International Journal on Engineering Technology (InJET)

www.kec.edu.np/kec-journal/
Volume 2, issue no. 1, Dec 2024, Page 71-79
Received Date: July 18, 2024
Accepted Date: Sept 29, 2024
ISSN: 3021-940X (Print)
DOI: https://doi.org/10.3126/injet.v2i1.72522

Unraveling the Traffic Congestion Due to Bottleneck: A Review

Saras Mainali[1,*], Swapnil Regmi[1], Kapil Wagle[1], Raju Bhele[1]
[1]*Department of Civil Engineering, Kathmandu University, Dhulikhel, Kavre, Nepal*

Abstract

In the metropolitan cities across the world, traffic congestion is a major problem due to growing urbanization, vehicle growth and infrastructure constrains. Bottleneck congestion is a major problem faced in traffic management in many urban centers as it affects travel time, emissions, and fuel consumption. It accounts for nearly 40% of congestion. This extensive literature review aims to discuss the main reasons behind traffic congestion, classify their patterns, and discuss how it can be detected and prevented. This paper focuses on the economic and social consequences of traffic bottlenecks by considering several traffic congestion research. The methods namely; Manual counting, social surveys, CCTV footage analysis, Navigation, and simulation software namely VISSIM are discussed in this paper. It also offers traffic control methods and other difficulties and contemporary control measures for congestion. In addition, this review emphasizes on the need of cost effective traffic congestion management, particularly in underdeveloped countries like Nepal, where video graphic survey is recommended as the most feasible approach. The purpose is to deliver pertinent information to transportation planners and engineers to address issues concerning traffic congestion in big cities and offer ways of improving the efficiency of transport systems in urban cities.

Keywords: Traffic congestion, Traffic bottlenecks, Videography survey, VISSIM, Contagion

1. Introduction

Increase in vehicular traffic, urbanization, and population growth, traffic congestion has become a serious problem in almost all modern metropolitan cities. This congestion reduces the efficiency of transportation infrastructure and increases travel time, air pollution, and fuel consumption, leading to various social and economic problems. As a major contributor to congestion, traffic bottlenecks account for 40% of traffic congestion. (Timalsena, Marsani and Tiwari, 2017; Li *et al.*, 2020). Locating these bottlenecks to identify the root causes of congestion is crucial and provides effective and cost-efficient means for traffic improvement. Besides increasing the capacity of bottlenecks by widening roads, advanced traffic control strategies such as traffic light control and vehicle rerouting can be implemented to relieve congestion. Traffic congestion is an extensive global phenomenon resulting from high population density, the growth of motor vehicles and their infrastructure, and the proliferation of rideshare and delivery services. (Afrin & Yodo, 2020; Aftabuzzaman, 2007)Although there are various ways in which researchers describe congestion, the most widely accepted definition is that it occurs when travel demand outpaces available road capacity. The disturbance of regular traffic flow brought on by a high vehicle density that results in longer travel times or higher expenses for road users is known as congestion. Recurring congestion is a result of excessive numbers of vehicles on the road during rush hour. In contrast, unforeseen circumstances including bad weather, construction zones, accidents, and special events bring on nonrecurring congestion. (Timalsena, Marsani and Tiwari, 2017; Afrin and Yodo, 2020; Yang et al., 2020).Despite the extensive research on traffic congestion, there is no universally accepted definition, and the debate continues about the most appropriate measures to represent the magnitude of congestion on urban roadways.

Traffic bottlenecks are often defined as the areas of a roadway with lower capacity or higher demand than other sections of the roadway. This congestion metric considers things like vehicle operating and maintenance

**Corresponding Author*

costs and delay times. The journey duration is ascertained by measuring and analyzing the distance in relation to the vehicle's speed. The public is prevented from reaching the theoretical time by a traffic bottleneck; as a result, the delay time can be examined. (Timalsena, Marsani and Tiwari, 2017a).In addition to inadequate traffic management being a major contributor to traffic congestion, intersections in road networks also play a significant part in it. (Cutrell & ACM Digital Library. 2012; Nepali et al., 2024). The two terms stand along together with the traffic bottleneck; Congestion and Congestion Contagion. Briefly, Congestion is a condition where traffic demand exceeds road capacity, leading to slower vehicle movement, delays, and increased queuing whereas, Congestion Contagion is the spread of traffic congestion from one area to surrounding roads, causing a ripple effect of delays across the network.

C. Li et al., 2020 proposes a method to apply bottleneck detection where the road sections are defined in alphabets as A, B, C, and D. It illustrates it with the help of Figure 1. This image outlines a bottleneck identification technique through several stages:

Congestion Map (a): The first panel shows a map of the area, identifying congestion points labeled A, B, C, D, and E.

Congestion Correlations (b): The second panel illustrates the correlation between the congested points. It represents a network where each node depicts a congestion point, and the edges between them signify how they are co-related or how congestion in one area may affect others.

Congestion Propagation Graph (c): This graph shows how congestion propagates through the network, suggesting that congestion in certain areas influences others. Each node is connected to several other nodes, showing how congestion at one location spreads.

Maximal Spanning Tree (d): From the congestion propagation graph, a spanning tree is generated, starting from a root (A in this case). This tree structure represents the most critical connections contributing to overall congestion in the network.

Bottleneck Identification (e): Finally, the bottleneck is identified. Node B, with the highest cost (1.1), is highlighted as the bottleneck. The costs for other nodes (A = 0.7, C = 0.8, D = 0.5, E = 0.4) are lower, indicating less impact on overall congestion.

In this approach, the point with the highest "cost" or influence on traffic propagation, in this case, B, is identified as the bottleneck.

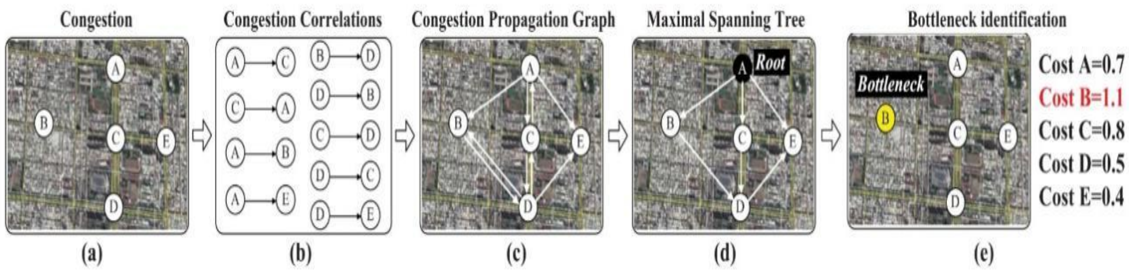

Figure 1. Roadmap of Bottleneck Identification Technique (C. Li et al., 2020)

1.1. History

Vickrey created the notion of a bottleneck in 1969. The purpose of this concept's development was to alleviate the departure time in the morning rush hour bottleneck roadway. (Z. C. Li et al., 2020) Bottlenecks, both recurring and non-recurring, are the primary cause of traffic congestion. Early on, researchers employed a variety of techniques to identify bottlenecks based on numerous traffic data, including flow variations, wait length, average vehicle travel speed, and road occupancy. (Yang et al., 2020)

When bottlenecks were first identified, they were mostly found on highways and were identified using matrices such as the ratio of traffic flow to road capacity. New strategies must be implemented because of the complexity of the topography of urban road networks and the resulting increase in traffic congestion. In metropolitan locations, traditional freeway approaches lose some of their effectiveness. (C. Li et al., 2020). To alleviate congestion at bottlenecks, traffic management strategies like metering were introduced. Metering regulates the inflow into the bottleneck to prevent excessive congestion and enhance overall traffic flow. However, paradoxically, adding capacity to a network can sometimes lead to congestion, as demonstrated by Braess's Paradox. This phenomenon underscores the intricate interactions among network components and the counterintuitive impact of infrastructure modifications. (Arnott, 1993; Li, Huang and Yang, 2020a)

1.2. Patterns of bottleneck

The traffic bottleneck presents the distinct patterns, which strongly influence traffic flow and congestion nature. The identification and understanding of these patterns are significant for the effective traffic management. Here is a breakdown of the different patterns of bottlenecks in road traffic (Yang et al., 2020a)

1st Pattern:

This pattern of bottleneck is characterized by a sharp reduction in the probability of oversaturation downstream showing that it has a very influential effect on traffic flow in the upstream section. If vehicles get to the bottleneck point, they can move immediately without any hindrance. Some of the examples include important transport intersection points which are the points where two main roads of different directions intersect to create a higher traffic flow upstream and a lower traffic flow downstream. In Figure 2(a), it can be seen that the oversaturation probability slowly increases, followed by sharp reduction after passing the bottleneck section in "Jianguomen".

2nd Pattern:

The second pattern is isolated with high probability of oversaturation in one sector and a relatively low probability in the adjacent sectors. Usually sited on the approaches to on and off ramps where traffic volumes are high resulting in traffic bottleneck. In Figure 2(b), the oversaturation probability sharply increases at the bottleneck section, "Guang' Anmen Bridge" and also sharply decreases after it.

3rd Pattern:

As with the first pattern in the upstream, oversaturation probability goes down in a step wise manner in the downstream. Downstream the range of influence may be shorter because factors that disrupt traffic flow may occur such as successive ramps that affect the smooth flow of traffic. The 3^{rd} pattern of bottleneck can be seen in Figure 2(c), where the oversaturation probability increases and decreases in step wise manner in both upstream and downstream of bottleneck section "Andingmen".

4th Pattern:

This pattern is a supersized bottleneck and oversaturation probabilities are still high in numerous road segments. This is because traffic is complex due to high demand, attractive locations, and many routes converging in one road. Congestion goes upstream, and consequently, more segments of the road are involved. The 4^{th} pattern of bottleneck is a complex system where the oversaturation probability goes slightly up and down over a long span. This behaviour of traffic can be seen in Figure 2(d) at the section between "West Corner - Fuxingmen - Jishuitan - Andingmen".

These patterns show the fluctuation of bottlenecks of road traffic and the characteristics of congestion in various situations. Such insights can be useful to the transportation planners and engineers in formulating specific measures that may be adopted in order to reduce congestion and enhance traffic flow in urban space.

The patterns of Traffic Bottleneck have been visualized in the bridges of Beijing city, China, and the graphical representation of the patterns has been shown figure 2 (a,b,c,d), (Yang et al., 2020). They shows the variation of oversaturation probability with the location of different detector sections in Ring roads in Beijing, China. The oversaturation probability is the peak hour probability, as the peak hour probability can effectively illustrate the conflict between traffic demand and supply.

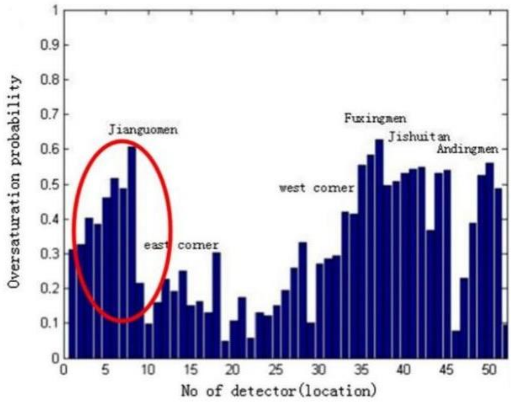

Figure 2(a): 1st pattern in Jianguomen

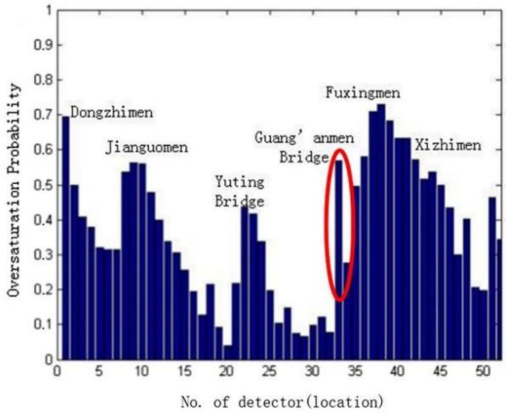

Figure 2(b): 2nd patter in Guang' anmen

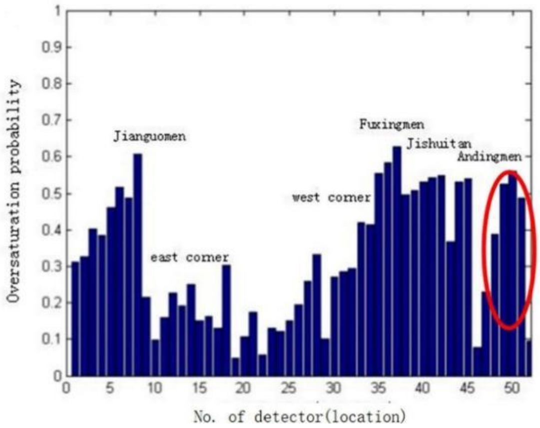

Figure 2(c): 3rd pattern in Andingmen

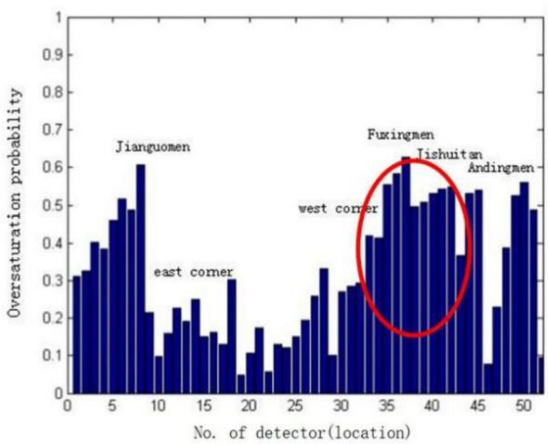

Figure 2(d): 4th pattern in Fuxingmen

2. Purpose and Scope of the Review

The article seeks to present the bottleneck idea as one of the primary causes of congestion. This paper highlights the importance of studying traffic bottlenecks in order to mitigate economic losses and travel time losses in a world where every minute counts. Similarly, the traffic bottleneck has also made the researchers emphasize the type and design of the vehicles, with changes required after the study.

As shown in table 1, all articles that are listed focus on the aspect of travel time. The studies on traffic congestion and bottlenecks have demonstrated a clear relationship to the economy, travel time, and vehicular design as presented in the tabular form below; the "✓" mark showing the articles' relation with the parameters stated above and the "X" mark showing lack of any relationship.

Statistical and economic considerations are also covered quite often though slightly less often than the preceding type of data. Vehicular design or replacement is the least addressed issue, mentioned in less than half of the articles. In conclusion, the literature sheds a lot of emphasis on the travel time consequences and pays substantial but somewhat differential attention to economic conditions and vehicular design.

Table 1: Relationship of the cited papers with economy, travel time, and vehicular design or replacement

S.N	Articles	Economy	Travel time	Vehicular design or replacement
1	(Timalsena et al., 2017)	✓	✓	✓
2	(Afrin & Yodo, 2020)	✓	✓	X
3	(C. Li et al., 2020)	✓	✓	X
4	(Witte et al., 2012)	✓	✓	X
5	(Agbonika, 2011)	✓	✓	✓
6	(Zhu et al., 2021)	X	✓	✓
7	(Carlos Mu~ N Noz, Daganzo and Daganzo, 2001)	X	✓	X
8	(Suryani et al., 2019)	X	✓	✓
9	(Z. C. Li et al., 2020)	✓	✓	X
10	(Lin et al., 2013)	X	✓	X
11	(Kroes et al., 1996)	X	✓	✓
12	(Nepali et al., 2024)	X	✓	✓
13	(Yang et al., 2020)	X	✓	✓
14	(Richardarnott et al., 1990)	✓	✓	X
15	(Badshah et al., 2022)	X	✓	✓
16	(Rudjanakanoknad, 2012)	X	✓	✓
17	(Wang et al., 2009)	✓	✓	X
18	(Arnott & Inci, 2006)	✓	✓	X
19	(Arnott & Lindsey, 1991)	✓	✓	✓
20	(Cao et al., 2017)	✓	✓	X
21	(Zhong et al., 2022)	✓	✓	X
22	(IEEE Signal Processing Society, 2017)	X	✓	X
	Total	12	22	10

3. Approach and Methodology

The simplest form of identification of traffic congestion is manual counting and social survey. Manual counting includes the use of manpower at intersections to determine traffic load passing through any roadways. Manual counting of vehicles gives accurate results for that instant but can be a tedious work for calculation of average data for a long time due to daily variations. The social survey is a method of collecting information about the road-traffic behavior from people by asking a series of questions. The collected information from a large sample helps us to understand patterns of traffic load, peak hours, average departure time, number of trips per day per person, average travel time, and so on. Looking at the past studies it can be seen that manual counting and social surveys have been used for some time now. (Kroes et al., 1996)interviewed about 5000 samples of households in Amsterdam and surrounding municipalities to analyze the short-term effects of removing a bottleneck by comparing the before and after data of travel time, departure time, frequency of trips and so on. (Agbonika, 2011)used a total of 200 questionnaires around the Central Business District area of Abuja metropolis to find out the effects of congestion on the daily working lives of residents of that territory. Since we are interviewing the actual population that is involved in the traffic congestion, the data helps to analyze the average characteristics of that traffic such as peak hour, travel time, departure time, frequency of travel, and so on. However, without extensive manual counting, there will be little evidence of the emergence of real induced trips in the data by social survey only(Kroes et al., 1996).

Videography and CCTV footage use CCTV camera images for vehicle counting and base front. (Timalsena et al., 2017) used CCTV footage during morning peak hours and evening peak hours to observe the behavior of public and private vehicles. This paper observed travel time from the CCTV videos along with use of spot speed data from the traffic police office. Human capital hour loss is determined by comparing travel time at peak hour and off-peak hour from CCTV footage along with occupancy survey data. This paper concludes, that at the Maitighar-Tinkune intersection human capital hour loss is more at morning peak hour than that of evening, and 70% of which is lost in Bus and Standard Bus. Similarly, (Nepali et al., 2024) used CCTV footage from the Metropolitan Traffic Police to get traffic data during peak hours. Manual counting was also done on some days. The paper used these data to determine saturation flow and cycle length for a particular lane which was further used for improvement analysis using the replacement analysis method. Similarly, using CCTV camera feeds, (Cutrell & ACM Digital Library., 2012) demonstrated an automated image processing algorithm for estimating traffic density at a hotspot using the videography method of traffic survey.

VISSIM has been widely used in assessing traffic conditions. Here, simulation refers to mathematical modelling of transportation systems through the application of computer software. VISSIM, a widely utilized microscopic traffic simulation software, is commonly employed for assessing traffic conditions which provides detailed insights into traffic flow, congestion, and other critical factors. (Ishaque and Noland, 2009) proposed an approach to incorporate pedestrians into the VISSIM model. They treat pedestrians as vehicles and subsequently adjust VISSIM parameters to align pedestrian behavior with speed-flow models specific to pedestrians. (Lin et al., 2013) used VISSIM to build road networks in different scenarios, especially comparing one-way layouts and two-way layouts on the road network of CBD in Beijing, China. This paper compared the queue length, travel speed, travel time, and delay. Similarly, (Chen, 2019) used MATLAB to achieve the correction of the simulation model by the genetic algorithm method. This showed a significant reduction in journey time. In this way, simulations using software have also been used for the analysis on road networks. VISSIM can model intricate traffic scenarios and provide diverse evaluation indicators.

GPS data from GPS-tracked vehicles and crowdsourced data from mobile devices have been used for bottleneck identification. (Zhao et al., 2013) generated both congestion and reliability indicators for assessing the performance of roadway segments and further identifying and ranking vehicle bottlenecks based on fleet management GPS probe data from trucks. (Yang et al., 2020) also used GPS data to find out the average speed of vehicles in different spatial units of the ring road in Beijing and compare it to critical speed. This comparison is used to determine whether the ring road part is over-saturated. (Yang et al., 2020) found four general patterns of bottleneck as explained earlier.

Solutions and recommendations for the mitigation of traffic bottlenecks have been studied by a lot of articles. (Richardarnott et al., 1990) found out that the imposition of optimal toll causes travel time costs to fall. Also, the optimal fine toll was found to be more effective than the optimal coarse toll. Similarly, (Se-il Mun, 1999) also used optimal peak-load toll to eliminate traffic jams and save travel time.(Nepali et al., 2024) concluded that the Lane Increment Approach is a possible solution to traffic congestion at Khanivivag, Kesarmahal, and Narayanhiti Intersections. (Yang et al., 2020) gave different solutions for different patterns of bottlenecks. This paper concluded the measures to reduce bottleneck congestion to be, the diversion of traffic flow to side roads or other city areas, signal control on the ramp, improved public transportation, and so on. (Lin et al., 2013) found out one-way layout of road to be a solution to traffic congestion using VISSIM.

4. Conclusion and Recommendations

Traffic bottlenecks present a significant challenge to urban mobility, causing delays, increased emissions, and economic losses. While advanced traffic management technologies such as navigation systems, real-time GPS tracking, and sophisticated simulation software have proven effective in managing congestion in developed countries, these technologies are not yet widely available or feasible in underdeveloped nations like Nepal. Moreover, vehicle and pedestrian behaviors in countries like Nepal are often unpredictable, further complicating traffic management efforts. The bottleneck patterns based upon the road infrastructure and traffic demand, provide significant insights into traffic congestion and its management. Thus, recognizing the distinct patterns of bottleneck and their impacts on traffic flow is significant for designing efficient road networks, alleviating urban congestion and improving overall performance of the transportation system.

Given these limitations, it is crucial to focus on alternative methods that are both cost-effective and adaptable to local conditions. In this context, videography surveys stand out as the most viable solution for studying traffic behavior. By using CCTV cameras and manual video analysis, traffic engineers can gather essential data on vehicle flow, congestion points, and pedestrian movements. This method provides a comprehensive view of traffic patterns without requiring advanced technological infrastructure. Therefore, videography surveys should be prioritized as a key tool for traffic analysis and bottleneck identification in Nepal and similar underdeveloped regions, enabling planners and engineers to design effective interventions and improve traffic management systems.

In case of traffic engineers, one of the key suggestions is the adoption of adaptive traffic control systems, which dynamically alter traffic signal timings in response to real-world traffic conditions. The real-world traffic conditions can be monitored by videographic survey. By reducing delays, preventing oversaturation, and optimizing traffic flow, these systems help relieve congestion at bottleneck locations. Another important tool is metering, which regulates the number of vehicles entering congested areas (like highway ramps) to maintain a smoother flow of traffic and prevent further congestion. Similarly, GPS tracking can also help minimize delays by promptly rerouting vehicles or modifying traffic signals to address bottlenecks as they arise. Even simulation software like VISSIM enables the modeling of different traffic situations and the testing of possible solutions in a virtual setting, is another recommendation for traffic engineers.

City planners should focus on creating urban road networks that can withstand traffic jams and bottlenecks. A crucial suggestion for urban planners is to integrate bottleneck solutions into their designs. This requires designing roads to handle future increases in traffic by guaranteeing adequate capacity and avoiding congested or troublesome intersections that might cause bottlenecks. One-way road layouts, which have been demonstrated to reduce traffic congestion in densely populated areas, should be taken into consideration by planners in areas experiencing high levels of congestion. Promoting public transportation as an alternative to driving a private vehicle is another important recommendation.

Legislators can enact and implement laws that facilitate effective traffic control and lessen traffic congestion. The introduction of traffic management measures, such as congestion pricing or toll systems, is a crucial recommendation for legislators. Politicians can discourage unnecessary travel and lower traffic volumes in important areas by imposing fees on drivers who use heavily trafficked roads during peak hours. Lastly, policymakers ought to encourage research and development initiatives aimed at comprehending the patterns of traffic congestion and creating remedies. This is especially crucial in developing nations where traffic systems might encounter particular difficulties. Through partnerships with academic institutions and industry professionals, policymakers can guarantee that traffic management tactics are customized to specific localities and efficiently alleviate congestion caused by bottlenecks.

Acknowledgments

The authors of this article would like to thank the Department of Civil Engineering, Kathmandu University for their immense assistance at the conceptualization and data collection stage. Furthermore, we would like to express our sincere gratitude towards the numerous authors of the cited articles whose research and hard work helped us to study this field more efficiently.

References

Afrin, T., & Yodo, N. (2020). A survey of road traffic congestion measures towards a sustainable and resilient transportation system. In *Sustainability (Switzerland)* (Vol. 12, Issue 11). MDPI. https://doi.org/10.3390/su12114660

Aftabuzzaman, M. (2007). *Measuring traffic congestion-A critical review*. https://www.researchgate.net/publication/282780229

Agbonika, F. O. (n.d.). *ROAD TRAFFIC CONGESTION AND THE QUEST FOR EFFECTIVE TRANSPORTATION*. https://ssrn.com/abstract=3511234

Arnott, R., & Inci, E. (2006). An integrated model of downtown parking and traffic congestion. *Journal of Urban Economics*, *60*(3), 418–442. https://doi.org/10.1016/j.jue.2006.04.004

Arnott, R., & Lindsey, R. (1991). DOES PROVIDING INFORMATION TO DRIVERS REDUCE TRAFFIC CONGESTION? In *Transpn Res-A t* (Vol. 25, Issue 5).

Article ID juec. (3233). In *Journal of Urban Economics* (Vol. 46). http:rrwww.idealibrary.comon

Badshah, I., Khan, Z. H., Gulliver, T. A., Khattak, K. S., & Saad, S. (2022). Modeling Sustainable Traffic Behavior: Avoiding Congestion at a Stationary Bottleneck. *Civil Engineering Journal (Iran)*, *8*(11), 2378–2390. https://doi.org/10.28991/CEJ-2022-08-11-02

Cao, Z., Jiang, S., Zhang, J., & Guo, H. (2017). A Unified Framework for Vehicle Rerouting and Traffic Light Control to Reduce Traffic Congestion. *IEEE Transactions on Intelligent Transportation Systems*, *18*(7), 1958–1973. https://doi.org/10.1109/TITS.2016.2613997

Carlos Mu~ N Noz, J., Daganzo, C. F., & Daganzo, C. F. (n.d.). *The bottleneck mechanism of a freeway diverge*. www.ce.berkeley.edu/$daganzo/'',

Chen, M. (2019). Modeling and Simulation Analysis of Road Network Based on VISSIM. *Proceedings - 2019 International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2019*, 32–35. https://doi.org/10.1109/ICITBS.2019.00017

Cutrell, Ed., & ACM Digital Library. (2012). *Proceedings of the 2nd ACM Symposium on Computing for Development.* ACM.

IEEE Signal Processing Society. (n.d.). *2017 IEEE International Conference on Acoustics, Speech and Signal Processing : proceedings : March 5-9, 2017, Hilton New Orleans Riverside, New Orleans, Louisiana, USA*.

Ishaque, M. M., & Noland, R. B. (n.d.). *Pedestrian and Vehicle Flow Calibration in Multimodal Traffic Microsimulation*. https://doi.org/10.1061/ASCE0733-947X2009135:6338

Kroes, E., Daly, A., Gunn, H., & Toon Van Der Hoorn, &. (1996). The opening of the Amsterdam Ring Road A case study on short-term effects of removing a bottleneck. In *Transportation* (Vol. 23).

Li, C., Yue, W., Mao, G., & Xu, Z. (2020). Congestion Propagation Based Bottleneck Identification in Urban Road Networks. *IEEE Transactions on Vehicular Technology*, *69*(5), 4827–4841. https://doi.org/10.1109/TVT.2020.2973404

Lin, D., Yang, X., & Gao, C. (2013). VISSIM-based Simulation Analysis on Road Network of CBD in Beijing, China. *Procedia - Social and Behavioral Sciences*, *96*, 461–472. https://doi.org/10.1016/j.sbspro.2013.08.054

Li, Z. C., Huang, H. J., & Yang, H. (2020). Fifty years of the bottleneck model: A bibliometric review and future research directions. *Transportation Research Part B: Methodological*, *139*, 311–342. https://doi.org/10.1016/j.trb.2020.06.009

Nepali, S., Bohara, S. S., Lama, N., & Rabin Thapa, R. (2024). Assessment of Traffic Characteristic at Major Urban Road Intersection of Kathmandu Valley: A Case Study of Khanivivag, Kesarmahal, and Narayanhiti Intersections. *Journal of Civil and Construction Engineering*, *10*(1), 22–31. https://doi.org/10.46610/jocce.2024.v010i01.003

Properties of dynamic traffic equllibrium involving bottlenecks, including a paradox and metering. (n.d.).

Richardarnott, ~~, Palma, A., & Lindsey~, S. (1990). Economics of a Bottleneck*. In *JOURNAL OF URBAN ECONOMICS* (Vol. 27).

Rudjanakanoknad, J. (2012). Capacity change mechanism of a diverge bottleneck. *Transportation Research Record*, *2278*, 21–30. https://doi.org/10.3141/2278-03

Suryani, E., Hendrawan, R. A., Eadipraja, P. F., Wibisono, A., & Dewi, L. P. (2019). Modelling reliability of transportation systems to reduce traffic congestion. *Journal of Physics: Conference Series*, *1196*(1). https://doi.org/10.1088/1742-6596/1196/1/012029

Timalsena, A. P., Marsani, A., & Tiwari, H. (2017). *Impact of Traffic Bottleneck on Urban Road: A Case Study of Maitighar-Tinkune Road Section*. Online. https://www.researchgate.net/publication/326684343

Wang, C., Quddus, M. A., & Ison, S. G. (2009). Impact of traffic congestion on road accidents: A spatial analysis of the M25 motorway in England. *Accident Analysis and Prevention*, *41*(4), 798–808. https://doi.org/10.1016/j.aap.2009.04.002

Witte, P. A., Wiegmans, B. W., van Oort, F. G., & Spit, T. J. M. (2012). Chokepoints in corridors: Perspectives on bottlenecks in the European transport network. *Research in Transportation Business and Management*, *5*, 57–66. https://doi.org/10.1016/j.rtbm.2012.10.001

Yang, Y., Li, M., Yu, J., & He, F. (2020). Expressway bottleneck pattern identification using traffic big data—The case of ring roads in Beijing, China. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, *24*(1), 54–67. https://doi.org/10.1080/15472450.2019.1579091

Zhao, W., McCormack, E., Dailey, D. J., & Scharnhorst, E. (2013). Using truck probe gps data to identify and rank roadway bottlenecks. *Journal of Transportation Engineering*, *139*(1), 1–7. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000444

Zhong, R., He, Z., Chow, A. H. F., & Knoop, V. (2022). Special issue on methodological advancements in understanding and managing urban traffic congestion. In *Transportmetrica A: Transport Science* (Vol. 18, Issue 1, pp. 1–4). Taylor and Francis Ltd. https://doi.org/10.1080/23249935.2021.1894266

Zhu, Q., Liu, Y., Liu, M., Zhang, S., Chen, G., & Meng, H. (2021). Intelligent planning and research on urban traffic congestion. *Future Internet*, *13*(11). https://doi.org/10.3390/fi13110284