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Simulation of interactions of road vehicles and pedestrians at public transport nodes: Pilot study

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Abstract

The paper focuses on the specific dynamics between pedestrians and road vehicles observed at the public transport nodes. The emphasis is on the organization of traffic flows in terminals or locations with interchange stops. There are specific situations that occur in such cases as increased pedestrians' demand for crossing by bus arrival or change of periods with rush and low traffic (in the case of almost collective arrival or departure of more buses to/from a node). The study is conceived as a pilot study; emphasis is therefore put on the definition of a set of such situations and on the assessment of the basic attributes influencing them. This is also the reason why the study deals with only a limited number of public transport nodes; crucial is the design of the nodes and their functional links. This study aims to define these interactions and provide an input framework that allows modeling/simulating the mentioned situations. Stochastic models will be developed on two levels – level of microsimulation using PTV Vissim and mesoscopic simulation represented by own designed model using Visual Basic for Applications and dedicated especially to testing of newly modeled situations.

Keywords: Pedestrians, public transport nodes, simulation, pedestrian-road vehicle interactions

1. Introduction

This paper focuses on the interactions between road vehicles (mainly buses and trolleybuses) and pedestrians at the public transport node (PTN). More specifically, on the situations associated with road crossing, movement near platforms, jaywalking, etc.

The movement and behavior of pedestrians at PTNs is inherently linked to the safety and efficiency of pedestrian-road vehicle interactions. Simulations of these interactions can be beneficial in making decisions about the design of PTNs and their surroundings, leading to improved operational safety and resilience. Furthermore, it is necessary to ensure as fluid operation as possible because acceleration and deceleration of vehicles can have negative environmental and energy consumption effects.

The purpose of the study is to provide an input framework for such simulations, i.e., to find and describe parts of the real situation that are essential for the simulation process and to define the required inputs. However, the interactions between pedestrians and road vehicles depend on the design of PTN (location of platform, platform access type, structure of the path network, etc.), and therefore even the outputs of these interactions may vary depending on the design of PTN. To mitigate possible inaccuracies, the study emphasizes outputs that can be generalized.

The results of the study will provide the basis for modeling/simulating these interactions. The research (and testing) stochastic simulation model will be designed as mesoscopic and will be programmed in the Microsoft Excel application by using the Visual Basic for Applications programming language. This represents a very flexible solution for research purposes, allowing one to put a focus on the topic despite the need to program the environment for the implementation itself. Some selected issues will be modeled by the support of PTV Vissim microscopic simulation software at a more detailed level as well.

The paper is divided into several sections. Section 2 presents an overview of the literature relevant to the topic discussed. This is done in a relatively brief manner with the aim of providing a basic background on the topic and its current state. Section 3 delves into the issue of modeling itself; it offers an introduction to methods, principles, and tools. Section 3 also partially describes the results and subresults of the individual methods. In Section 4, the authors define the results of the article and discuss the limitations and further research directions. Section 5 offers conclusions and summary of the paper.

2. State of the art

Current research works explore some attributes of PTNs; however, only a limited number of papers delves into the problem in the manner of modeling/simulating. On the other hand, there are papers dealing with road traffic simulations, but they usually do not consider pedestrian-road vehicle interactions at PTNs.

To some extent related to this research is a paper by Krivda et al. (2021). The authors of the paper used PTV VISSIM and VISWALK to simulate pedestrian movements at the transit nodes of public transport (PT). However, this simulation is more focused on accessibility and capacity aspects and less on pedestrian-road vehicle interactions and their safety and efficiency. Capacity of PTNs is partially reflected in our research as well.

Related to this problem is also the train platforming problem, discussed, for example, by Caprara et al. (2011). Our study does not focus primarily on railway vehicles; however, the train platforming problem may be altered and used also in bus terminals and other road vehicle infrastructure. Simulation is a typical tool applied in the railway field (Široký et al., 2021), but these models of railway operation can be adopted on a theoretical level for our topic.

In terms of safety, a paper by Lakhotia et al. (2020) exploring accessibility and safety of bus stops in Delhi can be mentioned. The authors of this paper used geographically weighted Poisson regression to identify links between access aspects and pedestrian fatalities.

Similarly deals with safety Gitelman et al. (2017). This paper aims at the links between pedestrian safety and design features of signalized junctions situated on central PT routes.

Also, Pulugurtha and Srirangam (2021) explore pedestrian safety near the PT infrastructure. The paper focuses on light rail transit stations and uses a combination of GIS data and statistical analysis to determine pedestrian safety near the stations. The GIS-based approach to assess accessibility of stops and stations is also used by Rossetti et al. (2020). This list can also be extended by a paper by Flores et al. (2015), which delves into the issue of urban transport infrastructure.

Some articles focus on pedestrian-road vehicle interactions in areas affected by pedestrian crossings. However, these papers generally do not consider specific dynamics at PTNs. For example, paper by Celinski (2020).

Part of the research oriented towards simulations is dealing with pedestrian movements in PT infrastructure, however, these are usually focused on movement in buildings and interactions with road vehicles are addressed only marginally. As an example, the paper by Bohari et al. (2016) can be referred to.

On the other hand, there are also papers that focus on the simulation of signalized intersections (Chen et al., 2017) or on hybrid simulations of railway systems (Novotný and Kavička, 2018). Insights from these papers (and others similar) may be important to our topic, even if they focus on different situations or modes of transport. Our topic is related to these papers also in the sense of a general description of transportation systems.

Other papers related to simulations can be mentioned. For example, a paper by Bažant et al. (2019) deals with the application of multicriterial analysis in a simulation environment. Different paper by Feng and Li (2022) debates the possibilities of nested Monte Carlo simulations. These papers are not directly related to the topic of our article. They could, nevertheless, offer significant insight into the simulation process. This insight could translate into the basis for the simulation of pedestrian-vehicle interactions. The mentioned insight is not only important regarding the application but is also linked to the simulation theory which is relevant to our paper.

It seems that there is currently a gap in the modeling/simulating research field. This pilot study aims to explore this gap and contribute to the problem of pedestrian-road vehicle interaction at PTNs.

3. Materials and Methods

There are two suitable approaches to model this issue. The first is mesoscopic and the second is microscopic. The mesoscopic level is represented by a model tool based on Microsoft Excel (Visual Basic for Applications) programming language) developed by the authors specifically for this paper. The microscopic level is used to model selected cases by the PTV VISSIM microsimulation software in a more detailed way.

There is also a difference in modeling methodologies according to these levels. Passengers at the microscopic level are modeled as individuals able to decide about their movement in space almost at every moment. The specific way this is managed is part of the software know-how. On the other hand, modeling on the mesoscopic level is, in contrast to the microsimulation level, more simplified and abstracted. The authors apply a method based on the combination of discrete choice theory (Pravinvongvuth and Chen, 2005) and of social forces model analysis (Kormanová, 2012). Discrete choice theory is a tool for selection between more transport routes when passengers could be distributed between all of them in certain parts. The LOGIT model is a well-known method that belongs to this field.

The research is based on five practical examples operated in the Czech Republic. Each of these examples is structurally different and therefore can be compared. Practical examples of the PTNs considered in this paper include:

- Pardubice, Masarykovo náměstí – bus/trolleybus PTN in the center of the city of Pardubice. Defined by five platforms (1-3 urban PT; A and B intercity buses), a signalized crosswalk and lanes separated by a median strip. Car traffic is prominent.
- Pardubice, Hlavní nádraží – bus/trolleybus node of urban PT in the city of Pardubice near the train station. Terminal with transfer links to the train transport system. Car traffic is only limited.
- Mariánské Lázně, Nádraží – intercity bus/train/urban PT terminal with multiple platforms in the southeast direction and one platform in the northwest direction. The traffic lanes are separated by a median strip. Car traffic is present.
- Kolín, Nádraží – intercity bus/train/urban PT terminal defined by a combination of straight-line layout and leaving-type layout. Car traffic can interact.
- Chrudim, Autobusové nádraží – intercity bus/train/urban PT terminal similar in type to the Kolín, Nádraží. However, the layout of the platforms at this node is different enough to create different pedestrian-road vehicle interactions.

Based on these practical examples, the paper deals with the problem of pedestrian-road vehicle interactions and explores how they influence traffic efficiency and safety at PTNs.

The paper focuses on situations caused mainly by a combination of pedestrian movement and arrival/departure of PT vehicles. For example, these situations include an increased demand for pedestrian road crossing after the arrival of PT vehicle or a delay in the departure of PT vehicle created by road crossing of disembarked passengers. Different situations may involve jaywalking as pedestrians choose the optimal path (based on their judgment) to their destination. High focus is placed on pedestrian routing at PTNs and on priorities at road crossings and at intersections of pedestrian flows as well. These and other situations and dynamics are subjects to simulation in this paper.

3.1. Traffic surveys

To assess the current situation at the mentioned PTNs, traffic surveys were conducted. These surveys were 90 minutes long and focused on behavior during rush hour. In this case, rush hour means a period with highly active PT – a large number of vehicles enter and leave the PTN. In these circumstances, pedestrian-road vehicle interactions are more pronounced, and it is easier to spot their specifics. For traffic surveys, simple graphic models were created to illustrate the design of the PTNs and pedestrian paths (although due to the scope of the paper, only two examples are presented in the text). The red arrows in these models represent crossings that were considered during the simulation. In this context, a crossing means a nonspecific pedestrian path (jaywalking included) that interacts directly with cars and PT vehicles. White arrows indicate entrances/exits of buildings and light blue marks areas dedicated to pedestrian crossing, but not defined as crosswalks.

Pardubice, Masarykovo náměstí – this PTN is not complex in terms of pedestrian-road vehicle interactions. The core of this node is a signalized crosswalk, which is important not only in terms of transfer links but also creates a connection between a shopping gallery in the south and the city center in the north. This means that a significant number of pedestrians leave the PTN area after crossing the road (they do not transfer between the PT lines). A specific move at this PTN is towards a ticket vending machine near platform 3. The traffic survey was conducted on Saturday between 11:30 and 13:00. Simulation in Vissim is shown in Figure 4.

Pardubice, Hlavní nádraží – in case of this PTN there are several observations to be made. It seems that pedestrians use the southern part of the PTN more dynamically. However, there is also a strong connection between the building of the railway station and the island platforms that is routed by a crossing area. The crossing area acts as a traffic calming and accessibility element, as it is made on a raised surface. It also lies directly opposite the entrance/exit of a railway station building. These attributes make the crossing area more attractive and comfortable for pedestrians, especially in the direction from the railway station building to the island platforms. In the opposite direction, pedestrians usually exit the PT road vehicle and continue to the building of the railway station on the most direct path. Another specific connection is between platform 7 and the building of the railway station. Platform 7 is used as an alighting platform for vehicles of lines that end in this PTN – also here pedestrians choose the most direct path. The number and size of pedestrian groups are largely dependent on passenger occupancy in PT vehicles (the group size varies from three to ten). The traffic survey was conducted on Saturday between 13:30 and 15:00.

Simulation in Vissim is shown in Figure 5.

Mariánské Lázně– the traffic survey at the PTN in Mariánské Lázně has shown that jaywalking is significantly less prevalent than was anticipated. Pedestrians prefer to use the crosswalk directly opposite the entrance / exit of a railway station building and the eastern crossing area. This is probably due to the transfer links between trains and buses/trolleybuses and pedestrian paths from and to the city center. The traffic survey was conducted on Tuesday between 14:00 and 15:30. Simulation in Vissim is in shown Figure 6.

Kolín – the PTN Kolín has a very specific interaction that is linked to its design and an adjacent street in the south (the street name is Pod Hroby). Most of the time, pedestrians jaywalk across this street to get to the platforms and the building of the railway station. The street is a dead end, and car traffic is quite sparse on it. Due to these factors, pedestrians use the area as a de facto shared space (as represented by crossings in Figure 1). The traffic survey was conducted on Friday between 14:30 and 16:00.

Chrudim – the PTN Chrudim can be divided into two sections, the south section consisting of the railway station building and urban PT platforms, and the north section with intercity bus platforms. Parallel to the PTN is a street named Čs. armády. Pedestrians cross the street more dynamically in the south section of the PTN, and the area is, similarly to the Kolín, used as a de facto shared space. This behavior is supported by a traffic calming measure (speed cushions) near the intersection of Čs. armády and Rooseveltova streets. Pedestrians also jaywalk in the north section, but the routes here are more "organized". An interesting interaction between pedestrians and PT vehicles manifests itself after the arrival of the intercity bus. Pedestrians wait for the bus in two different areas, part of them wait directly on the platform and part wait on a sidewalk that is connected to the platforms through crosswalks. After the bus arrives, pedestrians begin to flow from the sidewalk to the bus, and the line begins to form. Based on the number of pedestrians who want to board the bus, the line can reach the road that the buses use to exit the PTN. This occurs when more than ca. 15 passengers wait in front of a bus to check-in. The graphic model of this PTN is shown in Figure 2. The traffic survey was conducted on Tuesday between 14:30 and 16:00.

The Excel-based mesoscopic tool is especially useful in testing the conditions and dynamics that can be observed at the PTN Kolín and Chrudim. Graphical representation of these condition is shown in Figures 1 and 2.

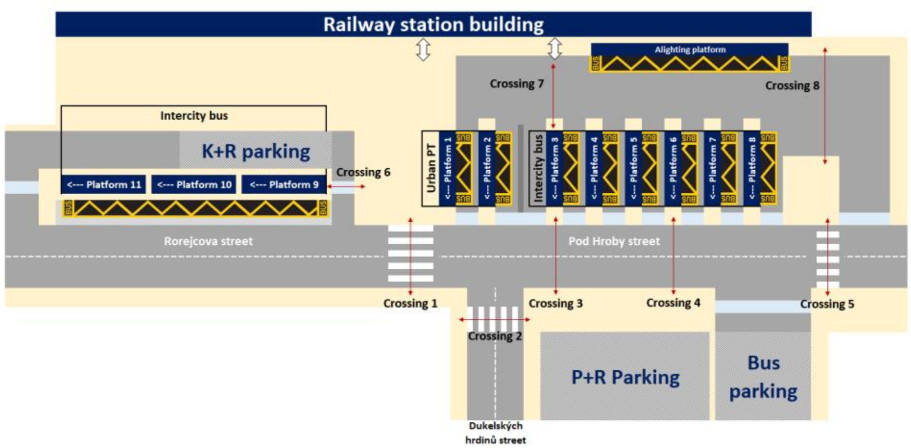

Figure 1. Graphical model of the PTN Kolín

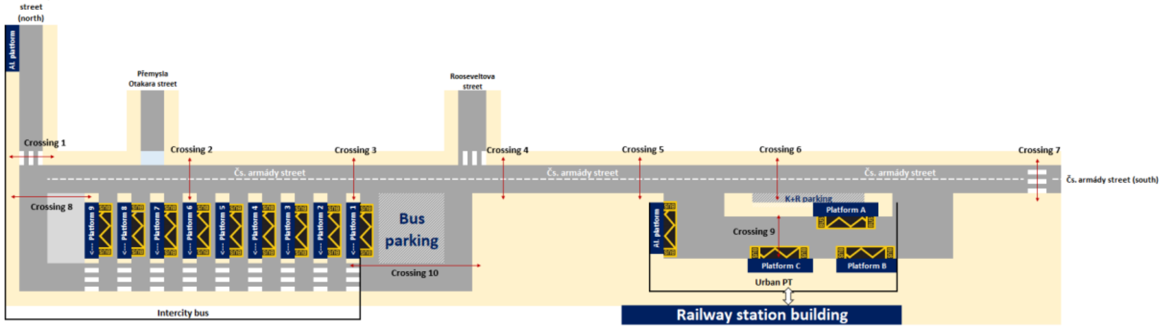

Figure 2. Graphical model of the PTN Chrudim

3.1. Simulated effects

The input of the simulation model was obtained by the traffic surveys defined in Section 3.1. Car flows were simulated as free flows using an exponential distribution to model the intervals of individual cars enters for time intervals between the arrival of individual cars. Public transport services were modeled according to the model time schedule. All current urban PT lines on the same route that pass through the modeled area in the same manner were aggregated. For these urban PT lines, the collective regular interval was applied. The input delay of the urban PT lines was modeled as an exponential random value with a mean of 2.25 min (Pardubice, Hlavní nádraží) and 2.08 min (Pardubice, Masarykovo náměstí). The dwell time of urban PT was modeled as a normal random value with a mean of 25 s and a standard deviation of 5 s. The traffic of intercity buses was modeled according to the real time schedule. Signalized crossings were modeled with a 6 s free interval for pedestrian flows and a 10 or 20 s interval for all vehicles, including PT vehicles.

Modeled features – some of the modeled features were based on the investigation at the selected PTNs. First, the willingness of pedestrians to jaywalk or do some other potentially risky movement depends on the extent of the traffic. Almost nobody crosses the street outside the signalized crosswalk area at the PTN Pardubice, Masarykovo náměstí, due to the high volume of car traffic (about ca. 550 cars per hour in each direction) and PT vehicles (every 75 s in each direction during rush hour). Higher rate of jaywalking occurs at the PTN in Mariánské Lázně due to the lower volume of traffic (ca. 150 cars/h and ca. 10 min interval of buses). The PTNs reserved for PT vehicles and closed for car traffic (Kolín, Chrudim and Pardubice, Hlavní nádraží) also have a higher rate of jaywalking. The PTN Kolín is designed as a more or less shared area for passengers and buses (pedestrian crossings almost do not direct passengers' paths). The most important role of marked crosswalks is at the PTN Chrudim, but passengers respect them only very partially. These facts are observed by the delays obtained as result of simulation.

Impact of the length of the signal cycle – this feature was observed at the PTN Pardubice, Masarykovo náměstí in both mesoscopic and microscopic models. The feature was evaluated in the relation between cars, PT vehicles and pedestrians (transferring passengers).

Place of alighting of passengers from PT vehicles – this effect was observed at the PTN Parubice, Hlavní nádraží and Chrudim. The location of an alighting stop can significantly influence the transfer time, as well as the pedestrian path choice. The transfer route between the intercity bus alighting platform and the railway station in Chrudim is 300 m, and this can be reduced to 120 - 205 m by using one of the boarding bus platforms also for alighting. The recommendation for drivers may be to stop twice at the PTN (especially in the case of delay, as this can help mitigate the impact of the short time available for transfer). The issue at the PTN Pardubice, Hlavní nádraží is the usage of platforms 7 or 8 for alighting. There is not much difference in distance to the building of the railway station (150 and 130 m, respectively), but the route from platform 8 is safer – pedestrians cross the routes of other PT vehicles at the elevated crossing in the middle of the terminal. In contrast to that, the route from platform 7 crosses the arriving and departing routes of PT vehicles, where vehicles usually move at higher speed (the movement is also less organized and individual paths are more diverse).

Coupling of passengers – all PT buses operated in Kolín, Chrudim and Mariánské Lázně require boarding of passengers at the first door of the vehicle only (drivers check or sell tickets). This can create a platoon of passengers waiting in front of a bus. Lines are not strictly organized. This behaviour can have consequences as a long enough line may be formed that will interfere with the infrastructure of PT vehicles and create conflict between passengers and PT vehicles (see Subsection 3.1; PTN Chrudim). Another complicated situation occurs at the PTN Kolín during the simultaneous (or nearly simultaneous) arrival of two urban PT vehicles (on platform 1 or 2). It can be difficult to board the first bus as one has to pass through the group of passengers waiting for the second bus. This can be evaluated by the number of such situations that occurred during a simulation run.

Location of passenger facilities – this feature is typical for the PTN Chrudim, where a sidewalk along the bus terminal is protected from rain and sun by a roof and rear wall. The area is complemented by street furniture. These factors, together with the placement of platforms, cause that part of the passengers prefer to wait for the bus on the mentioned sidewalk and walk to the bus only after its arrival (this is again linked to the observed behaviour at the PTN Chrudim that is described in Subsection 3.1). This behaviour can amplify the conflict at the crosswalk between passengers and other buses leaving the PTN, as described in the previous paragraph. This can also amplify the issue of creating lines in front of vehicles (the approaching routes of passengers are located at the head of platforms). For that reason, the so-called collision nodes were defined in the mesoscopic simulation model to allow the possibility of anticipating such problems. The PTN Mariánské Lázně should be mentioned as a best practice example, because the routes between the alighting platforms and the railway station are short and use suitable infrastructure (especially the crosswalks).

4. Discussion and Results

As follows from Section 3, there are multiple different effects and dynamics that arise from pedestrian-road vehicle interactions at PTNs. These effects can be divided into two main groups - time based effects and spatial based effects. Naturally, both parts can be involved in practical models (however, the rate of involvement may differ situation by situation).

The surveyed PTN located at Pardubice, Masarykovo náměstí is a typical example of a case where time effects are dominant, especially due to the signalized crosswalk at the core of the PTN. The signal plan of the crosswalk represents a fictive conflict between pedestrians' requirements for the green signal and drivers' expectations of longer signal cycles with only a limited time for the red signal. The final issue can be formalized as a decision on the structure of the signal plan and the lengths of individual signals.

The authors would like to present and discuss four indicators applied in our research for the general assessment of microscopic traffic simulation in the field of PTNs (realized in PTV Vissim). The first one is a basic indicator - the average delay caused by stopping. The second is the total volume of stops as traffic irregularities. Pedestrians and cars are treated in an aggregated manner to provide a system point of view. However, pedestrians are partially prioritized because cars are counted as one element without considering the actual occupancy. Travel time per km is also applied specifically – because of the aggregation of passengers and cars, secondary replications with different number of vehicles can be aggregated as well. The last but not least indicator is the rate of time spent by stops. As shown in Figure 3, the volume of stops decreases, and the rate of time spent by stops increases due to the extension of the length of the green signal for cars. The second advantage of this approach is that all stops in the model are assessed, including the traffic situation caused by lane changing, etc. (see Figure 4). Naturally, simulation models also provide a number of other indicators (like delay in a selected area, etc.). We follow the mentioned indicators as a base for studying the interactions at the PTNs.

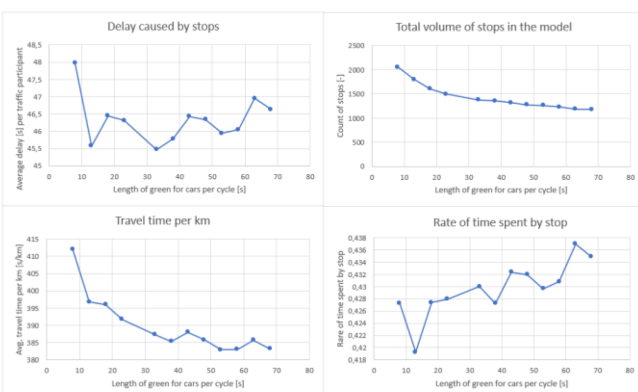

Figure 3. Recorded values of indicators for Masarykovo náměstí

The simulation in the case of the PTN Pardubice, Masarykovo náměstí consists of 12 simulation scenarios – each with different length of green signal for cars. The considered scope of green length ranges from 8 to 68 seconds with a step of 5 seconds. For each scenario, 25 simulation runs were performed. The same simulation seed was applied in each scenario (a set of 25 replications).

Figure 4. Simulation of the PTN Pardubice, Masarykovo náměstí
Source: Authors based on Mapy.cz using PTV Vissim

The model of the PTN Pardubice, Hlavní nádraží (see Figure 5) is dedicated to the assessment of transport organization. Two simulation scenarios were selected for the presentation of our research. The assessed issue is, how the interaction between passengers and PT vehicles will be changed due to the replacement of the alighting platform for terminating PT vehicles from platform 7 to platform 8. It is considered that 70 passengers per hour use this platform. Platform 8 provides a more straight and safer route (in contrast to platform 7) using an elevated crossing located in the middle of the PTN. The total number of stops (pedestrians together with buses) increases from 818 to 823 per hour, which is not very significant, but the average delay caused by stop increased from 35.5 to 53.1 s. This is due to the fact that the strong flow at the central crossing is amplified and the number of interactions (also between passengers) increases.

Figure 5. Model of the PTN Pardubice, Hlavní nádraží
Source: Authors based on Mapy.cz using PTV Vissim

The model of the PTN Mariánské Lázně (see Figure 6) is more focused on infrastructural effects. There are two different ways how to approach the PTN from the city center for pedestrians (by using Hlavní street or Příčná street). Each street leads to a different set of paths, some with crosswalks and others without.

One of the simulated infrastructure effects was focused on the eastern pedestrian crossing area (Hlavní street). Two simulation scenarios were considered: without crosswalk (current state) and with crosswalk. Each of the scenarios consisted of 50 random replications, and the same simulation seed was applied. The simulation was assessed using PTV Vissim. The application of crosswalk decreased the total number of stops by 0.72 % (from 832 to 826 stops). The total travel time spent in the modeled system was decreased by 0.28 % and the average delay caused by stopping by 3.39 % from 11.2 to 10.8 s. From the simulation, it seems that the application of the crosswalk has overall positive effects (at least in terms of the indicators monitored). On the other hand, these positive impacts are not so critical as to consider this measure a necessity.

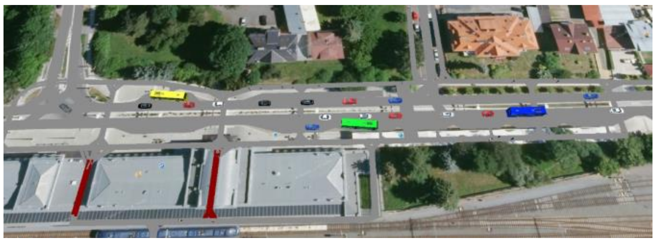

Figure 6. Model of the PTN Mariánské Lázně

Source: Authors based on Mapy.cz using PTV Vissim

Other considered infrastructure effects focused on capacity characteristics. The model based on state-of-the-art infrastructure was loaded with 14 traffic endurance situations. These situations are hypothetical and do not correspond to the current traffic load. However, the current state was used as a starting point. The endurance situation can be defined in two branches: the first branch represents the increasement of cars passing through the PTN (1, 2 and 3 times the current state) and the second branch which represents the increasement in transferring passengers (1, 2, 3, 4 and 5 times the current state). This leads to 15 combinations, each modeled as a simulation scenario. No increase in the number of PT vehicles is considered. For each scenario, 10 replications were made. This corresponds to the fact that the emphasis is on finding the theoretical capacity limits of the infrastructure - the number of scenarios is preferred to the number of replications. On the other hand, in complicated cases, the number of scenarios as well as replications should be increased. Secondary, the analysis should consider more operational features and effects as well (this should be part of the authors' future research as this paper is only a pilot assessment).

Figure 7 shows the relations between the total number of cars and pedestrians at the PTN and the average number of operational stops (aggregated for both cars and pedestrians). It is visible that the relation is almost a polynomial of degree 2 (the dependence is statistical in nature) at all 3 levels of car traffic load. For the decision, if the quality is suitable, one must define a qualitative limit, e.g., if the average number of stops must be 1.75 or less, then 2 times increasement in car traffic and 5 times increase in pedestrian traffic is still acceptable. The definition of capacity limits and the complexity of these evaluations should also be the focus of future research of the authors.

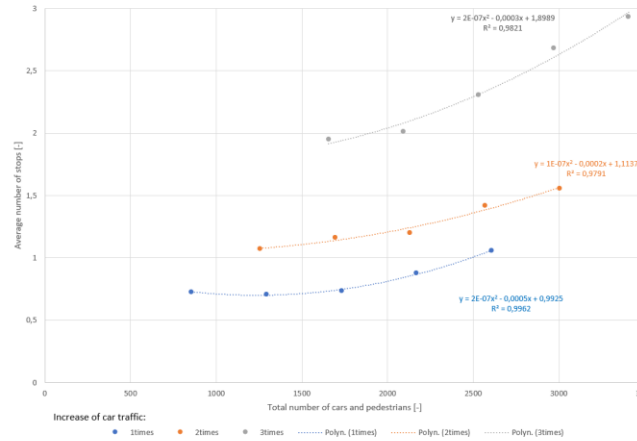

Figure 7. Results of endurance testing at the PTN Mariánské Lázně

The pedestrian-road vehicle interactions are largely dependent on the topology (design or architecture) of PTNs. Through the identification of bottlenecks and critical components, a "stability" of the PTN topology can be defined. As stability, the authors mean especially the safety of pedestrians (how probable is the risky behavior and how forgiving is the PTN topology to such a behavior) and the probability of PT vehicles delay due to interactions with pedestrians. This stability is also linked to the traffic intensity of pedestrians and vehicles. This means that stability should be defined for different PTN topologies and for different traffic intensities. It may be that some PTN topologies are inherently more stable than others. Another interesting prospect regarding the PTN design is the application of shared space near or at the PTN. Some PTN topologies appear to be more prone to jaywalking and generally to more "unorganized" road crossings. Legalizing shared space in some areas of PTNs may lead to more balanced dynamics between road vehicles and pedestrians. However, the decision to apply shared space must be based on some methodology or tool, which may be of modeling or simulating nature.

More research (and data collection) is required to compare the qualities of mesoscopic and microscopic models in a general sense (in relation to the research of dynamics at PTNs). Mesoscopic models developed using Microsoft Excel confirmed the authors' presumptions and allowed the study of some individual (partial) effects. This, for example, includes a grouping of passengers during a check-in at the PTN Chrudim. This may establish a relevant base for future research. The authors would like to point out that there is also practical application, as these simulations may be used to assess situations in less complex PTNs where only some of the mentioned effects occur.

5. Conclusions

The authors based their research on the usage of mesoscopic (own model tool developed in Microsoft

Excel) and microscopic (PTV Vissim) simulation. This article was conceived as a pilot study with the aim of specifying the possibilities of simulations in the field of pedestrian-road vehicle interaction at PTNs. The results of the research are listed in detail in Section 4. The authors believe (based on the results of this paper) that pedestrian-road vehicle interactions at PTNs can be successfully simulated and used to more closely specify the features of PTNs, their design, and overall their operational principles. However, to reach these goals, more research is needed that will verify these assumptions in a more complex way. Simulation tools strongly benefit from comprehensive methodologies, and therefore this topic should also be thoroughly researched to maximize its potential advantages.

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