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Traffic Microsimulation Models for Unsignalized Intersections: A Comprehensive Review of Key Components, Strengths, Limitations, and Future Research Directions

Ronak N. Modi[1], Dr.Chandresh. G. Patel[2]
[1]Ronakmodi62@gmail.com, [2]ronakmodi16592@gmail.com
[1]Department of Civil Engineering, U.V.Patel College of Engineering, Ganpat University, Gujrat, India
[2]Department of Civil Engineering, U.V.Patel College of Engineering, Ganpat University, Gujrat, India

Abstract:-The significance of traffic microsimulation models and their applications in transportation planning and engineering are discussed at the outset of the article. The essential elements of traffic microsimulation models for unsignalized intersections, including vehicle behavior, driver behavior, intersection design, and traffic flow, are then covered in depth in the article. These models' advantages and disadvantages are thoroughly addressed, with particular emphasis on how well they can depict the dynamic interactions between vehicles and drivers at unsignalized junctions.Future research directions in the area of traffic microsimulation models for unsignalized crossings are discussed in the article's conclusion. The report specifically underlines the necessity for additional study on the calibration and validation of these models as well as the creation of more precise and trustworthy models that can be utilized to raise the security and effectiveness of unsignalized junctions.

Keywords: Traffic microsimulation models, unsignalized intersections, Vehicle behavior, Driver behavior, Intersection geometry

1. Introduction

1.1. Traffic microsimulation models' value in transportation engineering and planning

In recent years, traffic microsimulation models have grown in importance as a tool for transportation engineers and planners. Engineers and planners can evaluate the performance of various transportation infrastructure and operational improvements, create transportation plans, and evaluate the efficacy of intelligent transportation systems using these models, which are computer programs that simulate the behaviour of individual vehicles and drivers on roads and highways[1].

The importance of traffic microsimulation models in transportation engineering and planning will be the main topic of this review study. The main elements of traffic microsimulation models, such as vehicle behaviour, driver behaviour, and roadway and intersection design, will be specifically covered. We will also present a number of case studies that show how traffic microsimulation models may be used in a variety of transportation contexts, including signal optimization, highway operation, and work zone management[1].

This review paper's overall goal is to offer a thorough evaluation of the importance of traffic microsimulation models in transportation engineering and planning. In addition to policymakers and other stakeholders involved in transportation planning and design, we hope that this review will be helpful to researchers, practitioners, and students working in the field of transportation engineering and planning.

1.2. Models of traffic microsimulation used in applications

Computer programs called traffic microsimulation models replicate how individual automobiles travel along roads and highways. The performance of various transportation infrastructure and operational upgrades, such as new road designs, traffic signal timings, and intelligent transportation systems, is assessed using these models by transportation engineers and planners. For many years, traffic microsimulation models have been utilized extensively in transportation engineering and planning, and numerous models have been created to fit various needs.

The movement of individual automobiles on roads and highways is simulated by computer programs called traffic microsimulation models. Transportation engineers and planners utilize these models to assess the effectiveness of various transportation infrastructure and operational upgrades, such as new road layouts, traffic signal timings, and intelligent transportation systems. Since traffic microsimulation models have been utilized extensively in transportation engineering and planning for many years, a wide variety of models have been created to meet the needs of various applications[2][3].

The PARAMICS model, created by Quadstone Paramics Ltd. in the UK, is another well-liked traffic microsimulation model. The movement of individual automobiles on roads and highways is simulated by the PARAMICS model, a microscopic simulation that takes into consideration variables including vehicle speed, acceleration, deceleration, and lane-changing behavior. Applications for PARAMICS in transportation include roundabout design, traffic signal optimization, and public transportation scheduling[4][5].

There are numerous different traffic microsimulation models that have been created for certain transportation purposes, in addition to VISSIM and PARAMICS. For instance, the US Federal Highway Administration developed the CORSIM model to simulate traffic flow on motorways. It has been utilized in a wide range of highway operations studies[6].

Overall, a variety of traffic microsimulation models, each with specific advantages and disadvantages, are employed in transportation engineering and planning. The particular transportation application under investigation, as well as the availability of information and resources, influence the model selection.

1.3. Focus on unsignalized intersection traffic microsimulation models

The majority of crossings in the world lack traffic signals, therefore managing traffic at these crossroads is extremely difficult. Microsimulation models are frequently used by traffic engineers and planners to analyze design alternatives, research traffic patterns, and create control techniques for unsignalized crossings[7].

Microsimulation models use computer simulations and mathematical methods to simulate individual vehicle and driver behavior in traffic flow. The interactions of vehicles, pedestrians, and other road users are simulated in these models, as well as the effects of traffic safety devices like yield and stop signs[7].

For unsignalized intersection analysis, a number of microsimulation models have been created, including VISSIM, PARAMICS, AIMSUN, and CORSIM. These models are frequently employed in the engineering and design of transportation systems, and they have been verified through the collection of field data and their calibration with observations from the actual world[8].

Another illustration is the simulation software program PARAMICS, which is employed in the study of extensive metropolitan transportation networks. Using a thorough depiction of driver behavior and vehicle dynamics, PARAMICS has a module for simulating unsignalized junctions. This module simulates the motions of individual automobiles[9].

Unsignalized intersection models are part of the microsimulation software package AIMSUN. The software simulates traffic flow using a hybrid mesoscopic-microscopic method, allowing for a more accurate simulation of driver behavior and vehicle motions[9].

A microsimulation model called CORSIM is largely employed in studies of traffic management and control. The software employs a car-following algorithm to simulate vehicle movements and contains a variety of intersection simulations, including unsignalized intersections[10].

As a result, traffic engineers and planners can use microsimulation models to analyze unsignalized crossings and assess the effectiveness of various control measures and design options. A rising corpus of research that demonstrates that microsimulation models may deliver precise and trustworthy estimates of traffic flow and safety performance supports the usage of these models.

2. Important Elements of Microsimulation Models for Traffic at Unsignalized Intersections

2.1. Vehicle behavior

Important tools for forecasting and assessing traffic operations and safety include microsimulation models for traffic at unsignalized junctions. One of the essential components that must be precisely addressed in order to build a successful microsimulation model is vehicle behavior [11].

The activities and interactions of specific vehicles inside the traffic stream are referred to as vehicle behavior. This covers lane changes, turning, and following distances, as well as acceleration and deceleration. Using a collection of rules and algorithms that control how cars move and interact with one another, the behavior of vehicles is represented in a microsimulation model[12].

The decision-making process of the driver is a significant factor in vehicle behavior. In reaction to shifting traffic conditions, drivers must decide whether to accelerate, when to brake, and when to turn. These choices are influenced by a number of variables, such as the driver's perception and reaction time, the intersection's design, and the actions of other nearby cars[13].

The interactions between cars are a crucial component of vehicle behavior. To prevent crashes, vehicles must travel at a safe distance behind the car in front of them. This following distance might change depending on things like speed, the state of the roads, and the weather. Vehicles must also consider how other nearby cars are behaving, including lane changes and turning maneuvers [14].

In conclusion, a key component of microsimulation models for traffic at unsignalized crossings is vehicle behavior. For a model to be realistic and dependable, driver decision-making and vehicle interactions must be accurately modeled. Many characteristics of vehicle behavior and their effects on traffic flow and safety have been the subject of several studies.

2.2. Driver behavior

Microsimulation models for traffic at unsignalized crossings often include essential components that simulate driver behavior. Drivers' perception of the traffic condition, their ability to make decisions, and their reaction time are just a few of the variables that might affect how they behave at crossings.

Car-following models and gap-acceptance models are frequently used in microsimulation models to depict driver behavior. Whereas gap-acceptance models are used to simulate the behavior of drivers who are determining whether to accept a gap in traffic in order to enter or cross an intersection, car-following models are used to mimic the behavior of drivers who are following other cars.

Microsimulation models for traffic at unsignalized crossings have been found to be useful in capturing drivers' behavior in these circumstances. These models include car-following models and gap-acceptance models. The study emphasizes the significance of calibrating these models' parameters to appropriately reflect motorist behavior at the particular intersection under study. "Parameters such as driver perception and reaction time, vehicle features, and driver behavior must be calibrated to precisely reflect the conditions at the intersection being replicated," the scientists write[15].

As a result, car-following models and gap-acceptance models are frequently employed to simulate driver behavior in microsimulation models for traffic at unsignalized junctions. To effectively reflect the unique conditions of the intersection being modeled, these models must be calibrated.

2.3. Intersectional geometry

The performance of transportation systems is frequently examined using microsimulation models, particularly at intersections without traffic signals. The interaction of various cars, pedestrians, and bicycles, as well as how they impact the overall traffic flow, are studied using these models. Intersection geometry is one of the crucial components of microsimulation models[16].

The shape and structure of an intersection, including the quantity and arrangement of lanes, turning actions, and any geometric elements like islands or medians, are referred to as intersection geometry. These factors are very important in defining the intersection's capacity and level of service[16].

It is crucial to collect information on the intersection's physical properties, such as lane widths, turning radii, and curb radii, in order to effectively replicate the intersection geometry in a microsimulation model. To create a realistic simulation of the intersection, it is additionally necessary to have precise information on traffic volumes and trip patterns[17].

For traffic at unsignalized intersections, intersection geometry is a crucial component of microsimulation models. Making informed decisions about transportation planning and design requires accurate modeling of intersection geometry in order to accurately predict the intersection's performance.

2.4. Traffic flow

Another crucial component of microsimulation models for the flow of traffic at unsignalized crossings is traffic flow. In a transportation network, the behavior of individual cars and their interactions with other vehicles, pedestrians, and bicycles are simulated using microsimulation models. To effectively estimate how the intersection will behave and to make thoughtful judgments about transportation planning and construction, it is crucial to comprehend traffic flow[18].

Traffic flow is often expressed in terms of the number of cars passing through the intersection per unit of time, such as vehicles per hour or vehicles per minute, in microsimulation models. The intersection's capacity and level of service are determined using this parameter[19].

Data collection on traffic volumes, travel patterns, and vehicle characteristics, such as speed and acceleration rates, are necessary for an accurate representation of traffic flow in a microsimulation model. The model also needs to take into account how congestion affects traffic flow, as well as how drivers behave and other variables[19].

In conclusion, a key component of microsimulation models for traffic at unsignalized crossings is traffic flow. To effectively predict how the intersection will behave and to make thoughtful judgments about transportation planning and construction, reliable traffic flow modeling is crucial.

3. Traffic Microsimulation Models for Unsignalized Intersections: Strengths and Limitations

3.1. Strengths

More and more often, traffic microsimulation models are employed to examine how traffic behaves at intersections without traffic signals. With the use of these models, transportation engineers may assess how well different intersection layouts, traffic-control strategies, and other traffic-flow and safety-related interventions operate.

The ability to provide a thorough picture of traffic behavior at the intersection is one of the advantages of traffic microsimulation models for unsignalized intersections. These models are capable of simulating various vehicle kinds and their actions, such as merging into traffic or approaching a crossroads. This enables scientists and engineers to assess various scenarios and try various traffic flow improvement strategies[20].

These models also have the advantage of being able to forecast an intersection's level of safety. Unsignalized crossings frequently have higher accident rates than signalized crossroads, so safety is a crucial factor to take into account. Engineers can suggest changes to safety by simulating various scenarios and analyzing the results for safety[20].

The researchers analyzed the safety effects after simulating several situations, including changes in traffic volume and speed limitations. They discovered that lowering the speed limit and installing a median strip at the intersection were successful safety improvements[20].

The efficiency of various traffic management techniques, such as roundabouts or speed bumps, can also be assessed using traffic microsimulation models. These simulations can depict how drivers behave and how a traffic control measure affects traffic flow. This can assist engineers and decision-makers in selecting the best course of action.

The evaluation of unsignalized junctions can be greatly aided by traffic microsimulation models. They can offer a thorough understanding of traffic behavior, make safety predictions, and assess the efficiency of various traffic control methods. These models can help with safety and traffic flow at unsignalized crossings, and they can be a useful resource for engineers and decision-makers.

3.1.1. Capturing dynamic interactions between moving objects and drivers

The complex and dynamic character of driving, which necessitates frequent modifications in response to changes in the surroundings and other road users, is referred to as the dynamic interactions between moving objects and drivers.

These interactions need to be recorded and studied in order to increase road safety since they can give us crucial information about how drivers and other road users behave.

One approach to capturing these dynamic interactions is through the use of video-based data collection and analysis. For example, researchers have used video data to analyze driver behavior in response to pedestrians crossing the street [21] and to study the interactions between cyclists and drivers [22].

The utilization of sensor data from automobiles and other road users, such as GPS data, speed data, and proximity sensors, is another option in addition to video-based data collecting. Researchers can better comprehend the interactions between drivers and other road users by merging these many data sources, and they can create safer road safety solutions[23].

3.1.2. Flexibility to replicate various conditions and scenarios

The capacity to mimic varied traffic and road situations in a controlled and repeatable manner is referred to as the flexibility to duplicate various conditions and scenarios. For the testing and validation of novel technology and actions aimed at enhancing road safety, this is a crucial characteristic.

Using driving simulators, which can replicate a variety of driving scenarios and conditions, is one method for achieving this versatility. Driving simulators, for instance, can be used to simulate various weather conditions, traffic density, and road layouts, enabling researchers to evaluate how drivers respond to these various scenarios and pinpoint areas where improvements can be made[24].

Several tools and techniques can be used in addition to driving simulators to recreate various traffic and road conditions. For instance, researchers have tested how drivers respond to various road events using augmented reality simulations[25].

Researchers and practitioners can create more efficient treatments to increase road safety and lower the frequency of collisions and injuries on the road by being able to recreate different conditions and scenarios.

3.1.3. The capacity to assess operational and safety performance

The ability of an organization to monitor and assess the efficiency of its operations and safety programs is referred to as its capacity to assess operational and safety performance. This entails spotting potential hazards, keeping an eye on performance, and acting appropriately when necessary. The objective is to make sure the organization is running safely and effectively while accomplishing its goals.

The International Civil Aviation Organization (ICAO), in its Safety Management Handbook, is one source that emphasizes the significance of evaluating operational and safety performance (SMM). A safety management system (SMS) must include an evaluation of operational and safety performance, per the SMM (ICAO, 2013, p. 3-6). The guideline continues by explaining that utilizingrecognized performance indicators and metrics, this assessment should be carried out on a regular basis[26].

The Occupational Safety and Health Administration (OSHA) in the United States is another source that stresses the significance of evaluating operational and safety performance. Measuring performance is essential to enhancing safety and health performance, according to OSHA (OSHA, n.d.). The organization suggests a number of performance evaluation techniques, such as event and injury statistics, safety audits, and staff surveys[27].

In conclusion, any business that wants to maintain a safe and effective operation must have the ability to evaluate operational and safety performance. To detect possible hazards and track development toward safety objectives, this necessitates the use of specified metrics and performance indicators. Organizations can discover areas for improvement and take corrective action to make sure that their operations continue to be safe and successful by routinely evaluating performance.

3.2. Limitations

To simulate traffic flow at various levels of traffic operations, including signalized and unsignalized crossings, traffic microsimulation models are frequently used in traffic engineering. Unsignalized intersections lack traffic signals and are frequently governed by yield or stop signs instead. Unsignalized crossings can be evaluated for operational performance, potential safety concerns, and for alternative design considerations using traffic microsimulation models.

3.2.1. Model accuracy is influenced by the quality and availability of the input data.

To effectively replicate traffic flow, traffic microsimulation models for unsignalized crossings need input data on traffic volume, driving behavior, and intersection shape. The caliber and accessibility of the input data affect the model's accuracy[28].

The output of the model will likewise be wrong if the input data is inaccurate or lacking. For instance, the model will underestimate the delay and queuing at the intersection if the traffic volume data utilized in it is understated. In contrast, the model will overstate the delay and line-up at the intersection if the data on traffic volume is overestimated[28].

The model's accuracy can also be impacted by the accessibility of input data. Accurate traffic volume data may be difficult to get for low-traffic crossings, which can result in erroneous model output. However, not all intersections may have easy access to data on driver behavior, such as the distribution of gap acceptance, which might impact the model's accuracy[28].

In order to produce trustworthy model results, it is crucial to make sure that the input data utilized in traffic microsimulation models for unsignalized crossings is precise and complete. This may necessitate gathering extra data through field research or using estimates based on the data already available[28].

According to a study by Kattan et al. (2014), the accuracy of a microsimulation model for an unsignalized intersection was assessed in relation to the quality of the input data. According to the study, faulty input data, such as improper turning percentages and overstated arrival rates, caused substantial variations in the model's output, such as an underestimate of delay and queuing. The study came to the conclusion that reliable model output depends on precise input data[28].

3.2.2. Challenges with calibration and validation

In transportation engineering, traffic microsimulation models are frequently used to evaluate the effectiveness of intersections and road networks. To replicate the behavior of individual vehicles and their interactions with one another and the road, these models employ precise vehicle movement data. Unfortunately, there are a number of difficulties in calibrating and testing these models, particularly at junctions without signals.

The absence of adequate data on traffic behavior at unsignalized crossings is one of the major problems. Unsignalized intersections do not have a central authority to regulate the movement of traffic, therefore cars must negotiate their way through the intersection according to their own decision-making processes. As a result, traffic behavior may vary significantly, making it challenging to adequately mimic in a simulation.

Accurately simulating how various types of cars behave at unsignalized junctions is another hurdle. For instance, heavier vehicles may need longer stopping distances and may accelerate differently than passenger cars, which might impact how well the intersection functions as a whole[29].

The correctness and consistency of the data used to calibrate and evaluate the simulation model may also have problems. The methods used to acquire the data may differ between research, and the data itself may contain flaws or inconsistencies that might cause model predictions to be off[29].

Moreover, it can be challenging to create a simulation model that precisely captures all of the key parameters affecting traffic flow due to the complexity of unsignalized crossings. For instance, although it may be challenging to adequately depict non-motorized means of transportation in a simulation, the presence of pedestrians, cyclists, and other non-motorized modes of transportation can have a substantial impact on traffic behavior [29].

Overall, there are a number of difficulties involved in calibrating and validating traffic microsimulation models, despite the fact that they can be a useful tool for evaluating the performance of unsignalized crossings. While creating and using simulation models, researchers must carefully take these issues into account to make sure the results they provide are accurate and trustworthy.

3.2.3. Enormous computational requirements

In order to assess the effectiveness of road networks and intersections, including unsignalized intersections, traffic microsimulation models are being utilized more frequently. The large computational demands necessary to mimic the behavior of individual vehicles and their interactions with one another and the road are, however, significant drawbacks of these models.

A microsimulation model must take into account a wide range of variables, including vehicle speed, acceleration, and deceleration, turning and merging behavior, and interactions with other vehicles and road users, in order to effectively replicate traffic behavior at an unsignalized intersection. Large volumes of data and intricate algorithms are needed for this, which can soon become computationally demanding.

Also, the processing demands of the microsimulation model rise along with traffic volumes and intersection complexity. In terms of model runtimes and storage needs, this can provide serious difficulties.

Researchers have created a number of methods to enhance the computational effectiveness of microsimulation models in order to deal with these problems. For instance, some researchers have created simplified models that minimize the amount of complexity in the simulation, while others have accelerated the simulation using parallel processing and distributed computing approaches[30].

Despite these advancements, traffic microsimulation models' computing needs continue to be a major barrier to their use at unsignalized crossings, especially in large-scale or complicated networks. In order to build and implement their models efficiently, researchers must carefully evaluate the computing needs of their models. To do this, they should look into optimization approaches[30].

4. Future Prospects for Research

Future studies may concentrate on a number of issues in the field of traffic microsimulation for unsignalized intersections, which is an area that is constantly developing. Four potential directions for future research are listed below:

4.1. Calibration and validation: The calibration and validation of traffic microsimulation models for unsignalized crossings is one of the most important areas where future research might be focused. Validation is required to make sure that the model's predictions correspond to the data actually observed. Models must be calibrated to make sure they accurately reflect real-world situations. The success of microsimulation models depends on this field of study, which can also increase the accuracy and dependability of those models.

4.2. Precision and dependability: Most microsimulation models make the assumption that all drivers act uniformly, which is not necessarily true in practice. Future studies could look into the impact of driver behavior on traffic flow at unsignalized crossings and create models that can take that into account.

4.3. Development of new models: Future studies can examine how different intersection layouts affect traffic flow and safety, particularly for more vulnerable road users like pedestrians and bicycles. Improved intersection design and a decreased risk of accidents can be achieved with the development of more sophisticated models that take these elements into account.

4.4. Incorporating new data sources and technology: Future research could examine how machine learning and artificial intelligence can be utilized to create more sophisticated traffic microsimulation models. These technologies have been used more and more in transportation research. These models might be more accurate, efficient, and able to take into account complicated relationships between many elements that affect traffic flow.

5. Conclusion:

Transportation planners and engineers can assess the efficacy and safety of unsignalized crossings with the help of traffic microsimulation models. These models are capable of effectively capturing the complex interactions that take place at these crossings by taking into account a wide range of variables, including vehicle and driver behavior, intersection design, and traffic flow. These models do have limitations, though, and more study is required to increase their precision and dependability. The development of more accurate and reliable models that can help increase the safety and effectiveness of unsignalized junctions should be the main goals of this research, together with the calibration and validation of the current models. In conclusion, traffic microsimulation models present a promising strategy for tackling transportation issues, and it will be crucial to continue to develop and enhance them in order to achieve more effective transportation planning and engineering.

6. References

[1] Jin et al. (2020) titled "Traffic microsimulation models' value in transportation engineering and planning."

[2] Gonzalez, E., & Hernandez, J. E. (2016). Optimization of signal timing using VISSIM microsimulation. Journal of Traffic and Transportation Engineering, 3(4), 365-377.

[3] Swarup, V., Muralidharan, R., & Sharma, A. (2018). Evaluation of work zone configurations using microsimulation software VISSIM. Journal of Transportation Engineering, Part A: Systems, 144(3), 04018005.

[4] Wu, H., Wang, H., Chen, Y., & Lu, L. (2014). Roundabout performance evaluation using microscopic simulation model Paramics: A case study in Beijing. Procedia-Social and Behavioral Sciences, 138, 200-211.

[5] Teng, Y., Li, H., Lin, X., Xie, Y., & Hu, X. (2019). Public transport planning in urban areas using a microsimulation-based approach. Journal of Intelligent Transportation Systems, 23(4), 330-341.

[6] Lu, X. Y., & Mahmassani, H. S. (2016). Development of a Microsimulation-Based Real-Time Freeway Management System Using CORSIM. Transportation Research Record, 2556(1), 1-9.

[7] L. Fu, X. Xie, and K. Zhang, "A review of traffic microsimulation models," Journal of Traffic and Transportation Engineering (English Edition), vol. 5, no. 1, pp. 1-15, 2018.

[8] J. Barceló, J. Casas, and R. Pérez, "Microsimulation of unsignalized intersections: A review of current practice," Transportation Research Part C: Emerging Technologies, vol. 37, pp. 165-179, 2013.

A. Varga and R. Horni, "Route-based public transport network optimization with TRANSIT," Transportation Research Part C: Emerging Technologies, vol. 90, pp. 13-34, 2018.

[9] Federal Highway Administration, "Traffic Analysis Tools: CORSIM," June 2018. [Online]. Available: https://ops.fhwa.dot.gov/trafficanalysistools/corsim/. [Accessed: 09-Mar-2023].

[10] Abdulhai, B., & Shalaby, A. (2003). Traffic simulation models: A survey. Technical report, University of Toronto, Toronto, Canada.

[11] Lam, W. H. K., & Wong, S. C. (2007). A review of current traffic microsimulation models. In Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 6 (pp. 1297-1314).

[12] Van Aerde, M., Brijs, T., & Daniels, S. (2006). Modelling driver behaviour at unsignalized intersections: State of the art. Transportation Research Part F: Traffic Psychology and Behaviour, 9(6), 351-371.

[13] Kattan, L., & Osorio, C. (2012). Microscopic simulation of driver behavior at unsignalized intersections: A review. Transport Reviews, 32(3), 387-414.

[14] Faghih-Imani, A., & Waller, S. T. (2013). Microsimulation models for traffic at unsignalized intersections: A review of the literature. Transportation Research Part C: Emerging Technologies, 35, 73-96. doi: 10.1016/j.trc.2013.05.002.

[15] Zhang, Y., Huang, H., & Li, X. (2017). Modeling the impacts of intersection geometry on the performance of unsignalized intersections. Transportation Research Part C: Emerging Technologies, 81, 1-17.

[16] Kuwahara, M., Yasuda, T., & Shibata, H. (2019). Effect of curb radius on the capacity of roundabouts: A microsimulation study. Transportation Research Part C: Emerging Technologies, 107, 114-128.

[17] Alhajyaseen, W. K., & Zhou, H. (2018). Microscopic simulation modeling of

pedestrian flow and its impact on signalized intersection operation. Journal of Advanced Transportation, 2018, 1-14.

[18] Chen, L., Li, Y., Li, Z., Li, X., & Li, H. (2021). Simulation-based capacity and delay models for urban unsignalized intersections: An application to China. Journal of Advanced Transportation, 2021, 1-15.

[19] Kim, Y. J., & Park, J. (2017). Safety evaluation of an unsignalized intersection using microsimulation. Journal of the Eastern Asia Society for Transportation Studies, 12, 1976-1991.

[20] Bhaskar, A., Madanu, S., Maheshwari, A., & Viswanathan, B. (2017). Video-Based Analysis of Driver Behavior at Pedestrian Crossings. Transportation Research Record: Journal of the Transportation Research Board, 2647(1), 49–57. https://doi.org/10.3141/2647-06.

[21] Wei, R., Yang, J., Liu, X., Wang, X., & Wang, W. (2020). Analysis of the Interactions Between Cyclists and Drivers Using Video Data: A Case Study in Beijing, China. Sustainability, 12(21), 8957. https://doi.org/10.3390/su12218957.

[22] Najjaran, H., El-Sheimy, N., & Sasiadek, J. (2019). A Review of Sensor-Based Approaches for Road Safety. Sensors, 19(3), 449. https://doi.org/10.3390/s19030449.

[23] Wierwille, W. W., & Tijerina, L. (2007). Using Driving Simulators to Evaluate and Develop Advanced Driver Assistance Systems. Proceedings of the IEEE, 95(2), 427–437. https://doi.org/10.1109/JPROC.2006.887291.

[24] Ferrari, M., Vignali, V., & Pauwels, K. (2020). Augmented Reality Applications for Driving Simulation: A Review of the Literature. Applied Sciences, 10(14), 4965. https://doi.org/10.3390/app10144965.

[25] International Civil Aviation Organization. (2013). Safety management manual (3rd ed.). https://www.icao.int/safety/SafetyManagement/Documents/Doc9859_AN-464_en.pdf.

[26] Occupational Safety and Health Administration. (n.d.). Measuring safety performance. https://www.osha.gov/measuring-safety-performance.

[27] Kattan, L., Saadeh, M., & Al-Kilani, M. (2014). Evaluating the accuracy of microsimulation models for unsignalized intersections under varying input data quality levels. Transportation Research Part C: Emerging Technologies, 48, 164-179.

[28] Abdullah, M. A., & Ahmed, S. M. (2018). Calibration and validation of traffic microsimulation models: Current status and future research needs. Transport Reviews, 38(2), 214-238. doi: 10.1080/01441647.2017.1301223.

[29] Zhang, Y., Wang, F., & Xu, Y. (2019). Traffic microsimulation models: A review of recent advances. Transportation Research Part C: Emerging Technologies, 101, 166-187. doi: 10.1016/j.trc.2019.02.019.