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ORIGINAL RESEARCH
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Merging and crossing movements in the congested and the non-congested traffic flow

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ABSTRACT

The congested traffic flow is significantly different from both the free flow and the non-congested but limited flow. Two of those differences are in the merging and crossing movements. Based on the conducted measurements, this movement could be up to 10 times faster in the congested condition. Another important feature is the giveaway gestures. It was found that the vast majority of the gaps needed to merge or cross are not generated by the traffic dynamic, but created by the arterial road's drivers in the interactions with drivers wishing to merge or cross.

KEYWORDS

congestion theories, traffic management, gap acceptance, merging, giveaway

1. INTRODUCTION

Congestion is the consequence of the intensive car usage in prosperous regions and one of the most negative factors in urban and suburban life worldwide. This paper introduces some specialties from a comprehensive congestion research [1, 2]. According to the results, in the congestion not only the speed changes, but also the route of vehicles, the hierarchy of the roads and even so fundamental factors can be changed like the priority. But not just the network operation could change. One of the general experiences of the research was that the congested queue operates in a significantly different way than non-congested (under-saturated) flow. In this paper some interesting traffic phenomena are described and quantified, like traffic absorption and traffic permeability of the traffic flow, and the importance of the giveaways in the congested traffic operation.

The land use and its effects on the transport networks is an important and unavoidable field in the congestion research as well [3].

Similarly, the traffic control design, mainly the predictive control and its modeling is a rising field [4]. Merging and crossing the traffic flow at un-signalized intersections is specified by the gap between the vehicles and the critical gap accepted by the merging and crossing drivers. So, the critical gap is a paramount but not directly measurable parameter for capacity calculation [5]. The literature discusses broadly the concepts of gap, critical gap and gap acceptance [6, 7]. In these topics, mathematical and statistical works are typical, aiming the statistical description of gap acceptance, time headway and time gap, like in the works of Daganzo [8], Mahmassani [6] and others [9–17], which were usually based on large samples. It is also common to compare the non-congested and congested traffic condition, but the outcomes are mostly theoretical. Another commonly discussed phenomenon is ramp metering. Most studies rely on measurement data to provide operational solutions, but with serious limitation due to the complexity of vehicle interactions [18]. Most of these papers are also based on large samples and looking for the most appropriate parameters [9, 18]. Another approach is creating micro-simulation models, where the volume-delay functions and their

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changes can be analyzed [19]. Gurupackiam et al. [20] claim that when traffic approaches saturation, drivers take greater risks and accept smaller gaps. However, in the evaluation of the statistical data, certain human interactions have not been examined, for example, in the congested traffic; the results do not pay attention to the spontaneous or deliberate creation of the gaps. Only Kita [21] studied the interactions between drivers while merging the congested traffic flow. He claims that previous studies did not address the interaction between drivers, particularly the giveaway motion, which he believes is a decisive factor of the traffic operation. The phenomenon was studied with the tools of game theory.

2. METHODOLOGY

The hypothesis about the congested traffic operation at an un-signalized intersection was the following: It is easy to cross and merge the traffic flow at low traffic volume, as there are large gaps between the vehicles on the arterial road. In the case of large traffic, both movements are getting more difficult, because the gaps are short and the speed of the traffic flow on the arterial road is too high. It is easy to cross and merge an oversaturated arterial road, because although the gaps are short, drivers of the arterial road tend to let cross and merge the waiting drivers, often using a zipper merge. It was needed to measure the difficulty of merging and crossing movements by measuring the waiting times in the minor directions. The more difficult is to perform the movement, the greater the waiting time. In the research, the main goal was to define the differences between the over-saturated and the under-saturated traffic.

From the point of view of the traffic planning of the congested intersections, the most important is how the oversaturated queue responds the merging and crossing traffic. To describe this factor, two new concepts were introduced, the traffic permeable and the traffic absorption capabilities of the traffic flow. *The traffic absorption of a traffic flow describes the difficulty of merging the traffic flow. The traffic permeability of a traffic flow describes the difficulty of crossing the traffic flow.*

These two attributes can be measured through the waiting times and serve to compare different traffic flows. It was assumed that the two abilities are similarly altered by the change in the volume of the traffic of the arterial road. Due to the large number of gaps in small traffic, the average waiting time is very small. With increasing traffic, the waiting time also increases, and finally reaches its maximum at saturated traffic flow with high speed. When the congestion occurs, the value is expected to decrease rapidly (Fig. 1).

For the description of the phenomena it was defined the concept of giveaways based on the work of Kita [21]. He described the giveaway as a cooperative act of the drivers on the arterial road towards the subordinate drivers by slowing down and sign the giveaway. It is important that the concept makes no distinction between the enforced or voluntary giveaways, but it is worth noting the difference. It is assumed

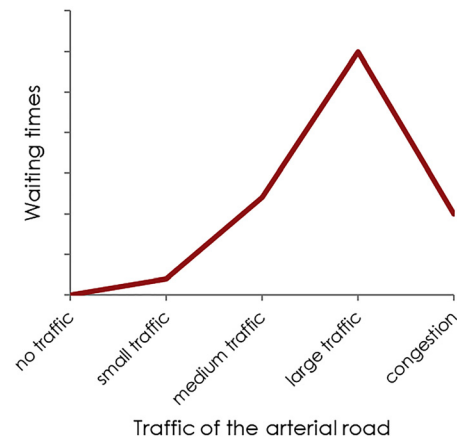


Fig. 1. The traffic volume on the arterial road and the average waiting time for merging and crossing – hypothesis

that the numbers of giveaway gestures change by the volume of the traffic on the arterial road. In the case of under-saturated traffic flow, the number of giveaways is very small. With the increase in traffic, the number of giveaways increases and finally, in the oversaturated situation, the value rises rapidly (Fig. 2).

3. DATA COLLECTION

In order to justify the assumptions, it was needed an un-signalized intersection where the two aimed condition, i.e., the high traffic volume with high speed and the congested condition can be well observed, and in both cases, there are significant merging and crossing flows. This may seem like a controversy, but a significant part of the congestion measurements in the research were near signalized intersections, where queues could occur in any part of the day. Finally, luck has come to help the data collection. The “Balatoni” Road (Budapest, Hungary) is one of the most important routes, which links the southwestern suburbs of Budapest to the city. On this road, there is a bridge over a

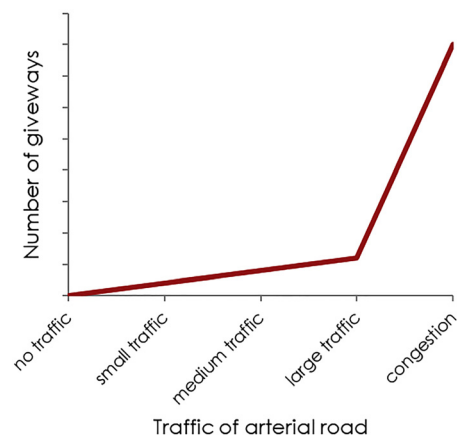


Fig. 2. The traffic volume on the arterial road and the number of giveaways – hypothesis

railway line and this bridge was repaired in May 2017, and a cable was crossed on the road. Due to the cable protector, the vehicles had to slow down, causing congestion on the otherwise busy, but not congested road section. In this condition it was possible to observe and record the traffic characteristics and after the completion of the works, it was possible to observe the traffic in the non-congested condition as well. The intersection is a yield-sign controlled one, but it is operating as TWSC due to the high traffic. The measurements were used to describe the difference between high traffic with high speed and congested traffic, the small traffic condition was not targeted.

The location of the measurement (Fig. 3) is a T-intersection of the “Balatoni” Road-“Péterhegyi lejtő” where all possible turning flows are present at the junction. The measurements took place in the morning peak period when the biggest traffic flow was towards the center of Budapest. In the study it was examined the traffic condition of the arterial road (“Balatoni” Road) towards the city and the three main merging and crossing movements (Fig. 3). A 15-min video recording was made of both conditions at the same period in the morning peak hour. The footages were used to learn the traffic volumes (number of vehicles/15 min), the waiting times (as control delays described in the HCM, s/veh), and the giveways (number of giveways/15 min) for the 4 examined nodal movements.

The drivers of the arterial road have an important role in the feasibility of the merging and crossing movements. It was necessary and important to take into account this role by the number of giveways. Thus, when a driver of the arterial slowed down to give a way to the crossing or merging driver, it was considered as a giveway.

4. RESULTS

4.1. The traffic volumes and the speeds

According to the results of the traffic counting, there was no significant difference in the traffic conditions of the high traffic volume with high speed and the oversaturated condition (Table 1). In the under-saturated condition, the total traffic (including all the examined flow) was 351 and 319

veh/15 min in the saturated condition. There was hardly any difference in the merging and crossing flows. The only significant change was that in the oversaturated condition the traffic of the arterial road towards Budapest decreased by 78 veh/15 min, while the merging flow increased by 39 veh/15 min. The merging flow increased from 29 to 68 veh/15 min, the left-turn movement from the arterial road remained the same value and the left-turn merging into the arterial increased from 3 to 10 veh/15 min. There is a small difference between the high traffic volume with high speed and the oversaturated condition, which provides a good basis for comparing the other factors.

There was a significant difference, however, in the speed of the traffic. The traffic flow on the arterial road in the high traffic volume with the high-speed condition was at a speed of ~59 km/h, although the speed limit is 50 km/h. In the oversaturated condition the speed decreased to about 26 km/h.

4.2. The waiting times

The changes in waiting times also show interesting results (Table 1). In the under-saturated condition, there is no delay on the arterial road, almost all vehicles move at a steady speed along the route. The only exceptions the few drivers who stop and give way for the long-awaited drivers wanted cross or merge. In the oversaturated condition the arterial road's drivers had 10 s of delay only on the examined short road section, which amounts to a total of 2,110 s in 15 min. The total waiting time in the long queue could have been much more. More interestingly, *the loss of the merging and crossing drivers decreased overall from 418 s to 111 s. That means the merging and crossing drivers waited considerably less in the oversaturated than in the under-saturated condition. That means in the congestion the waiting involves mainly the arterial road's drivers. In contrast, in the non-congested condition the waiting affects the merging and crossing drivers.*

In the under-saturated condition, the average waiting times were 12.3 and 6.7 s in the two crossing flows. In

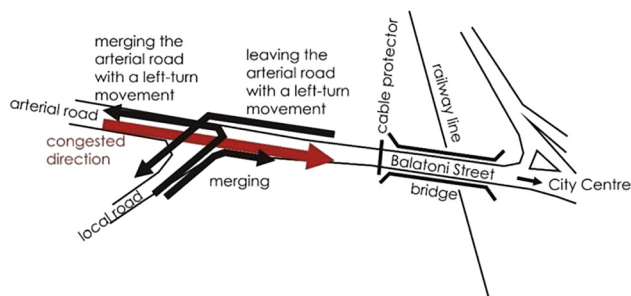


Fig. 3. The location of the measurement, the examined T-intersection of the “Balatoni” Road and “Péterhegyi lejtő” with the cable protector and the examined movements; for the merging movement a merging lane is provided

Table 1. Results of waiting time measurements; in the oversaturated condition, the prevalent proportion of the waiting time belongs to the oversaturated arterial road. In the under-saturated condition, the waiting time of the merging and crossing flows are significantly bigger and affects mainly the merging and crossing flows

Nodal movements	Without congestion	With congestion
Arterial road	0	10
merging into the arterial road	1	0.8
leaving the arterial road with a left-turn movement from the opposite direction	12.3	1.1
merging the arterial road with a left-turn movement from the local road	6.7	2.4
∑ average waiting time	418	2,110+111
Average waiting time in s/15 min		

reality, the average value is somewhat deceiving in this case as these values typically came from some very long waiting time and a relatively large number of short waiting time. In the oversaturated traffic, not only the average waiting time was much lower (1.1 s comparing to 2.4 s), but there were no long waiting, most vehicles actually waited for quite a short time. *In crossing flows, the difference in the under-saturated (12.3 and 6.7 s) and the oversaturated traffic (1.1 and 2.4 s, respectively) was surprisingly high.*

The waiting time of the merging traffic was slightly different in the two cases. However, in fact, there was a big difference in the way of merging: in the under-saturated case, drivers could accelerate on the merge lane and join to gaps between vehicles. In the oversaturated condition, almost all movements needed the giveway help of the drivers of the congested arterial road, because there are no natural gaps in the oversaturated traffic flow.

4.3. The number of giveways

The last measured factor was the number of giveways (Table 2). In the non-congested case, there was counted a total of 11 giveways, which helped a total of 13 drivers. The difference between these numbers of giveways and the number of helped drivers is due to the frequent phenomenon that several drivers used simultaneously the same gap created by one giveway.

In the congested case, the number of giveways was 78, and the total number of helped drivers was 87. The quite big difference was due to the merging traffic, where many drivers have used the gaps created by the giveways for crossing drivers. In the merging movement, the use of the zipper merge was observed by the drivers of the congested arterial road.

5. DISCUSSION

The results of the measurements helped to find the profound relationship between the characteristics of the congested queues.

Table 2. Number of giveways; the number of giveways was considerably higher in the congested condition. Comparison with traffic data (Table 1) clearly shows that in this condition all movements required the giveway gesture of the drivers on the arterial road

Results of the measurements	Without congestion	With congestion
For merging into the arterial road	7/7	46/47
For leaving the arterial road with a left-turn movement from the opposite direction	3/5	23/30
For merging the arterial road with a left-turn movement from the local road	1/1	9/10
∑ giveways/helped drivers	11/13	78/87
Number of giveways/number of helped drivers/15 min		

Waiting times for the crossing movements in the congested case are much smaller than for the non-congested condition. There is a tenfold difference between the measured values, which means that crossing the congested queue is not simply an easier movement but it is much easier. *The congested queue has virtually no resistance to crossing movements, all the crossing movements were done without considerable waiting time, i.e., the congested queue has very strong traffic permeability.*

It is easier to merge the congested queue than a non-congested one. On the basis of the measurements, in the non-congested condition it was needed an average of 1 s compared to the 0.8 s in the congested condition. The difference between the numbers is not great, but there is a great difference between the two cases in the simplicity and safety of the movement. For the congested queue, during the merging the needed speed is slow and the drivers can expect the giveway gestures of the drivers in the queue. On the other hand, for the non-congested queue there is needed a higher speed to merge and the drivers of the arterial road are less helpful in this situation.

It can be said that it is easy to merge both the congested and the non-congested condition, the waiting time values in the two cases are quite similar. The congested queues have about 20% higher traffic absorption than the high traffic volume with high speed situation. The real difference is in the quality of merging movement. In congested condition, merging is safe and supported movement, but in the high traffic with high speed condition it is often dangerous and the drivers of the arterial road are less helpful. Generally, *the traffic absorption of the traffic flows is quite similar in the two examined cases, although in the quality there is a considerably difference.*

The gesture of giveway plays a very important role in merging and crossing the congested queue. In these movements, the helping gestures of the drivers of the arterial road are necessary and inevitable. The most important thing, however, is that the gesture of the giveway makes it safe and convenient for both merging and crossing movements.

Based on the data it is possible to judge the correctness of the graph of the hypothesis of correlation of the waiting times in Fig. 1 with the results, at least in the most interesting two states: high traffic with high speed and congestion (Fig. 4). As the no traffic and the low traffic cases are considered to be certain, only medium traffic is questionable. The shape of the graph for crossings is the same as that shown in the hypothesis, although there is a quite great – twofold – difference between the values of the two crossing movements.

In the case of merging, the peak is virtually non-visible; it is practically a near horizontal line with low values. Particularly interesting is the fact that behind the almost equal values can be found very different phenomena described above. In case of high traffic with high speed, the merging is a dangerous and non-supported movement, by comparison in the case of the congested queue the merging is a secure and supported movement.

It is also possible to judge the correctness of the graph of the hypothesis of the relationship between the giveways as

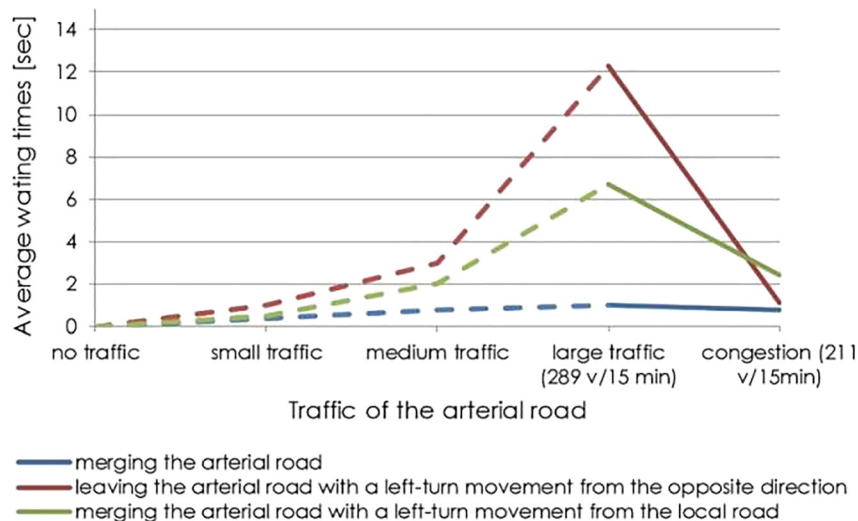


Fig. 4. Waiting times for merging and crossing movements in case of high traffic with high speed and congestion and the assumed value of small and medium traffic. Dotted lines indicate the probable run of the graphs in unmatched ranges. The results are close to the hypothesis shown in Fig. 1, however, in different way

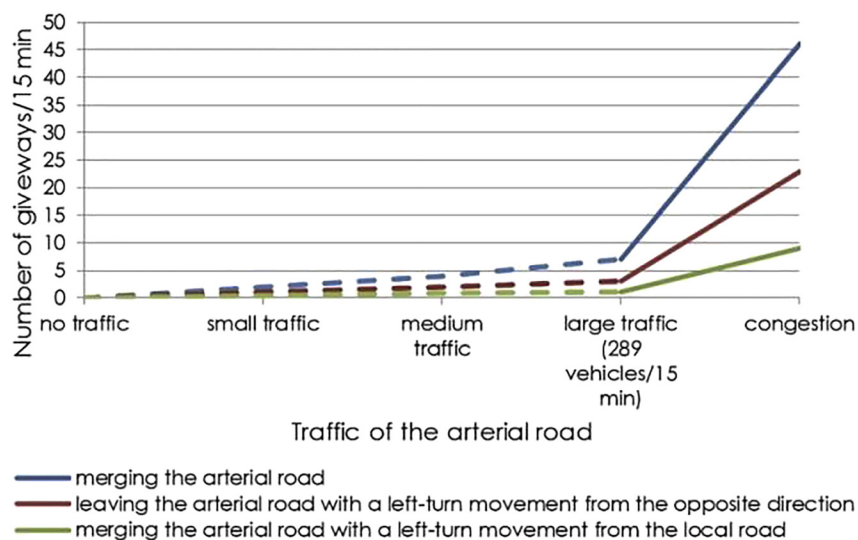


Fig. 5. Number of giveaways in the three movements, dotted lines indicates the probable shape of the graphs in unmatched ranges. The hypothesis shown in Fig. 2 is well approximated by all three cases, albeit with different values

shown in Fig. 2 based on the results, only in the condition of the high traffic and congestion (Fig. 5). It can be seen that all the three movements examined have a similar shape. In this case, however, the highest values belong to the merging and the smallest values are at the crossing of the arterial road. The values of no traffic and low-traffic cases can be estimated well, as presumably very low values. The values of medium traffic can be probably found on the line linking the values of the high traffic and the no traffic cases. Perhaps the most important result is that the number of giveaways in the oversaturated condition is very high compared to the high traffic with high speed condition, where the values are generally very low.

These results lead a bit further. If it is accepted that the results are true and could be generalized (which is worth

considering without wide-ranging measurements), then the following statements must be correct as well:

- If the oversaturated queue can be crossed and merged much easier, than the concept of the priority of the roads cannot be interpreted in the traditional way, because in the congested situation the traffic acts like the local roads had priority;
- If the concept of the priority of the roads has changed in the oversaturated situation, then the road hierarchy also changes. The arterial road is not the main directions and the local roads work not as subordinate directions, which questions the entire used traffic control system;
- The results on gap and gap acceptance found in the literature can hardly be interpreted in light of the

measurements and analysis. The prevalent majority of gaps for merging and crossing in the oversaturated traffic flow are deliberately created by the drivers in the queue. Those gaps are not the outcomes of the traffic dynamics.

6. CONCLUSION

In this paper, two special features of the congested queue were introduced. The traffic permeability and traffic absorbing both change significantly in the congested period and could be an important input data for traffic planning. To learn and quantify these properties, measurements were conducted on a road section where both the oversaturated and the under-saturated (high traffic with high speed) condition occurred. It was found that there was no significant difference between the two conditions in terms of traffic volumes. By contrast, the waiting time for crossing the arterial was significantly reduced in the oversaturated flow and the waiting time for merging the arterial decreased slightly in the oversaturated case. According to the results, the oversaturated queues have very strong traffic permeability and considerable traffic absorption capacity compared the under-saturated flow. As a consequence of these statements, the concept of the priority of the roads cannot be interpreted in the conventional way in the congestion and this also entails a change in the planned road hierarchy. The number of the giveway gestures of the arterial road's drivers was also measured. The results show that the giveways are basic property and acting force of the oversaturated traffic operation. Based on the measurements, the prevalent majority of the gaps for merging and crossing in the oversaturated queue are not the consequence of the traffic dynamics, but the result of the giveway gestures of the arterial road's drivers.

REFERENCES

- [1] A. Szele and L. Kisgyörgy, "Traffic operation on the road network with recurrent congestion," *WIT Trans. Built Environ.*, vol. 179, pp. 233–243, 2018.
- [2] A. Szele and L. Kisgyörgy, "The vitality of traffic directions on road network with recurrent congestion and its effect on road traffic design," in *International Conference on Traffic and Transport Engineering*, Belgrade, Serbia, Nov. 24–25, 2016, 2016, pp. 1012–1018.
- [3] M. Juhász, "Development of a land-use and transport interaction model as a part of policy assessment framework for urban traffic calming," *Pollack Period.*, vol. 10, no. 2, pp. 81–92, 2015.
- [4] T. Tettamanti and I. Varga, "Traffic control designing using model predictive control in a high congestion traffic area," *Period. Polytech., Transport. Eng.*, vol. 37, no. 1–2, pp. 3–8, 2009.
- [5] A. Gavulová, "Use of statistical techniques for critical gaps estimation," in *Proceedings of the 12th International Conference on Reliability and Statistics in Transportation and Communication*, Riga, Latvia, Oct. 17–20, 2012, 2012, pp. 20–26.
- [6] H. Mahmassani and Y. Sheffi, "Using gap sequences to estimate gap acceptance functions," *Transport. Res. B: Methodol.*, vol. 15, no. 3, pp. 143–148, 1981.
- [7] S. Y. Hwang and H. C. Park, "Modeling of the gap acceptance behavior at a merging section of urban freeway," in *Proceedings of the Eastern Asia Society for Transportation Studies*, Bangkok, Thailand, Sep. 21–24, 2005, 2005, Vol. 5, pp. 1641–1656.
- [8] C. F. Daganzo, "Estimation of gap acceptance parameters within and across the population from direct roadside observation," *Transport. Res. B: Methodol.*, vol. 15, no. 1, pp. 1–15, 1981.
- [9] X. Wu and H. X. Liu, "The uncertainty of drivers' gap selection and its impact on the fundamental diagram," *Proced. Soc. Behav. Sci.*, vol. 80, pp. 901–921, 2013.
- [10] M. Treiber, A. Kesting, and D. Helbing, "Understanding widely scattered traffic flows, the capacity drop, platoons, and times-to-collision as effects of variance-driven time gaps," *Phys. Rev. E*, vol. E 74, Paper no. 016123, 2006.
- [11] S. K. Dubey, B. Ponnu, and S. S. Arkatkar, "Time gap modeling under mixed traffic condition: A statistical analysis," *J. Transport. Syst. Eng. Inf. Technol.*, vol. 12, no. 6, pp. 72–84, 2012.
- [12] K. Nishinari, M. Treiber, and D. Helbing, "Interpreting the wide scattering of synchronized traffic data by time gap statistics," *Phys. Rev. E*, vol. E 68, Paper no. 067101, 2003.
- [13] A. S. Al-Ghamdi, "Analysis of time headways on urban roads: A case study from Riyadh," *J. Transport. Eng.*, vol. 127, no. 4, pp. 289–294, 2001.
- [14] A. K. Maurya, S. Das, S. Dey, and S. Nama, "Study on speed and time-headway distributions on two-lane bidirectional road in heterogeneous traffic condition," *Transport. Res. Proced.*, vol. 17, pp. 428–437, 2016.
- [15] P. Solberg and J. C. Oppenlander, "Lag and gap acceptances at stop – Controlled intersections," Joint Highway Research Project, Purdue University, Lafayette, Indiana, pages 1–57, 1964.
- [16] K. Fitzpatrick, "Gaps accepted at stop-controlled intersections," *Transport. Res. Rec.*, no. 1303, pp. 103–112, 1990.
- [17] M. A. Sahraei and O. Che Puan, "Determination of gap acceptance at priority intersections," in *8th South East Asian Technical University Consortium Symposium*, Skudai, Johor, Mar. 4–5, 2014, 2014, pp. 9–12.
- [18] D. R. Drew, L. R. LaMotte, J. A. Wattleworth, and J. H. Buhr, "Gap acceptance in the freeway merging process," Final Report on Gap Acceptance and Traffic Interaction in the Freeway Merging Process, vol. 2, Report no. 430-2, Texas Transportation Institute, 2020.
- [19] G. Vasvári, "Volume-delay functions of minor junctions created by micro-simulation," *Pollack Period.*, vol. 9, no. 1, pp. 29–40, 2014.
- [20] S. Gurupackiam, S. Jones, and D. Turner, "Characterization of arterial traffic congestion through analysis of operational parameters (Gap acceptance and lane changing)," University Transportation Center for Alabama, Report no. 07112, 2010.
- [21] H. Kita, "Merging-giveway interaction model of cars in a merging section: a game theoretic analysis," *Transport. Res. A: Pol. Pract.*, vol. 33, no. 3–4, pp. 305–312, 1999.