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Development of Empirical Equation to Estimate Corridor Speed of Vehicles in Metro Construction Work Zone

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Abstract: Construction of elevated metro line leads to a reduction in the average speed of vehicles due to congestions, diversions, and road incidents. This reduction in speed depends on recurring (e.g., congestion in rush hours) and non-recurring (e.g., road accidents) delay factors. Non-recurring factors involve incidents such as accidental bus stops, pedestrian crossings, or clearing debris from road, etc., some of which may occur at very short notice. This research paper presents a case study of Pune Metro Rail Construction (Corridor II) in India for developing an empirical equation to estimate corridor speed of vehicles in metro construction work zone. Observations were recorded in spatial and temporal zones using floating car method through video recordings and traffic count using manual method. Based on the traffic behavior pattern, five non-recurring delay factors (NRDFs) were defined, namely vehicles in lateral entry, slow moving vehicles, vehicles in the wrong direction, on-street parked vehicles, pedestrian interference and their correlation with speed of vehicles was tested. It was concluded that these factors have a strong negative correlation with the speed of the test vehicle. To estimate corridor speed with given NRDFs, nonlinear equation was formulated using empirical evidence and validated using larger simulated data.

Keywords: Recurring factors, non-recurring delay factors, logest function, spearman's rank coefficient

1. Introduction

Metro is a popular commuter choice around the world for a variety of reasons, including shorter commute times, less traffic congestion, improved comfort during travel, and reduced air and noise pollution. It plays a key role in urban development due to the sustainable level of transportation system, system effectiveness and efficiency [1]. With the increase in the urban population, the demand for infrastructure systems including metro networks, also increases, which can be described as one of the most tangible examples of complex transportation infrastructure systems [2]. The benefit in the form of reduced travel time can be expected to increase productivity leading to improved gross domestic product (GDP) of regions [3]. While these benefits are enjoyed by commuters and citizens after the start of its operations, during construction stage, diversions of routes and congestions on roads increases the travel time [4]. Traffic delay can be reduced by introducing detours and rerouting lanes depending on traffic intensity, which requires accurate planning under specific conditions [5]. It is observed that microscopic (related to traffic conditions on a road section) or macroscopic (e.g., land use pattern, regional growth, etc.) incidents play a significant role in it [6].

The delay caused by congestion is a function of the reduced speed in the work zone and is calculated as specified in eqn. 1.

$$\boldsymbol{delay} = \boldsymbol{L}\left({}^{\boldsymbol{1}}/_{\boldsymbol{v_z}} - {}^{\boldsymbol{1}}/_{\boldsymbol{v_f}}\right), \quad [\text{hr}] \tag{1}$$

where: L is the length of the work zone [km], $\boldsymbol{v_z}$ is work zone speed [km/h] and $\boldsymbol{v_f}$ is the free flow speed [km/h] [7]. Along with these parameters, the number of lanes, percentage of heavy vehicles, and accident rate are used by various researchers as decision variables for estimating the reduction in speed [8,9]. The effect of the congestion index value, pedestrian movement, road surface conditions, traffic density, vehicle travel time, average speed, and the proportion of time vehicles are stopped at different locations are also considered to estimate the traffic congestion value, which is a measure to calculate speed delay [10]. The collision intensity and visibility also affects speed and may change the travel time predictions [11].

Apart from these spatial reasons that affect the speed of vehicles, there are also temporal reasons that increase travel times. These are classified as recurring and non-recurring congestions depending on road conditions and traffic characteristics. As stated in IRC SP 55 [12], congestion on roads occurs when road capacity cannot be provided for peak demands, which leads to waiting and delays. They are classified as recurrent and non-recurrent, with recurrent being those when demand exceeds the capacity of roads, which usually occurs in the morning and afternoon peak hours [13]. Non-recurring congestions refer to unusual and disruptive maneuvers by individual drivers, random minibus stops, and random pedestrian crossings [14,15].

Further research focused on calculating time loss due to congestion [16] using flow of traffic, average speed, and speed in light traffic. Non-recurrent traffic congestions caused e.g., by roadway patching, roadway paving, facility repairs, lane marking, weeding, planting, and debris removal, were quantified using one-year historical data [17]. Other non-recurrent delay factors such as pedestrian interference and on-street parking were studied and confirmed the reduction in speed resulting from varying conditions [18].

The researchers analyzed a variety of factors, including incident-driven delays in urban areas with homogeneous or heterogeneous traffic using recurring and non-recurring delay factors, short roads with localized construction work zones (CWZ), highways with short-term repair work, and more. In India, various characteristics of CWZ with varying length and width together with heterogeneous traffic account for most of the travel delays caused by metro development. These are the main causes of ongoing delays. In the spatial and temporal work zone of road construction, other non-recurring delay factors (NRDFs) based on travel behavior patterns must be considered. Considering the traffic behavior pattern, travel speed is also affected by dynamic incidents such as slow-moving vehicles, vehicles going in the wrong direction and vehicles merging in lateral directions. These are prevalent in the metro work zone due to reduction in the roadway width and need to be accounted for at all times of the day due to their random occurrence.

Based on the literature research, it was found that a combined study of the non-recurring factors has not been carried out before. In addition, there is a lack of study on the effect of metro construction works on traffic speed, which directly affect travel delay. To bridge the gap, this paper defines five novel non-recurring delay factors (NRDFs) based on traffic behavior pattern (TBP) and presents a methodology for their quantification. Also, an empirical equation is developed to determine the relationship between NRDFs and speed of vehicle to identify non-recurring costs.

2. Methodology

The study of NRDFs and their quantification is divided into three phases: (1) identification of non-recurring delay factors (NRDFs) by means of literature research, questionnaire survey and floating car method; (2) analysis of data collected using the correlation coefficient and Spearman's rank correlation coefficient; (3) formulation of empirical equation. The field study was conducted on Pune Metro corridor II (between Vanz-Ramwadi) in Pune city (see Fig. 1).

(a)

(b)

Fig. 1 (a) Location of Pune city (b) Study route (V-D and D-V). Source: authors

The corridor extends between Vanaz and Deccan, with a total length of 5.566 km with diversion in the direction Vanaz to Deccan (V-D) and 5.12 km without diversion in the direction Deccan – Vanaz (D-V). The region was chosen due to its unique characteristics of heavy heterogeneous traffic on the main arterial road, i.e., Karve Road with varying CWZ areas depending on the stage of construction. The total length under study was divided into several nodes spread between consecutive intersections. Seventeen such nodes were identified in the direction Deccan to Vanaz (D-V) and nineteen in the direction Vanz to Deccan (V-D), which included the diversion between SNDT college and Nalstop. (Ref. fig. 1 b). At the time of the survey, construction of the elevated metro was in different stages and the work of superstructure was in progress. The road occupied for construction varied as per requirement and its details such as length and width were noted. In the central meridian, where the lowering of the girders was in progress, a road space of 9 m (4.5 m either side) was occupied.

2.1 Identifying NRDFs.

After selecting the study area and identifying NRDFs, the first phase of survey was divided into three stages as (i) literature research (ii) questionnaire survey and (iii) road survey using floating car method. First, comprehensive literature research was conduct, according to which road user costs in CWZ are influenced by recurring (congestions) and non-recurring factors (accidents). Non-recurring factors which have impact on road user costs include pedestrian interference, random bus stops, and on-street parking [14,18-22]..

To identify other non-recuring factors that affect traffic speed, a questionnaire survey was conducted. A total of 86 filled in questionnaires were collected from commuters who use the selected route regularly and were asked to rate the significant factors that affect the speed of vehicles. The questions asked were based on the reasons for delays and rated on a scale of 1 to 10, with 1 being the least likely to affect the speed whereas 10 being the most common cause of delay. Daily traffic experiences were recorded, and the causes were categorized in six groups as seen in Table 2. These were shortened and categorized as follows: (i) road conditions (RD) (ii) types of vehicles moving ahead including construction vehicles, i.e., slow moving vehicles (P_{sl}) (iii) on-street parking (P_{pk}) (iv) pedestrian interference (P_p) (v) vehicles coming from wrong side (P_{wr}) (vi) vehicles merging in the traffic in lateral direction (P_{lt}). These non-recurring delay factors are detailed in Table 1.

Table 1 Summary of questionnaire survey. Source: authors

Sr. No.	Names of non-recurring factors	Abbreviation	Average score
1.	Road conditions	RD	7.571
2.	Roadside Parking of vehicles in the vicinity of metro rail construction work zone	P_{pk}	7.012
3.	Slow moving vehicles	P_{sl}	6.702
4.	Vehicles coming in lateral entries	P_{lt}	6.671
5.	Vehicles coming in wrong side	P_{wr}	6.424
6.	Pedestrian interference	P_p	5.429

Out of these factors, road condition (RD) is a static factor i.e., it does not depend on the time, while others are dynamic, which means that they change with time and space. Accordingly, the NRDFs finalized were P_{pk}, P_{sl}, P_{wr}, P_{lt} and P_p as mentioned above (Fig. 3).

2.2 Defining Non-recurring Delay Factors (NRDFs)

Non-recurring congestions occur at any time of the day on any type of road whose its capacity is greater than traffic demand [16]. Based on the literature research and questionnaire survey conducted, five most common non-recurring delay factors (NRDFs) were identified. (Fig. 2)

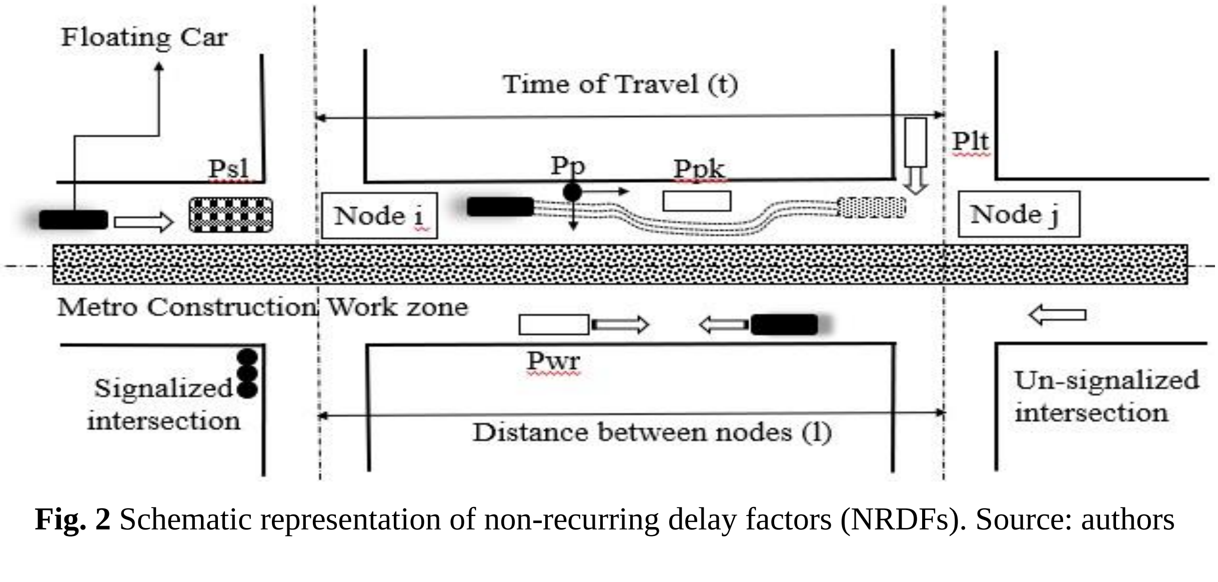

Fig. 2 Schematic representation of non-recurring delay factors (NRDFs). Source: authors

1. Vehicles in lateral entries (Plt): Traffic from sub-arterial roads and traffic from arterial roads occasionally mix, slowing down through traffic. Sometimes, parked cars also make lateral entrance into the main flow of traffic, slowing it down and causing congestion in some regions.

2. Slow-moving vehicles (Psl): Due to the narrower road width, slow-moving vehicles in front of you cannot be overtaken, which leads to occasional traffic jams. These reduce the speed of vehicles behind them.

3. Parked vehicles (Ppk): The maneuver of "on street" parked automobiles in various areas of the corridor delays vehicles behind them [22]. Parked cars narrow the route that is also a construction zone, which in turn causes increased travel times and reduced speed.

4. Vehicles in the wrong entrance (Pwr): In an effort to shorten their travel distance, vehicles, particularly two-wheelers, often travel in the wrong or opposite direction from oncoming traffic. This has a negative impact on the speed of oncoming traffic. Due to the narrowing of roads, this is even more noticeable near construction zones.

5. Pedestrian Interference (Pp): If there are not appropriate facilities (such as sidewalks and crossings), pedestrians and vehicle traffic may conflict on the road. Random pedestrian crossings across the road in the middle of a block slow down the test vehicle. Moreover, pedestrians use the width of the road while crossing, thereby slowing down traffic.

2.3 Floating Car Method

The floating car method provides an unbiased estimate of flow, allowing for simultaneous collection of speed and flow data. [23]. It enables traffic engineers and planners to obtain accurate and reliable traffic parameters, such as speed, travel time, and delay [24,25]. In this study, NRDFs are quantified using the floating car method combined with measurements of "running speed" between adjacent nodes and travel speed. The floating car/test vehicle moved between different nodes at free flow speed (SFF) ranging from 30 km/h to 35 km/h (average 32.5 km/h) for a period of sixteen hours (between 6 am and 10 pm) in both directions (V-D and D-V), as the speed limit in the work zone was 30 km/h. [26]. On the test vehicle's dashboard, a mobile camera was installed to take video recordings, and the traffic circumstances were manually evaluated. The speed in the corridor (Sco), the actual speed between the nodes, signal stop timing, and the vehicle speed between successive nodes were all recorded. NRDFs that affect the test vehicle's speed were observed every sixteen hours between two nodes. Except for walkers, all vehicles were converted into passenger car units (PCU) based on their number and type using the corresponding PCU factors listed in IRC: 106-1990.

2.4 Analysis of Data Collected

The speed in the corridor was affected by the non-recurring incidents happening while travelling between two nodes. Its correlation with speed of test vehicles was tested using two methods.

2.4.1 Coefficient of Correlation

Karl Pearson established a factor ‘r’ to represent correlation between two variables X and Y as follows:

$$r = \frac{Cov\ (X,Y)}{STDEV\ (X), STDEV\ (Y)} = \frac{\sigma_{XY}}{\sigma_X \sigma_Y}, [-] \tag{2}$$

where: $\sigma_{XY}, \sigma_X, \sigma_Y$ represent the standard deviations of the series of observations for XY and X, Y respectively [-] [27]. This equation was applied to find the coefficient of correlation between NRDFs and the speed in the corridor (Sco), as mentioned in Table 2. It was found that all NRDFs show a strong negative correlation with the speed in the corridor Sco, which means that the speed of the test vehicle decreased with the increase in these factors.

Table 2 Correlation coefficient with speed of test vehicle. Source: authors

	Ppk	Psl	Plt	Pwr	Pp
V-D	-0.81	-0.88	-0.86	-0.65	-0.72
D-V	-0.77	-0.83	-0.76	-0.66	-0.78

The NRDFs were added to get total PCU (TP) which affect the speed of test vehicle while travelling on the road under study in one direction.

$$TP = P_{pk} + P_{sl} + P_{lt} + P_{wr}\ [-] \tag{3}$$

where: TP is Total PCU [-]; P_{pk} is the PCU value of parked vehicles [-]; P_{sl} is the PCU value of slow-moving vehicles [-]; P_{lt} is the PCU value of vehicles in lateral entry [-]; P_{wr} is the PCU value of vehicles in the wrong entry [-]. Pedestrian interference, which is the sum of the number of pedestrians crossing the road as well as walking on the road, is a separate variable which was counted separately.

2.4.2 Spearman’s Rank Correlation Coefficient

To determine the correlation between two rank variables with a specified level of significance, Spearman's rank correlation is used. It is a useful method for defining the dependency between a pair of series [27]. It was also used by researchers to derive rankings of attributes between various methods [28]. In this paper, Spearman’s rank is used to establish correlation between NRDFs and the speed in the corridor (S_{co}) with level of significance α = 0.1. Fig. 3 presents a box and whisker chart of Spearman’s rank coefficient between P_{sl}, P_{pk}, P_{wr}, P_{lt} and P_{p}.

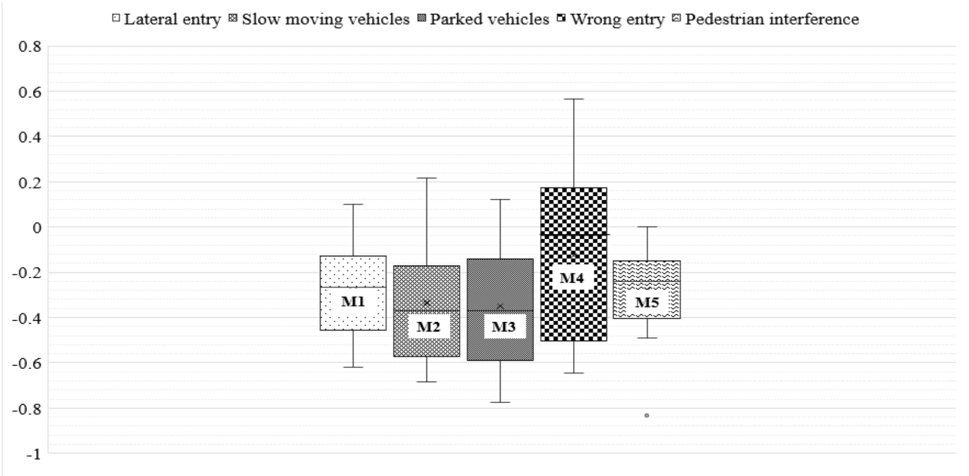

Fig. 3 Box and Whisker Chart showing Spearman's Rank Coefficient with Speed of Test Vehicle. Source: authors

The medians M1, M2, M3, M4 and M5 lie below X axis, which confirms the conclusion that the decrease in the speed of test vehicle is a result of an increase in the NRDFs.

3. Development of Empirical Equation between NRDFs and Speed of Test Vehicle

The discussions in the previous sections shows that there is a correlation between the total NRDFs (TP) (eqn. 1) and the speed of the test vehicle (Sco). In addition, three other factors considered are (i) the number of stops for signals (ST) resulting in acceleration and deceleration of vehicles with an average speed reduction; (ii) traffic density factor (TDF) which is a ratio of the actual volume to capacity of road in a given period of time (iii) the percentage of road occupied for construction (RD), which affects the level of service (LOS) of roads throughout the day. It ranges from A to E depending on Sco, as specified in IRC 106:1990 as the number of vehicles increases. These additional factors are described below.

3.1 Number of Signals (ST)

Acceleration and deceleration of vehicles due to signal stops results in a decrease in speed. With an average delay of 11.8 seconds per vehicle, the estimated delay caused by signal stops accounts for nearly 93 % of the total intersection delay [29]. By calculating the number of stops made by the test vehicle, signal stops were also included in this study to account for this delay.

3.2 Traffic Density Factor (TDF)

It is the ratio of the traffic demand between two nodes at a given time to the capacity of the road. TDF is a dynamic recurring factor that varies according to the daily peak hours. According to IRC 106:1990, the total design traffic volume for a four-lane sub-arterial road is 2900. TDF was calculated for the complete section under study at various times of the day by dividing the traffic count by 2900 and included in the empirical equation formulation.

3.3 Percentage of Road Occupied for Construction (RD)

The corridor II metro project in Pune was at various phases of development with varying road widths being used for construction between nearby nodes. For each node, a percentage of road occupancy was calculated and used to formulate the equation.

Following the completion of this analysis, TP, ST, TDF, and RD were chosen as the components most likely to affect the speed in the corridor Sco. The Logest function was used to create an empirical equation that calculated an exponential curve to fit the data set. The array of values that this method returns best describes the curve. The data sets were taken as (I) direction V-D (II) direction D-V (III) both directions for the development of equations.

To find the optimum equation that produces the same average observed speed and estimated speed, these equations underwent hypothesis testing (Student 't' test). With 95% confidence, a two-tailed hypothesis test was performed. The following equation confirmed the validity of the hypothesis, which can be used to estimate the speed in the corridor in km/h.

$$S_{co} = 0.9988^{RD} \times 0.981^{ST} \times 0.957^{TDF} \times 0.999^{TP} \times 25.39 \ \text{[km/h]} \tag{4}$$

where: S_{co} is the speed in the corridor [km/h]; RD is the percentage of road occupied for construction [-]; ST is the number of signals [-]; TDF is the traffic density factor [-]; TP is the total PCU [-]; and 25.39 is the constant in Equation 4.

This equation was validated for a larger data set generated using a Monte-Carlo simulation technique using random number to create a realistic scenario. The data was generated for 365 days resembling one complete year for all NRDFs and traffic speed. The simulated average results of RD, ST, TDF and TP in the directions V-D and D-V were used in Equation 4 and Sco was calculated. Fig. 4 compares the average speeds for twelve survey days, the simulation results, and the logest function results. Thus, a validation of the equation was performed, which shows that the deviation is less than 2 % and is within the acceptable limit of 95% confidence interval (i.e., between 19.23 km/h to 21.28 km/h).

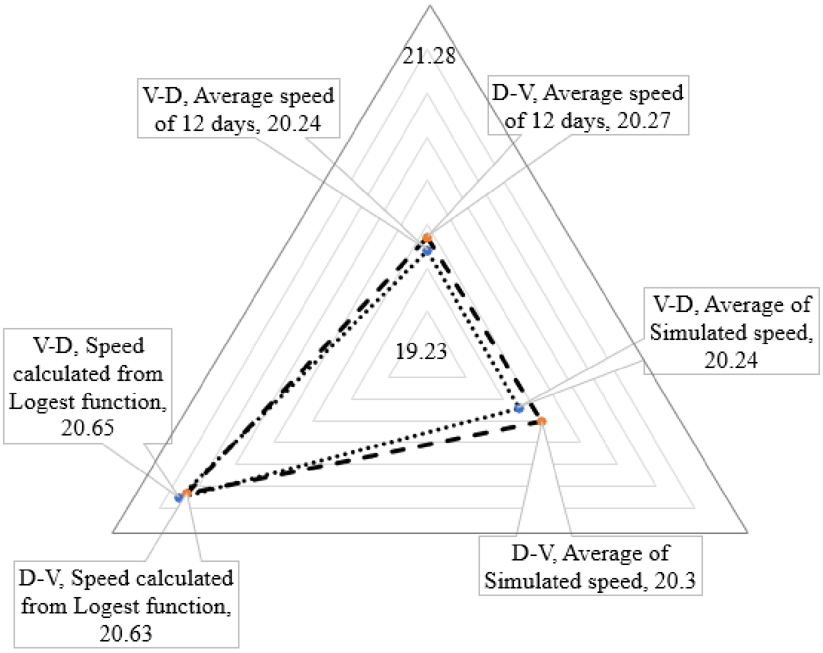

Fig. 4 Validation of Logest function with Simulated speed and NRDFs. Source: authors

4. Results and Conclusions

This research presents five unique non-recurring delay factors (NRDFs), namely pedestrian interference (Pp), vehicles in lateral entry (Plt), vehicles coming in the wrong direction (Pwr), slow-moving vehicles (Psl), and on-street parking (Ppk), which affect the speed in the corridor S_{co} and show a strong negative correlation with each other. Also, the level of significance is confirmed by using Spearman's rank coefficient. Non-recurring delays were caused by incidents occurring on roads irrespective of peak hours, traffic density, or level of service of the roads but were significantly observed in the vicinity of construction work zone. The observations of the study area were made for a sample size of twelve days. Additional data was generated using a Monte-Carlo Simulation with random numbers for 365 days resembling larger number of data set spanning for one year. In the simulation process, this random aspect accounted for the heterogeneity of each section of the road infrastructure. The comprehensive methodology adopted in this research can be extended to accommodate the diverse real-life characteristics of such work zones. In the future scope, primary data may be generated for various metro zone routes other than Pune metro using the methodology mentioned in this paper.

According to the authors, the speed in the corridor should be increased by providing (i) good facilities for pedestrians, (ii) adequate parking on sub-arterial roads (iii) extending road width in the construction work-zone and (iv) educating the commuters to follow traffic rules.

The sections discussed above indicate that there is a significant increase in the number of NRDFs in the construction work zone. Hence, they were taken as one of the variables for calculating the delay time in similar work conditions and traffic behavior.

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References

[1] Zhang, Z., Wang, G., Zhou, Z., Xu, X. & Lin, W. (2020). Technologies and Strategies for Promoting Metro Rail Sustainability: A Case Study in China. Construction Research Congress, Nov. 2020. DOI: 10.1061/9780784482858.005.

[2] Saadat, Y., Ayyub, B.M., Zhang, Y., Zhang, D. & Huang, H. (2019). Resilience of Metrorail Networks: Quantification With Washington, DC as a Case Study. ASCE-ASME J Risk Uncert Engrg Sys Part B Mech Engrg 5(4). DOI: 10.1115/1.4044038.

[3] Poliak, M., Kubáňová, J., Zhuravleva, N.A., Jaśkiewicz, M. & Lakhmetkina, N. (2023). Identification of the Impact of Transport Performance on the Economy of Particular Area. LOGI – Sci. J. Transp. Logist. 14(1), 192–202. DOI: 10.2478/logi-2023-0018.

[4] Zhu, Z., Ahmad, I. & Wang, L. (2009). Estimating Work Zone Road User Cost for Alternative Contracting Methods in Highway Construction Projects. J. Constr. Eng. Manag., 601–608. DOI: 10.1061/(ASCE)CO.1943-7862.0000020.

[5] Gravelle, E. & Martínez, S. (2018). Distributed dynamic lane reversal and rerouting for traffic delay reduction. Int. J. Control 91(10), 2355–2365. DOI: 10.1080/00207179.2017.1344909.

[6] Almotahari, A. (2019). Analysis of incident induced capacity reduction for improved delay estimation. J. Transp. Eng. Part A Syst. 145(2), 0401808301–1. DOI: 10.1061/JTEPBS.0000207.

[7] Jiang, Y., Chen, H. & Shuo, Li. (2014). Computation of User Costs at Freeway Work zone using Weigh-in-motion Traffic Data. J. Constr. Educ. Res. 197–219. DOI: 10.1080/15578770903152823.

[8] Ramadan, O.E. & Sisiopiku, V.P. (2018). Modeling Highway Performance under Various Short-Term Work Zone Configurations. J. Transp. Eng. Part A Syst. 144(9). DOI: 10.1061/JTEPBS.0000176.

[9] Meng, J.W.Q. (2013). Impact Analysis of Work Zone Configuration, Traffic Flow and Heavy Vehicle Percentage on Traffic Delay at Work Zones. Asian Transp. Stud. 2(3), 239–252. Retrieved Jul. 19, 2023, from https://www.jstage.jst.go.jp/article/eastsats/2/3/2_239/_pdf/-char/en

[10] Patel, N. & Mukherjee, A.B. (2015). Assessment of network traffic congestion through Traffic Congestability Value (TCV): a new index. Bull. Geogr. Socio-economic Ser. 30(30), 123–134. DOI: 10.1515/bog-2015-0039.

[11] Li, H., Wang, W. & Xiong, W. (2021). New Model of Travel-Time Prediction Considering Weather Conditions: Case Study of Urban Expressway. J. Transp. Eng. Part A Syst. 147(3). DOI: 10.1061/JTEPBS.0000491.

[12] IRC SP 55. (2014). India: Indian Road Congress. Retrieved Jul. 19, 2023, from https://law.resource.org/pub/in/bis/irc/irc.gov.in.sp.055.2014.pdf

[13] Fazal, A.B.S, Ectors, W., Ali, M.S., Knapen, L., Janssens, D. & Yasar, A. U.H. (2016). Estimation of value of time for a congested network- A case study of the National Highway, Karachi. DOI: 10.1016/j.procs.2016.04.124.

[14] Chakrabartty, A. & Gupta, S. (2015). Estimation of Congestion Cost in the City of Kolkata—A Case Study. Curr. Urban Stud. 03(02), 95–104. DOI: 10.4236/cus.2015.32009.

[15] Qiang, M. & Jinxian, W. (2013). Estimation of direct economic cost of traffic congestions in Cairo. Asian Transp. Stud. 2(3), 239–252. Retrieved Jul. 19, 2023, from https://vdocuments.net/4-estimation-of-direct-economic-costs-of-traffic-4-estimation-of-direct-economic.html?page=1

[16] Chien, S. & Schonfeld, P. (2001). Optimal Work Zone Lengths for Four-Lane Highways. J. Transp. Eng. 127(2). 124–131. DOI: 10.1061/(ASCE)0733-947X(2001)127:2(124).

[17] Chung, Y., Kim, H. & Park, M. (2012). Quantifying non-recurrent traffic congestion caused by freeway work zones using archived work zone and ITS traffic data. Transportmetrica 8(4), 307–320. DOI: 10.1080/18128602.2010.522609.

[18] Praburam, G.K. (2015). Effect of on-street parking on traffic speeds. IPENZ Transp. Gr. Conf. Christchurch 1–10. Retrieved Jul. 19, 2023, from https://ir.canterbury.ac.nz/bitstream/handle/10092/10954/12655275_paper-koorey-glen-effect-parking-speeds.pdf?sequence=2&isAllowed=y

[19] Yang, Z., Zhang, Y., Zhu, R., Ye, X. & Jiang, X. (2015). Impacts of Pedestrians on Capacity and Delay of Major Street Through Traffic at Two-Way Stop-Controlled Intersections, Math. Probl. Eng.2015, 1–11. DOI: 10.1155/2015/383121.

[20] Amado, H., Ferreira, S., Tavares, J.P., Ribeiro, P. & Freitas, E. (2020). Pedestrian–Vehicle Interaction at Unsignalized Crosswalks: A Systematic Review. Sustainability 12(7), 2805. DOI: 10.3390/su12072805.

[21] Li, X. & Sun, J.Q. (2016). Effects of vehicle-pedestrian interaction and speed limit on traffic performance of intersections. Phys. A, Elsevier, 235–242. DOI: /10.1016/j.physa.2016.05.034.

[22] Cao, Y., Yang, Z.Z. & Zuo, Z.Z. (2017). The effect of curb parking on road capacity and traffic safety. Eur. Transp. Res. Rev. 9(1), 4. DOI: 10.1007/s12544-6-0219-3.

[23] Kadiyali, L.R. (2013). Traffic Engineering and Transport Planning, (8th edition). Delhi. India. Khanna Publishers.

[24] Zhao, L., Chien, S.I. & Du, B. (2019). Optimizing Work-Zone Schedule with Floating Car Data Considering Traffic Diversion and Managed Lanes. J. Transp. Eng. Part A Syst. 145(1). DOI: 10.1061/JTEPBS.0000202.

[25] Xuesong, W., Haobing, L. & Rongjie, Y. (2014). Exploring Operating Speeds on Urban Arterials Using Floating Car Data: Case Study in Shanghai. J. Transp. Eng. part A Syst. 140(9). DOI: 10.1061/(ASCE)TE.1943-5436.0000685.

[26] IRC 106. (1990) India: IRC 106, 1–10. Retrieved Jul. 19, 2023, from https://archive.org/details/gov.in.irc.106.1990

[27] Kothari C.R. & Gaurav, G. (2019). Research Methodology - Methods and Techniques. (4th edition). New Delhi. India: New Age International.

[28] Shubhajit, S., Banerjee, U. & Bhargava, M. (2015). Commuters' Perception towards Transfer Facility Attributes in and around Metro Stations: Experience in Kolkata. J. Urban Plan. Dev. 141(4). DOI: 10.1061/(ASCE)UP.1943-5444.0000243.

[29] Mousa, R.M. (2002). Analysis and Modeling of Measured Delays at Isolated Signalized Intersections. J. Transp. Eng. 128(4), 347–354. DOI: 10.1061/(ASCE)0733-947X(2002)128:4(347).