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Distance of bus stops from junctions: Simulation assessment

Zdeňka Stojaspalová[1,*], Josef Bulíček[1]

[1]University of Pardubice, Faculty of Transport Engineering, Studentská 95, CZ-532 10, Pardubice, Czech Republic

[*]Corresponding author. Email address: zdenka.stojaspalova@student.upce.cz

Abstract

The paper is focused on application of stochastic microscopic simulation model by design of a methodology to support preliminary decision-making about bus stops by using analytical data. The emphasis is put on bus stops with berth in driving lane located near road junctions. Four different bus stop types are applied for possibility to generalize the results. Relations between different operational features like e.g., traffic intensity, frequency of bus services or distance between junction and the bus stop are assessed. The relations are assessed by using stochastically generated inputs. PTV Vissim simulation software is applied.

Keywords: Bus stop; junction; road traffic; simulation.

1. Introduction

The paper is focused on a question if bus stops with berths located in a driving lane (not in separate bus bay) close to road junctions can be accepted for operation or not.

Application of this type of stop is not preferred nowadays, because it can cause delay of traffic. It is typically realized as solution in areas with limited space or as temporary solution e.g., in the case of closure of a regular stop. On the other hand, it can be also applied as a specific type of traffic calming measures as well.

The core thing is if such stop is suitable or if serious operational problems can be invited due to interaction with other traffic.

The main effort of this research is to propose the methodology able to simplify this decision making of authorities responsible for road operation (e.g., municipalities, road administration etc.). Inappropriately chosen location of bus stops can reduce the capacity of the junction, and even cause a traffic collapse.

Design of methodology and examination of relations between selected operational features are based on micro and microsimulation models. Following application of this methodology in practice should be based on analytical data only, so it is designed especially for preliminary and quick decisions.

An ideal approach is to consider each specific bus stop by using an individual simulation model reflecting all local conditions. Remaining question and the reason for this research is that this is not possible in all cases. For instance, it could be ineffective to develop own simulation model for a temporary bus stop applied for e.g. 2 weeks as an alternative solution due to such reconstruction works on infrastructure etc. This way of individual simulation is also one of possible results reached by proposed methodology which should be suitable for complex cases. On the other hand, development of specific simulation model can increase punctuality of assessment anytime.

The focus of the methodology is to provide basic recommendations, what are the main factors to be regarded and how. This can be suitable for lot clear and not complicated cases.

Set of 5 stochastic microsimulation models developed by using of software PTV Vissim is applied. This assessment is also equipped by 2 own supplementary mesoscopic stochastic simulation models developed by using of Visual Basic for Applications in Microsoft Excel. Although this is a simple solution, this allowed the assessment to be extended for specific research conditions.

The aim of this paper is to refer about proposed methodology supporting decision about public transport (bus) stop with berth in driving line close to road junction. Proposed methodology creates recommendation only, because it is much more general than simulation model developed for given specific conditions, but it should make this decision more accurate when development of such model is ineffective or impossible.

2. State of the art

Application of simulation is relative common by solving of different transport issues. The range of applications starts from general ones like (Kavička et. al, 2014) focused on train movement dynamics and it is finished by some specific ones like (Brambila Loza et. al, 2019) focused on simulation of airport luggage delivery system or (Chen et. al, 2017) dealing with optimization method for control of signalized road junctions. Assessment of signalling plans by using of average vehicle delay and average queue length is taking a part of the paper (Ratrout et. al, 2014). These indicators are utilized in our research as well, because it is common way, how to assess junctions by simulation.

Topic close to our research is discussed by (Wong et al., 1998) for the situation without possibility to overtake the bus at the bus stop.

Impact of distance of bus stops near signalized junctions is also discussed by (Weihua et al., 2014). Main goal is to find difference between impact of near-side and far-side bus stops. Bus stops near roundabouts and non-signalized junctions are not mentioned.

Complex point of view on simulation of public transport stops including issues of articulated trams operation is provided by (Fernández, 2010).

The questions of stops capacities, including multiple bus berths, are solved by (Gibson, 1996) in relation to neighbour signalized junctions. Specific simulation model designed for this purpose is presented as well.

Also (Minyu et. al, 2019) was interested in multi-berth and single berth curbside stops near signalized junctions. But these selected stops were in dedicated bus lanes.

(Xiao-mei et. al, 2007) and (Xiao-mei et. al, 2008) described impact of bus-stops located near junctions. These publications considered only two-lane traffic (via cellular automaton model).

Basic overview about dimensioning of signalized junctions on realistic urban environment by using of the Highway Capacity Manual can be found in the paper (Dobovšek et. al, 2005).

There are also several information sources referring about associated effects able to be applied within modelling process. For example, decision making process and multi-criteria analysis is a core of the paper (Kleprlík et. al, 2017). Questions of modelling of road transport emissions are discussed by (Matthias, V. et. al, 2020). Organisation issues of substitute bus services (temporarily replacing trains) is theme of the paper (Gašparík et. al, 2019). Temporary transport organisation and scientific knowledge about it is creating a framework for our research as well.

The novelty of our research is the fact that we characterize influencing features in general way and then we present a methodology how to decide about them.

3. Materials and Methods

Simulation is selected as the main method for this research. Models of 6 different road junctions are developed (5 in microscopic way, 1 in mesoscopic). This model infrastructure is designed as framework for partial generalization of the results.

3.1. Research base

Conducted research is based on 4 types of bus stop with different operational conditions (type A–D), see Figure 1.

As follows from the Fig. 1 all the bus berths are located close behind or in the area of junction in driving lane.

All these typical stops are based on practical examples of selected urban public transport stops from different cities in the Czech Republic. Stop names are displayed in the Figure 1.

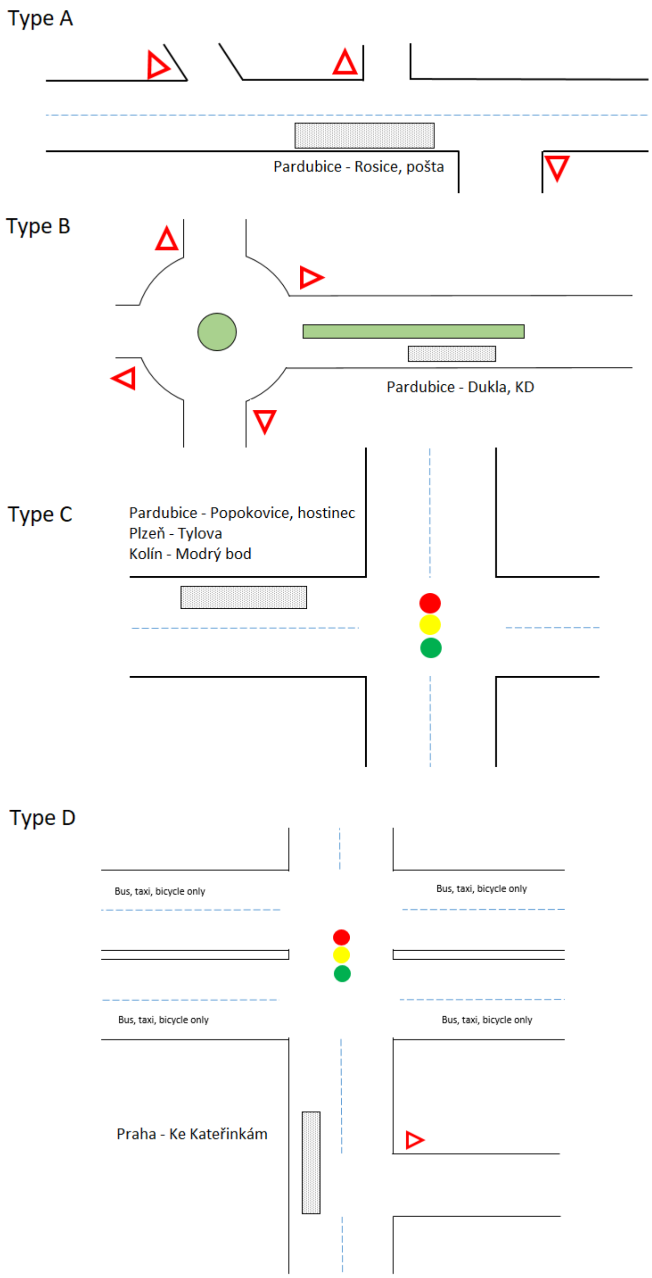

Figure 1. Types of considered stops

Type A represents basic case with no interaction with signalling plan. It is incorporated for definition of basic relations and principles.

Type B represents interaction with roundabout. Vehicles are strictly obligated to stop behind bus at stop, because driving lanes are divided by traffic island. Type B represents using of a bus berth as a transport calming measure. The stop Dukla is in the residential area with need to calm traffic.

Type C could be marked as most common situation. It is supported by 3 practical examples, because it is a common case. The case of Popkovice represents road with rush traffic. The case of Plzeň-Tylova represents rush operation of trolleybus transport and set of two stops of this type on relative narrow streets (Tylova (west) and Koperníkova (south) Streets). The case Kolín stands in-between as common case.

Type D represents more complex nodes with rush traffic as well as with some specifics like reserved bus&taxi&bicycle lane at the trunk road.

3.2. Output variables

It is necessary to define which output variables are applied for assessment of these issue.

Average vehicle delay [s] – average delay related to one vehicle (individual vehicle) passing over the bus stop.

Number of delayed vehicles [-] – number of delayed individual vehicles.

Ratio of delayed vehicles [-] – ratio of delayed vehicles in number of vehicles passing at the bus stop.

Average queue length [m] – length of queue beginning at stop area.

Maximal occurred length of queue [m] – both queue indicators can also be expressed in terms of the count of vehicles.

Newly proposed indicator is count of cases when queue was longer than distance from junction to the stop. This shows that congestion has also occurred at the junction. This may also have affected vehicles in other directions (e.g., by not being able to enter the junction due to queue).

3.3. Input (changeable) variables

Input model variables characterizes operational features of assessed situation. Generalization of the results is associated with the possibility to change these inputs or to compare them for different cases.

Distance of bus stop from the junction [m].

Bus headway time [s] – time difference between bus services is also a crucial factor influencing number of vehicles influenced by delay.

Bus dwell time at stop [s] – time of blocking of a driving lane. This input is related to the previous one, where the total occupancy time is related to the count of bus services. Thus, this indicator is applied indirectly in the models.

Probability of blocking is one of crucial indicators for this research. It is because the situation (congestion, blocking) occurred behind the bus can be serious. Time headway between buses affects total number of e.g. delayed vehicles, but not the core of the situation itself.

Intensities of traffic flows [vehicles/h].

3.4. Methods

Authors' approach is based especially on the fact that we will not model the state-of-art situation only, but we will conduct a set of experiments, where selected input values will be changed for possibility to get as general results as possible. For illustration, model traffic flow intensities will be utilized for testing the situation in different operational conditions with possibility to characterize (define) stochastic relations between input and output variables. On the other hand, models are simplified in comparison with state-of-art state at the locality. This simplification is made for better possibility to concern on solved issue and for replacement of some features which are not crucial for generalization of results. It is not an aim to develop complex models of these localities for different purposes (like design of signalling plan or possibility to assess closures etc.) as it is common in transport planning, but to prepare testing infrastructure.

Two methods of simulation were chosen. First approach works via microsimulation software PTV Vissim. Second one is based on MS Excel mesoscopic model by using of Visual Basic for Applications programming language. The mesoscopic model was also used for modelling of a "universal junction". Main of the reasons for using this model are simple possibility to move a nearby bus stop in driving lane and high flexibility according to research purposes.

These 2 methods are equipped by one mesoscopic model for the type A stop. This model is realized also in Microsoft Excel.

3.4.1. Microscopic simulation

Almost all stops together with associated junctions (mentioned in the Figure 1) were modelled by an individual stochastic microsimulation model. The stop Pardubice-Rosice (type A) is an exception (see subsubsection 3.5.2).

These 5 models are developed in the software PTV Vissim. Traffic surveys were done at each junction by authors (05-06/2021) for initial calibration. The main goal of the surveys was to set the traffic intensity at the junction (directivity and intensity itself), distance between successive vehicles, to map public transport journeys and, if necessary, to set a signal plan in a model. The values obtained were marked at each junction as the "intensity 1.0" setting and they created a baseline variant for the research.

Each simulation scenario is then evaluated with 50 stochastic replications (simulation runs) using the same simulation handle within each replication. This allows to compare simulation of possible changes in input parameters.

Output data are collected by using of implemented software tools. Successive external data analysis is made by using of Microsoft Excel. The length of evaluated time frame is 3600 seconds at all the models (cases). Data are evaluated by time periods with the length of 120 seconds into which the evaluated time frame is divided.

3.4.2. Mesoscopic simulation

There are 2 mesoscopic models applied as it was mentioned above. Both are based on scripts (macros) in Microsoft Excel developed by authors for this purpose.

The first one is focused on general signalized junction. The model is based on a cellular automaton in combination with control by program code. Despite the fact that this principle is old, it efficiently supports the function of the model. The model contains signalling plans, priority in driving, public transport stops. The main reason for decision to develop this model is the fact that it is not dedicated to one specific case of junction and it allows to create chains of changes in parameters. The application of this principle is assessment of bus stop by stepwise changing of its position to obtain a relation between position (distance from junction) and operational features (delay, queue length etc.). This is seen as very flexible for such research tasks.

The second one is dedicated to the type A stop (Pardubice-Rosice), because this stop allows to assess initial thing – influence of stop occupation on traffic. This model allows consideration of vehicle delay, queue length as well as possibility to overtake the bus. It is possible to make an evidence if the vehicle pass through clear stop, wait behind the bus or overtake. The combination of waiting and overtaking can be evaluated as well. The reason for development of this model is also the fact that chains of evaluations by changing inputs can be flexibly done.

Mesoscopic way of simulation seems to be flexible and effective for such research purposes and this effectivity should be increased by combination with results obtained in microscopic way.

3.5. Simulation scenarios

It is suitable to separate scenarios for microscopic and mesoscopic modelling by using described models.

3.5.1. Scenarios: Microscopic simulation

For each junction (type B, C and D) modelled in PTV Vissim 9 simulation scenarios were applied. These scenarios differ in traffic volume and in headway time between bus services (see Tab. 1).

As it is mentioned in subsubsection 3.4.1, initial setting was marked as "intensity 1.0". In other words, this setting should be explained that it represents state-of-art traffic situation (based on surveyed intensities).

Next scenarios are based on systematic increase in traffic intensity at the junction to 1.3 and 1.6. This is based on the fact, that we are not optimizing each specific junction, but we search for more general results improving transport technology field.

This systematic approach is a reason why initial data were surveyed for off-peak time frame. In other case, this traffic increment can cause exceeding the capacity of a junction.

Therefore, the question was how the delay caused by the bus stop will be reflected at higher intensity. The same increase is for possibility to compare different junctions. Higher increase than 1.6 was not applied because of possible capacity exceeding.

At the same time, the value of the bus headway time was adjusted (3, 10 and 20 minutes). Different values of bus headway time were chosen because of the possibility to compare the effect of slowing down the vehicles in the junction.

Table 1. Scenarios for microsimulation.

Scenario No.	Intensity	Bus headway time [min]
1	1.0	3
2	1.0	10
3	1.0	20
4	1.3	3
5	1.3	10
6	1.3	20
7	1.6	3
8	1.6	10
9	1.6	20

During the simulations, a certain simplification was applied - only one type of bus (Mercedes Benz – 12 m), the absence of pedestrian crossings, a fixed signal plan, simple visual design. It is true that some of these simplifications will be not acceptable by modelling of each junction as a specific individual case, but they can simplify the process on this more general level.

3.5.2. Scenarios: Mesoscopic simulation

The key factor influencing the situation is a position of a bus stop expressed by distance from a junction. Mesoscopic model for assessment of this is developed.

Related simulation scenario is that the bus stop is moved in 9 steps by 10 meters. So, the locations of stop 15, 25, 35, ..., 95 m behind the junction are considered. Authors considered as input model unchangeable variables: intensity of traffic flows, signal plan, length of turn lanes. Each scenario (with different distance of bus stop) was simulated 10 times via generated random input values reflected initial setting (input variables. The bus stop is always located in the same part of the junction (east part).

Finding out the opinion of public transport passengers on a possible moving of a stop was not taken into account, because the paper is focused on operational and possibly safety points of view. It is always necessary to consult any changes in a specific case / location individually. We assume that a suitable alternative stop position can be found in the vicinity to meet passenger demand, so that this methodology is not about full cancellation of a stop, but about positioning only. On the other hand, in some specific cases this can be also an important point of view, especially when the stop is in front of hospital or similar object.

The second application of the mesoscopic simulation is focused on the stop type A. It is an examination of the core effect that a bus standing at stop will block a driving lane.

There are applied 3 simulation scenarios within this simulation. They differ in headway time between bus services (3, 10, 20 minutes).

Different values of traffic intensity were simulated within each scenario. These values came from interval from 25 to 500 vehicles/hour. In total, there are 14 variants of this value. Time gaps between entering of vehicles are simulated by using of exponential probability distribution. The same value of this intensity is applied in both directions of drive on truck road (see Fig. 1, type A).

Each combination of intensity and bus headway is evaluated by 50 stochastic replications. It means that one scenario consists of 700 replications and 2100 replications have been done in total.

4. Results and Discussion

4.1.1. Meso simulation of the stop type A

The type A stop can be considered as baseline case because it is not located close to a signal-controlled junction. Driving line is blocked by bus occupying the stop. Thus, an important aspect is what is the probability of this situation (see Formula 1).

$$p = \frac{N \cdot t_{occup}}{T} \quad (1)$$

N is number of buses in assessed time frame [-], t_{occup} is occupation time of stop by one bus [min], T is the length of time frame to be assessed [min], p is the probability of driving lane blocking [-].

Probability values reached by Formula (1) are: p = 0.2500 for 3min bus headway; p = 0.0750 for 10min headway and p = 0.0375 for 20min headway. Simulation confirms it, because very similar values were reached as an average from set of 700 replications (0.256; 0.077 and 0.039 respectively).

The issue is how this simple indicator should be relevant for characterizing the operational situation.

Research of stop type A can be extended by question whether it is possible to overtake bus at the stop. Finally, there can be 3 states how passing vehicles can pass the stop: no stop; waiting behind bus; overtaking the bus. Sometimes waiting and overtaking can be occurred together as well. This can occur when a lane for opposite direction will became clear earlier than the bus will leave. All vehicles driving in the same direction as a bus will be indicator value which of these 4 states occurred.

Obtained probabilities that a vehicle will wait or overtake bus at stop for each headway of bus services are displayed in the Figure 2 Waiting includes also the cases when a vehicle waits and then overtake the bus together.

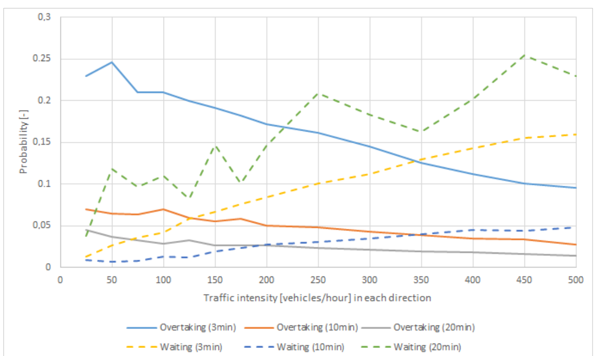

Figure 2. Probability of waiting / overtaking at stop type A by different bus headways and different values of traffic intensity. Source: Authors.

Partial conclusion applicable within the proposed methodology is that probability of blocking computed by the Formula (1) is an illustrative value able to contribute to complex evaluation of the stop. Figure 2 shows that division of vehicles between waiting or overtaking depends on traffic intensity. Probability of overtaking decreases by rising value of intensity. The opposite relationship applies to waiting.

All following micro and mesoscopic models (with exception of this model dedicated for stop type A) are simulated without possibility to overtake a bus at stop since it is often prohibited by traffic signs (Popkovice and Dukla, Plzeň - west stop). On the other hand, overtaking is possible in cases of Praha, Kolín bod and Plzeň - south stop), but this possibility is seldom used due to operational conditions, like traffic intensity in opposite direction or due to location of stop at junction area in Prague.

4.1.2. Distance of bus stop from the junction

Mesoscopic simulation of a junction with the same setting (the random distribution of vehicle entrances is changed and distance of the bus station from the junction) was implemented in MS Excel. The monitored output was the ratio of delayed vehicles passing in the same direction as the bus. Standard deviation of the outputs of 10 experiments was very low (approx. 0.2 vehicles), therefore the data could be used to create a graph of the dependence of the length of the section on the share of slowed-down vehicles (see Figure 3).

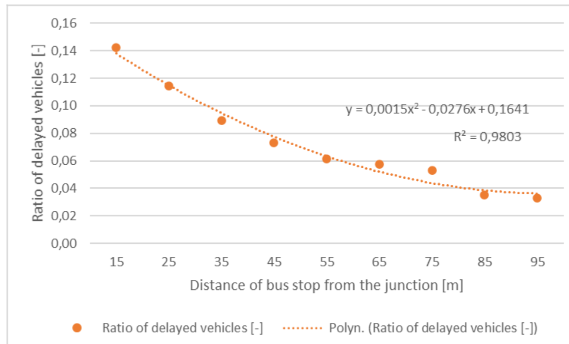

Figure 3. Ratio of delayed vehicles (mesoscopic simulation). Source: Authors.

A declining trend of delayed vehicles can be seen with the increasing distance of the bus stop from the junction.

4.1.3. Ratio of delayed vehicles

Each of 5 junctions simulated in PTV Vissim (type B, C and D) was analysed to know the ratio of delayed vehicles, which is percentage of delayed vehicles going through selected section between stop and junction compared to all vehicles going through this section. This section starts behind the bus and ends at the junction (see yellow rectangle in Figure 4 near the bus station Pardubice – Dukla, KD). The delay is caused by bus dwelling at the bus stop.

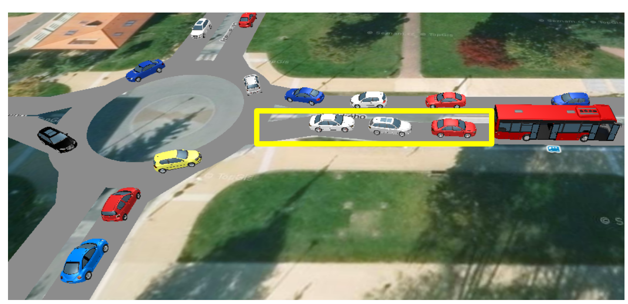

Figure 4. Bus stop – Dukla, KD, Source: Mapy.cz, ©Seznam.cz, a.s.

Comparing results from simulation scenarios is obvious if we reduce bus headway time, the share of delayed vehicles increases (see Figure 5). The great sensitivity to the increase in intensity of traffic flows was reflected especially in the Popkovice and Praha stops. This is probably because the monitored junctions (with 1.3 and 1.6) approaching their maximum capacity.

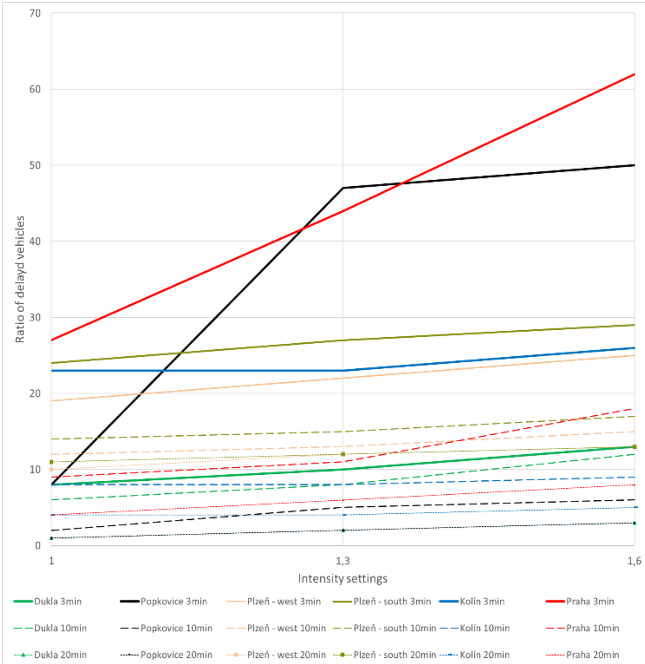

Figure 5. Ratio of delayed vehicles. Source: Authors.

It is therefore clear from the Figure 5 that the share of delayed vehicles is influenced by both - bus headway time and by the intensity of traffic flows. The increase in the number of delayed vehicles is also growing more if we are already close to capacity limit of the junction.

4.1.4. Genesis

The dependencies of the inputs and outputs used in the methodology consist in the interconnection of individual outputs during the evaluation.

For each junction simulated in a microscopic way using the PTV Vissim software, the length of the average queue, the length of the queue in each evaluated 120s interval and the frequency of queues that were longer than the section between the stop and the junction were determined. Subsequently, the model went to quantify the proportion of when the queue of vehicles hits the junction and when it will be zero or will be formed only behind the bus stop and will not affect other drivers passing through the junction.

The turning point came with the compiled graph of the dependence of the distance of the stop from the junction and the ratio of queues extended to the junction. The longer the bus headway time is, the smaller the proportion is. However, it has been found that vehicle intensity is also an important factor. With increasing intensity, the ratio increases more than with increasing bus headway time.

4.1.5. Final methodology

The resulting dependence of traffic intensity, stop distance from the junction and bus headway time is shown in the following figures 6, 7 and 8. Each figure as well as found mathematical function is intended for a different value of the bus headway time (3, 10 and 20 minutes), so whoever uses the proposed methodology must first determine which value of bus headway time will be most appropriate for problem to be solved.

If it is needed to know the probability of moving the queue behind the bus to the junction. This is key indicator, because this extension of a queue can cause operational problems at junction, including safety problems as well as possible blocking of vehicles driving also in other directions. we must know the inputs (intensity, distance and bus headway time). Formula (2) shows that it is necessary to calculate the ratio of the traffic volume V [vehicles/hour] and distance between junction and stop L [m].

$$r = \frac{V}{L} \qquad (2)$$

Thanks to the given context, we can estimate what position of a stop will be suitable according to required probability of queue extension into the junction area.

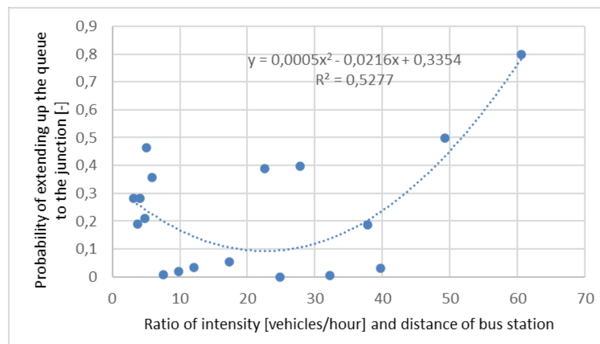

Figure 6. Bus headway time 3 min. Source: Authors.

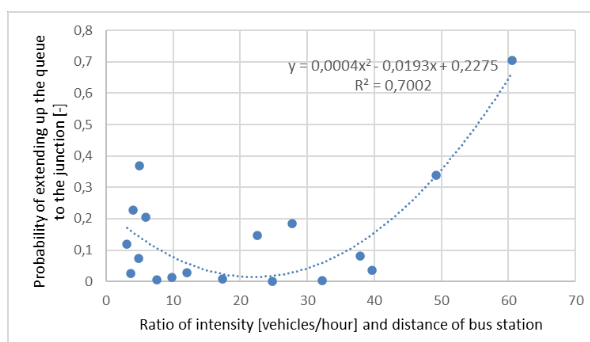

Figure 7. Bus headway time 10 min. Source: Authors.

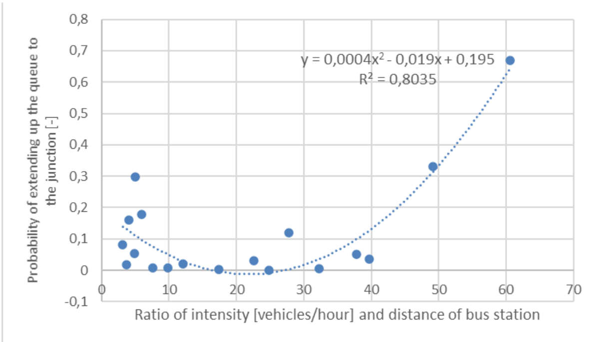

Figure 8. Bus headway time 20 min. Source: Authors.

An example is the difference between the location of a stop near a junction in a quiet part of the city (e.g., bus headway time 10 min, intensity 200 vehicles per hour and the distance of the stop 10 meters from the junction), where there is a probability of crossing the queue of vehicles into the junction) almost zero. In contrast the same location of the stop in a place where the intensity is threefold (600 vehicles per hour). In this case, the probability of the queue overlapping into the junction is between 0.6 and 0.7. Then we can decide to move the stop further away from the junction and thus reduce this "negative" probability.

5. Conclusions

The proposed methodology is a recommendation. It can provide a basic guideline for simply cases and cases needed to be decided quickly when there is no time for application of more advanced and accurate simulation assessment.

Value of the coefficient of determination in Figures 6,7 and 8 shows, that with decreasing bus headway time, the mentioned innovative methodology is more accurate. However, it is necessary to realize that the given dependencies apply according to the data collected by the authors under specific conditions (Czech Republic, traffic off-peak time, only a selected sample of junctions, etc.) and the chosen evaluation (a certain degree of simplification, etc.). At the same time, it applies that the mentioned methodology shows the expected situation, but it is also suitable to supplement it with other simulations, always for a specific solved area.

The aim of the research has been fulfilled. As follows from the subsubsection 4.1.5. it is possible to find a methodology supporting decision-making about position of bus stop in relation to distance from a junction. On the other hand, conducted research shows that there are some possible topics of further research in this field as well. Implementation of actuated signaling plans into the model or implementation of delay of public transport services can be the examples. This can possibly lead to improvement of accuracy of proposed methodology.

References

Brambila Loza, K.E., Wellens, A.G. & Pérez Juárez, S.K. (2019). Simulation of baggage delivery management for an increase in demand in a Mexican airport. EMSS 2019. 268-275. ISBN 978-88-85741-25-6.

Diviš, R. & Kavička, A. (2014). Train movement dynamics within AnyLogic tool. EMSS 2014. 307-312. ISBN 978-88-97999-38-6.

Dobovšek, M, Sever, D. (2005). Dimensioning of Signalized Intersections in Realistic Urban Environment. Promet - Traffic&Transportation. 1;17(3):143-8.

Fernández, R. (2010). Modelling public transport stops by microscopic simulation. *Transportation Research Part C: Emerging Technologies.* 18:6:856-868.

Gašparík, J., Zitrický, V., Široký, J., Černá, L. (2019). Substitute bus transport task and definition. ransportation Research Procedia 40 (2019) 225–228.

Gibson, J. (1996). Effect of a downstream signalized junction on a capacity of a multiple berth bus stop. *Traffic management and road safety. Proceedings of seminar held at the 24th European Transport Forum, Brunel University, England. Volume P407.* ISSN: 0952-3103.

Chen, Y., Li, L., Shen, Y. & Liu, B. (2017). A simulation optimization method for design and control of signalized intersections in urban areas. EMSS 2017. ISBN 978-88-97999-85-0.

Kleprlík, J., Matuška, J. (2017). The demand for public transport and modeling decision-making process of passengers. Transport Means 2017. ISBN 1822-296X.

Matthias, V., Bieser, J., Mocanu, T., Pregger, T., Quante, M., Ramacher, M.O.P., Seum, S. & Winkler, Ch. (2020). Modelling road transport emissions in Germany – Current day situation and scenarios for 2040. Transportation Research Part D 87 (2020): 102536.

Minyu, S., Weihua, G., Sangen, H. & Han, C. (2019). Capacity approximations for near- and far-side bus stops in dedicated bus lanes. *Transportation Research Part B: Methodological. Volume 125.* Pages 94-120. ISSN 0191-2615.

Ratrout, N.T. & Reza, I. (2014). Comparison of optimal signal plans by Synchro & TRANSYT-7F using PARAMICS – A case study. rocedia Computer Science 32 (2014) 372 – 379.

Weihua, G., Vikash, V., Cassidy, M. J. & Saade, N. (2014). On the impacts of bus stops near signalized intersections: Models of car and bus delays. *Transportation Research Part B: Methodological. Volume 68.* Pages 123-140. ISSN 0191-2615.

Wong, S. C., Yang, H., Au, Y., Cheuk, S. L., & Lo, M. K.

(1998). Delay at Signal-Controlled Intersection with Bus Stop Upstream. *Journal of Transportation Engineering, Volume 124:3(229)*. Retrieved from https://doi.org/10.1061/(ASCE)0733-947X(1998)124:3(229)

Xiao-mei, Z., Zi-you, G. & Ke-ping, L. (2008). The capacity of two neighbour intersections considering the influence of the bus stop. *Physica A: Statistical Mechanics and its Applications. Volume 387. Issue 18.* Pages 4649-4656. ISSN 0378-4371.

Xiao-mei, Z., Zi-you, G. & Bin, J. (2007). The capacity drop caused by the combined effect of the intersection and the bus stop in a CA model. *Physica A: Statistical Mechanics and its Applications. Volume 385.* Pages 645-658. ISSN 0378-4371.