamdaniFIS is the most used in the developing fuzzy models.Mamdaniarchitecture used in this paper for estimation of road traffic congestion is designed with three inputs, one output parameter and thirty eight fuzzy rules. The manner in which the fuzzy rules are executed is as follows. The specific values of speed reduction rate, very-low-speed rate and v/c ratio are the inputs to the rules. For a given rule, a match between the input values and the antecedent of the rule is calculated using Figures 1, 2, & 3. Then the minimum value of the membership degrees among the two is taken as the truth of the antecedent. Thus, this value controls the truth of the consequent of the rule. When the given values of speed reduction rate, very-low-speed rate& v/c ratio correspond to more than one class, all applicable rules can be used (or “fired”). Consequents for different rules are aggregated to form the conclusion. Figure 5illustrates the process of computation.

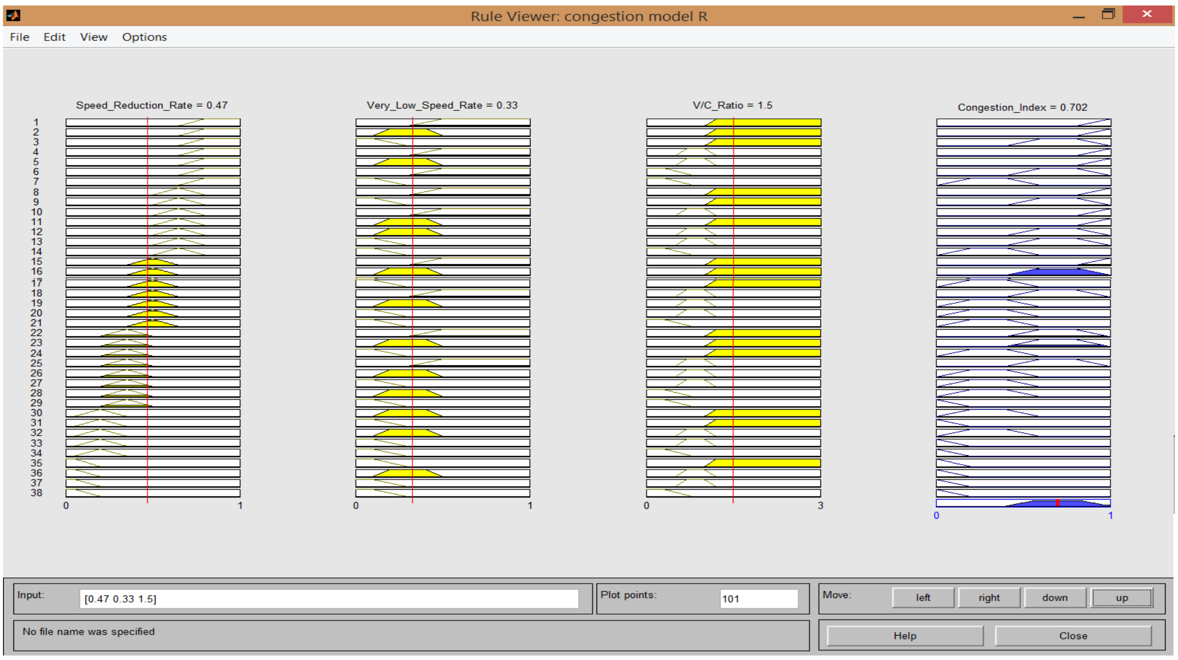

Figure 5: Proposed Fuzzy Model

The conclusion derived is a number between 0 and 1. This value carries the information about the current situation in terms of congestion index. It is a continuous measure. For different combinations of speed reduction rate, very-low-speed rate& v/c ratio, Figure 5 shows the corresponding congestion measure according to the rules framed. While demonstrating model, it is observed that when all the three input parameters are near 0, the congestion index is close to 0, indicating a very good condition. Furthermore, when these input parametersare close to 1, the congestion index is close to 1, indicating a very bad condition.

VI. RESULT & DISCUSSION

The proposed congestion model is applied to a real-world road network of study area. The relevant traffic data i.e. distance between consecutive intersections, travel time, delay time& traffic volume required for computing input parameter are collected on all major traffic links of study area. The values of input parameters i.e. speed reduction rate; very-low-speed rate and v/c ratio for each link are calculated as per equation 1, 2& 3. The resulting congestion index is obtained in last column showing the congestion status of each link. The proposed model is demonstrated on Central Avenue road; which is one of the busiest road of Nagpur is as shown in Table No.1.

Table 1: Input Data & Result

Road-way Link		Distance (km)	Travel Time (sec)		Time Spent In Delay (sec)	Traffic Volume (pcu/hr)	Non-Peak Flow Speed (km/hr)	Peak Flow Speed (km/hr)	Speed Reduction Rate	Very- Low Speed Rate	V/C Ratio	Congestion Index
From	To		Non-Peak Flow	Peak Flow								
Variety Square	Old Morris College Square	0.4	45	60	22	2073.15	32.00	24.00	0.25	0.37	1.15	0.44
Old Morris College Square	Zero Mile Square	0.25	25	34	8	4025.5	36.00	26.47	0.26	0.24	2.24	0.454
Zero Mile Square	RBI Square	0.4	32	48	12	3313.3	45.00	30.00	0.33	0.25	1.84	0.596
RBI Square	BHEL Office Square	0.3	32	60	20	2707.8	33.75	18.00	0.47	0.33	1.50	0.702
BHEL Office Square	JaistambhaChowk	0.3	45	68	33	3978.4	24.00	15.88	0.34	0.49	2.21	0.668
JaistambhaChowk	PoddareshwarChowk	0.3	40	55	21	3750.10	27.00	19.64	0.27	0.38	2.08	0.488
PoddareshwarChowk	Mayo Hospital	0.18	28	38	8	2211.85	23.14	17.05	0.26	0.21	1.23	0.443
Mayo Hospital	DosariBhawan Square	0.21	28	35	5	1939.25	27.00	21.60	0.20	0.14	1.08	0.258
DosariBhawan Square	Gitanjali Talkies	0.23	30	38	8	2385	27.60	21.79	0.21	0.21	1.33	0.316
Gitanjali Talkies	Agrasen Square	0.4	55	85	27	2426	26.18	16.94	0.35	0.32	1.35	0.7
Agrasen Square	Bhawsar Square	0.3	36	55	18	2229.9	30.00	19.64	0.35	0.33	1.24	0.7
Bhawsar Square	M.G. Square	0.25	34	52	15	2431.9	26.47	17.31	0.35	0.29	1.35	0.676
M.G. Square	Darodkar Square	0.24	30	40	9	2507.75	28.80	21.60	0.25	0.225	1.39	0.425
Darodkar Square	Azad Hind Square	0.2	25	35	8	2727.35	28.80	20.57	0.29	0.23	1.52	0.52
Azad Hind Square	Telephone Exchange	0.5	48	60	18	2107.2	37.50	30.00	0.20	0.30	1.17	0.3
Telephone Exchange	Chapru Nagar Square	0.4	42	54	14	3149.6	34.29	26.67	0.22	0.26	1.75	0.357
Chapru Nagar Square	Ambedkar Square	0.3	38	53	12	2065.4	28.42	20.38	0.28	0.23	1.15	0.497
Ambedkar Square	Wardhaman Nagar Square	0.55	48	59	8	1870	41.25	33.56	0.19	0.14	1.04	0.247
Wardhaman Nagar Square	Vaishnavi Devi Square	0.4	30	42	5	2135.5	48.00	34.29	0.29	0.12	1.19	0.387
Vaishnavi Devi Square	HB Town Square	0.8	68	90	0	1776.3	42.35	32.00	0.24	0	0.99	0.228

From above table, it may be observed that, using either one of the input parameter cannot give real picture of traffic congestion. The combination of all three parameters captures the real status of condition. It is observed that if one of the input parameter is much higher and remaining two parameters are on lower side as in case of Old Morris College Square to Zero Mile Square link, the congestion effect is moderate. However on traffic link between RBI Square to BHEL Office Square, all three parameters are of noticeable amount resulting higher congestion effect. Similarly the links subjected to lower values of speed reduction rate, very low speed rate and v/c ratio resulting lower congestion index. The proposed model gives more realistic and detailed congestion picture compared to that obtained in traditional methods by considering single parameter.

VII. CONCLUSIONS

In this paper, we proposed fuzzy inference method to evaluate congestion status on links of real road network.In proposed congestion model, three traditionally used congestion measures i.e. speed reduction rate, very low speed rate & v/c ratio are combinedinto a single composite measure of congestion. Each one of thesemeasures can individually indicate characteristic of traffic flow qualitywith the help of sharp boundaries where possible error in measurementmay misleadwith actual traffic condition similarly each individual method have their own limitations.To overcome this, fuzzyinferenceapproach is proposedwhich consider every small variation in each of input parameterand their composite effect gives true and realistic image of traffic condition. Since the proposed model is based on natural-language rules, which are consistent with the general feelings of the travellers therefore it is possible to use such fuzzy model with greater accuracy & low error margin.

The proposed model is simple to use and follows commonsenselogic. Itcan be applied to represent the traffic conditionsover roadway segments, corridors, or a highway network. Future research, however, is needed to determinehow the model can be expanded to include other factors influencing traffic congestion suchas encroachments on road, on-street parking, roadway condition etc. Further researchis also needed to fine-tune the shapes of the membershipfunctions and defining rules more precisely.

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