Traffic Congestion Modeling Using Data-driven Technique In Mixed Traffic

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Abstract: *Congestion on urban roads considerably impacts urban mobility, travel time, and fuel consumption. To develop a Traffic Congestion Index (TCI), this study examines the values of traffic stream speed for various types operating in mixed traffic conditions. Free flow, moderate congestion, heavy congestion, and severe congestion are the four congestion stages utilized to determine the Traffic Congestion Index. The TCI is computed based on the different speed values. A regression model is developed to forecast congestion degrees and is validated using statistical parameters. The study can help transportation planners with information that may be used to evaluate the severity of congestion on urban roads for similar urban road segments.*

Keywords: **Traffic Congestion Index, Mixed Traffic, Regression Model, Urban Mobility.**

1. Introduction

Urban Road congestion challenges transportation planners, resulting in extended travel times, safety issues, and adverse economic effects. Assessing congestion becomes difficult in mixed traffic, where various vehicles operate without lane discipline. Conventional approaches are inadequate for accurately representing the dynamics of such an environment, emphasizing the need for a more precise methodology. The Traffic Congestion Index (TCI) is a measurable parameter used to assess the severity of congestion, using speed values as its basis for evaluation. The TCI classifies congestion levels into four distinct categories: free flow, moderate congestion, heavy congestion, and severe congestion, enabling the assessment of traffic performance. Real-time congestion prediction is essential for effective traffic management.

Speed values of different vehicles were gathered under mixed traffic conditions, and the Traffic Congestion Index (TCI) was computed for various congestion levels. A predictive model using a regression approach was developed to estimate TCI using real-time speed inputs. The model underwent validation through observed data, and a comparative analysis of calculated versus predicted congestion values confirmed its reliability. Visualizations of congestion levels provided insights into traffic patterns, helping planners develop effective congestion mitigation strategies. This study aims to establish a predictive model for estimating congestion levels based on speed data, assisting planners in making data-driven decisions.

2. Literature Review

Congestion occurs when traffic speeds decrease below the specified speed limit. This phenomenon is closely linked to traffic engineering and urban planning, especially concerning environmental considerations and air quality impacts. Taylor et al. [1] suggested evaluating traffic congestion using the equation (C-C0)/ C0). Widyantoro and Enjat Munajat [2] applied a fuzzy system to study traffic congestion. Nilanchal and Mukherjee [3] presented a new formula to assess the congestion of networks characterized by different land uses. Zheng et al. [4] studied the impact of high occupancy rates due to large office buildings on road traffic. Kong, X et al. [5] presented a risk-based traffic congestion duration model considering the example of Beijing traffic. Qin et al. [6] examined an analysis of the stability and safety of mixed traffic flow within the context of connected and automated vehicles (CAVs), considering the feedback conditions of the front vehicle. They derived the basic diagram of mixed traffic flow. Ramezani and Ye [7] presented a lateral flow-control strategy for autonomous vehicles to mitigate traffic congestion. Xu et al. [8] simulated the environment of the mixed traffic flow by VISSIM.

Zhu et al. [9]) studied the impact of variations in driver personality on traffic congestion and the capacity of mixed traffic flow. Some researchers recommend different approaches for measuring congestion related to traffic flow efficiency. [10], [11], while others measured traffic congestion using Google or online maps [12], [13], [14].

3. Study area

The Sabarmati Riverfront Road (West) segment of Ahmedabad city was considered for speed data collection. This urban road carries mixed traffic of different vehicles with varying speed values. The road segment has four lanes and a total carriageway width of 12.10 m. No gradient and undulations were observed on the selected road segment. One video camera was set up at the entry and another at the exit point to collect speed data.

4. Methodology

The Traffic Congestion Index (TCI) assesses the congestion level on the road based on the amount by which observed speeds deviate from the Free-Flow Speed (FFS). Generally, the amount of congestion is lower when the observed speed is closer to the free flow speed at which traffic is moving freely; conversely, lower speeds imply higher congestion levels.

The Free-Flow Speed (FFS) is observed as FFS = 64.1 km/h. The given dataset consists of speed values gathered from a roadway under given conditions. These speeds range from 64.1 km/h (highest) to 13.7 km/h (lowest).

Traffic Congestion Index:

The Traffic Congestion Index (TCI) is calculated using the following formula:

$$TCI= 1-\left(\frac{\boldsymbol{FFS}}{\boldsymbol{V_s}}\right)$$

Where:

V_s= Observed speed (km/h)

FFS = Free-flow speed (km/h)

TCI values and its Interpretation:

0 indicates no congestion (as observed speed equals free-flow speed). Close to 1 indicates high congestion (observed speed is much lower than free-flow speed), and 1 shows maximum congestion (observed speed is zero, which means complete stop traffic).

Computation of TCI for Each Speed Observation:

Considering the eq. (1) The TCI formula is applied using the provided speed data.

Example Calculations for a few sample speeds:

When speed = 64.1 km/h,

$$TCI= 1-\left(\frac{\mathbf{64.1}}{\mathbf{64.1}}\right) = 0$$

No congestion, i.e., free-flow condition.

When speed = 45 km/h,

$$TCI= 1-\left(\frac{\mathbf{45}}{\mathbf{64.1}}\right) = 0.3$$

Moderate congestion,

When speed = 25 km/h

TCI= 1-($\frac{25}{64.1}$) = 0.61, heavy congestion

When speed = 13.7 km/h

TCI= 1-($\frac{13.7}{64.1}$) = 0.79, Severe congestion.

5. Results

This study's TCI values range from 0 to 0.79, where higher values indicate more congestion. Speed values below 25 km/h generally indicate significant congestion (TCI > 0.6). Speeds above 50 km/h suggest relatively free-flowing traffic (TCI < 0.22). Figure 1 shows the plot of speed(km/h) and TCI for the different TCI values.

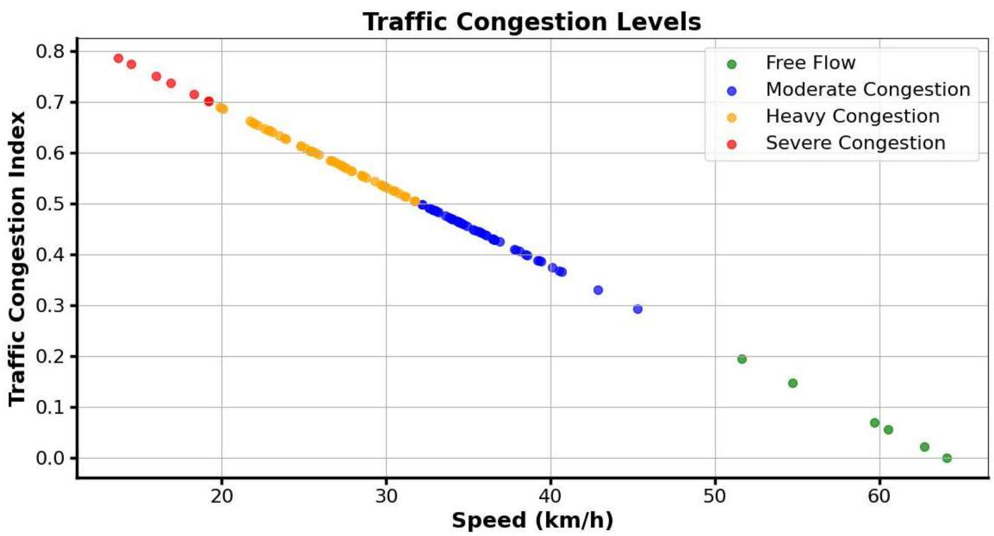

Figure 1. A plot of speed(km/h) and TCI.

The next step is to predict TCI values. The regression model created in this study shows the predicted Traffic Congestion Index (TCI) values in mixed traffic conditions, establishing it as an appropriate option for congestion analysis. To validate the model, a statistical parameter R^2 was utilized. The basic statistical metric employed for model assessment—R^2, obtained a value of 1, signifying an ideal fit between the predicted and actual TCI values. Due to this perfect relationship, supplementary error measurement parameters like Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) were excluded from the study, as they would yield very negligible insight. Figure 2 represents the plot of actual speed(km/h) and TCI against predicted speed(km/h) and TCI. The negative slope of the regression line confirms that as speed increases, TCI decreases. This aligns with theoretical expectations, as lower speed values relate to higher congestion levels, while higher speeds show free-flowing traffic conditions.

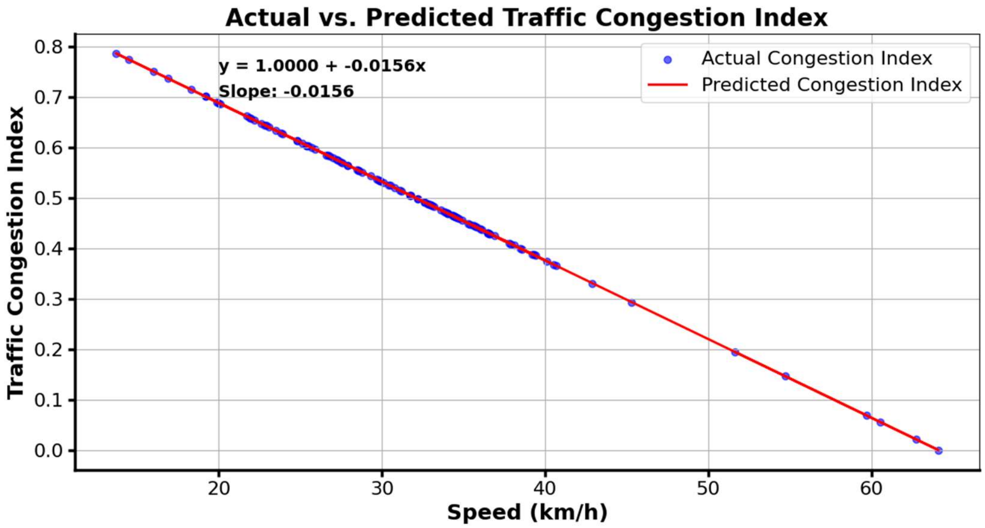

Figure 2. A Plot of Observed and Predicted speed(km/h) and TCI.

6. Conclusions

This study presented a regression-based model for the Traffic Congestion Index using speed values under mixed traffic conditions. It demonstrated a perfect statistical fit with $R^2 = 1$, indicating high prediction accuracy. Therefore, it is accepted as a reliable approach for estimating the Traffic Congestion Index based on speed values in mixed traffic conditions. The negative slope of the regression line shows an inverse relationship between speed and TCI, indicating that increased speeds correspond with decreased congestion levels, and the opposite is also true. Also, the model predicted absent data in this study, as shown in Fig. 2.

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