SIMULATION ASSESSMENT OF RELIABILITY BY INTERCHANGE BETWEEN RAILWAY AND PUBLIC BUS TRANSPORT WITH REGARD TO LOCATION OF A BUS TERMINAL IN THE MUNICIPALITY

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Abstract

The paper is focused on interchange nodes between trains and regional buses. Sometimes it is necessary to use railway station and bus terminal located at different positions in the municipality. The issue is how to improve operational stability and reliability for passengers walking between these stops. State-of-art effort by organizing public transport is to minimize transfer time. This is contrast with possible delays of individual public transport services. Operational reliability of interchanges may be affected in a negative way. Need to walk between stations can amplify passengers' discomfort. Simulation model designed as result of this research will provide possibility to check time schedules of both public transport modes and to indicate connections (pairs of trains and buses) with not so good operational stability (high risk to lose connected service). The benefit of the model is the fact that it combines microscopic with macroscopic into mesoscopic point of view. The case study is focused on interchange node of Přelouč located in the city agglomeration of Hradec Králové and Pardubice in the Czech Republic. There are 2 bus terminals in this municipality, the first in front of the railway station, the second in distance of ca. 600 m from the railway station. This allows assessment of impact of this distance on operational reliability. The model allows transport planners to identify which interchanges are unstable. Possible modifications of time schedule can be considered by this model as well to protect worsening of stability at different interchanges.

Keywords: Interchanges, public transport, reliability, simulation, time schedule

1. INTRODUCTION

Individual modes of public passenger transport should be interconnected one to another, including trains and regional buses. Sometimes it is not possible to construct one terminal for both modes allowing direct interchange. It can be caused by historical reasons, terrain topology or other spatial limitations and sometimes also by operational reasons. The issue is how to ensure and improve reliability for passengers changing between transport means of both modes in such case with necessity to walk between different stations.

The research is conducted within the project mentioned in acknowledgement of this paper. This project is located to the city agglomeration of Hradec Králové and Pardubice in the Czech Republic, ca. 100 km to the East from the capital of Prague. Case study is focused on an interchange node of Přelouč, located in this agglomeration.

The locality of Přelouč was selected because there are 2 bus terminals. The main is located close to the municipality centre, the second one is in front of the railway station. Distance to be walked between railway station and the main bus terminal is ca. 600 m (i.e. ca. 10 minutes of walk). Specific distance between departure information tables is 527 m. This configuration creates suitable study conditions to compare both ways of interchange organisation (with walk/at the same place).

In general, state-of-art effort by organizing public transport is to minimize time needed to change from one mode to another. This is in contrast with need to have time reserves for compensation of possible delay. Need to walk between stations should amplify passengers' discomfort in this case of time lack. Operational reliability of interchanges should be affected in a negative way.

Simulation is well-known mathematical modelling procedure. It is widely applied in transport (e.g. simulation of road junctions, railway line operation etc.). Stochastic (random) simulation should be applied for this research as well.

The research aim is to create mesoscopic stochastic simulation model as a tool for assessment of operational stability (reliability is considered as more general synonym expressing impact on passengers) at interchange node where stations of different modes of public passenger transport are not at the same place and interchanging passengers must walk.

Research hypothesis can be stated as follows. When both stations (railway and bus) creating node are not at the same place, operational reliability should be worsened (in the point of view of changing passengers).

Simulation model designed as result of this research will provide possibility to assess time schedules of both public transport modes in the point of view of interchanging passengers. It will be able to indicate connections (pairs of trains and buses) with insufficient operational stability (high risk to lose the connection).

The second important function of this model is a possibility to check impacts of possible modifications of time schedules (e.g. moving of a selected transport service in time) in complex point of view. It is a prevention that removing of one complication does not create a new one. Keeping of system regularity should be checked in this way.

2. STATE-OF ART OF KNOWLEDGE

Reliability of transport system belongs to its important features. It is very important especially for passengers as a criterion of public transport quality. Passengers should consider interchanges as an integral part of transport process [1,2].

Accuracy of trains is about 90 % (as accurate are considered trains with delay less or equal to 6 min) in Sweden according to [3]. On the other hand, the value of this accuracy is below 90 % in Norway according to [4]. Similar values are valid for the Czech Republic as well, the accuracy was 90.6 % in 2017 and 89.1 % in 2018 [5]. Train accuracy is considered more strictly in the Czech Republic (trains with delay ≤ 5 min). These values show that such public transport system is suitable for application of line structure based on interchanges, but such system becomes more sensitive as well. It means that it is necessary to deal with this topic – reliability of interchanges between modes of transport, because each minute of delay can increase passengers' discomfort by walking between stations. It must be mentioned also in context that effort to reduce travel time is state-of-art feature of public transport [6]. Balanced solution between reliability and travel time attractivity must be found because both aspects have impact on passengers' decision to use public transport.

Length of route for interchange, vertical difference and places where passengers should wait (e.g. zebra crossings signalized by traffic lights) are mentioned by [7] as main factors influencing transfer time. Gradient of the road used by pedestrians and need to climb staircases are considered as main aspects by construction of so-called walkability index of the surroundings applied by [8]. Multilevel crossing of pedestrian route and car road realized in the way of footbridge and acceptation of it by passengers are assessed by [9].

Impact of technical measures on transfer time needed to interchange is researched by [10]. They assessed that it is possible to increase speed of passengers' movement by a simple modification of space near doors of vehicles. This can also help to reduce transfer time.

Overview about simulation tools applicable by modelling of passenger flows at railway stations is provided by [11]. Passenger flows at interchange nodes as well as at pedestrian routes in public places by different conditions (e.g. in crowd) are modelled by [12-15]. Speed of pedestrians by different values of pedestrian flow density for different groups of passengers is researched by [16] using the Viswalk modelling software. Microscopic and mesoscopic models are applied as a method for definition of transport demand by [17]. Transport demand in relation to time schedule (arrivals, departures, traffic peak and off-peak time periods etc.) by aggregated groups of passengers is solved by [18]. Selected aspects of interchange nodes, its configuration and features of transport demand after different transport modes (long-distance, regional, sub-urban, individual car transport) are solved regarding operational reliability by [19,20].

Optimization of interchange connections by transfer between different subsystems of public transport is mentioned by [21-23]. Waking distance by interchange between trains and substituting buses applied by track closures and its impact on travel time are mentioned by [24].

3. MODEL

The character of stochastic (random) simulation models is descriptive, but it is suitable for a lot of transport issues. Presented model is developed in the Microsoft Excel application by using of Visual Basic for Applications (VBA) programming language. This way allows to develop the model according to our specific needs. VBA is a flexible way especially for research purposes like this one.

The structure of the model as well as the data (to be used as default) were found according to transport surveys realized in Pardubice, Hradec Králové, Přelouč, Hlinsko v Čechách, Kolín, Žďár nad Sázavou, Olomouc, and Praha (Prague). The scope of surveyed localities is wider than the case study because some elements (like escalators) are unavailable in Přelouč. There is an effort to prepare the model for more general application.

3.1. The concept of the model

The model covers two stations (railway station and bus terminal) as well as all transport services operated at both stations sorted in so-called destination profiles (**Figure 1**). Destination profile can represent a point of view of passengers, they should use more lines for their journey (profiles A, E, 2 in the **Figure 1**). On the other hand, one line can take a part in one or more destination profiles. More precise assessment in comparison to assessments based on lines or individual transport services is ensured due to this profile-concept. Destination profiles are different for each mode of public passenger transport (railway/bus transport). Similar conception was introduced by the authors of this paper in [25], but for railway transport only.

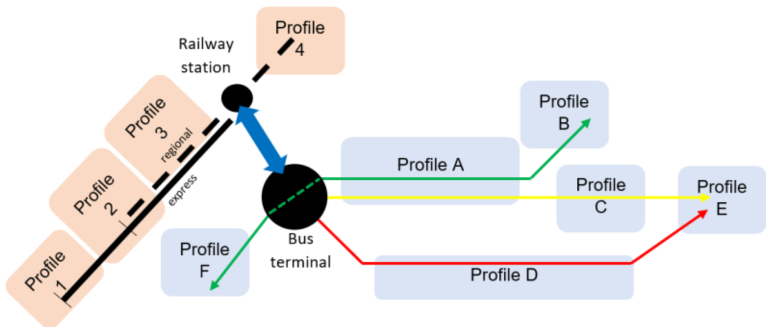

Figure 1 The idea of destination profiles [own study]

3.2. Main static model inputs

The model is based on time schedules of all assessed lines in both modes. Naturally, it is possible to make difference between business days, Saturdays, and Sundays with different extent of public transport services.

Preconditions for vehicle circulations should be implemented as well (e.g. that the next bus service will not depart before delayed vehicle will come).

3.3. Stochastic model inputs and replications

Random generation of stochastic inputs allows automated creating of stochastic replications within the model, because number of situations to be assessed is needed to be generated. It can be illustrated that a set of different days (of operation) is created. Exponential probability distribution is applied generation of input delay on arrival of individual transport services (trains and buses). Individual parameters for generation of input delays should be set according to individual public transport lines (in railway as well as bus mode).

Collective assessment of set of replications brings an aspect of generalization into an assessment. The case study is based on performing of 1000 replications for each simulation scenario. Each one expresses different situation to be assessed. These scenarios (situations) can differ in infrastructure of interchange node or in time schedule as well.

The model allows saving of so-called simulation seed for generation of stochastic inputs, so different simulation scenarios can be compared by the same conditions. For example, two variants of time schedule should be compared by the same values of input delays of individual transport services (trains, buses).

4. THE CASE STUDY OF PŘELOUČ

Population of Přelouč is ca. 10,000. There arrive 93 trains and 82 buses and depart 86 trains and 83 buses per day (naturally with some weekend exceptions).

Figure 2 Přelouč: main bus terminal - walking route - bus terminal at railway station [own study]

Figure 3 Přelouč: walking route [26]

The main bus terminal with 8 stops (**Figure 2** - left) is located ca. 600 m from the railway station. It is necessary to cross a road 6times (**Figure 2** - middle and **Figure 3**) by walking. There are only two crossings equipped by zebra-crossing on this route. Both are near to the main bus terminal (marked by red circles in **Figure 3**).

One of them crossings the 2nd Class road No. 333 and the second one access route to the bus terminal. Second possibility, how to get bus, is bus terminal with 5 stops located directly in front of the railway station (**Figure 2** - right).

The stochastic simulation model applies 2 simulation scenarios. Each with one of these variants of bus terminal. State-of-art extent of operation (time schedule) was adopted.

There are 7 railway destination profiles defined at the node for 3 physical railway lines in Přelouč. In simple, 3 are for regional (Pardubice-regional, Kolín-regional, Heřmanův Městec); 2 for express transport (Prague, Moravia) and 2 combined (Pardubice, Kolín) expressing substitutability of both regional as well as express train segments by reaching these neighbour cities.

There are 16 destination profiles in regional bus transport although there are operated 9 bus lines only. This is caused by the fact that there are some common segments served by more bus lines together in close surroundings of Přelouč. Diametric (transiting) bus line No. 623 is divided into 2 profiles by directions East and West. So, there can be made a difference between passengers able to switch between lines and passengers using given line obligatory (travelling to places served by one individual line). Each group of passengers should be assessed parallelly in the model with consideration of almost all the possibilities to travel which they have.

4.1. Transfer time limits, interchange categories

Setting of limits for transfer time are crucial for the assessment. These limits were set according to a set of experimental transfers made by authors. Four interchange categories were applied for this assessment. *Uncomfortable interchange* means that transfer is possible, but not for all passengers. It is necessary to go in a hurry, there is almost no time for searching for information or for train ticket purchasing. It should be also a problem for people with reduced mobility. *Optimal interchange* represents adequate time with not too much serious time loss. The category named as *"with reserve"* stands for transfers with easy acceptable time loss, which can be filled by train ticket purchase, small refreshment, phone call etc. *Acceptable interchange* means that it is unattractive, but it can be accepted especially on connections with low number of passengers or by uncommon individual trips.

Interchange between main bus terminal and railway station (ca. 600 m of walk): uncomfortable 7 - 11 min; optimal 11 - 17 min; with reserve 17 - 23 min; acceptable 23 - 55 min.

Interchange between bus terminal at railway station and railway station (ca. 50 m of walk): uncomfortable 3 - 6 min; optimal 6 - 12 min; with reserve 12 - 18 min; acceptable 18 - 45 min.

4.2. Assessment of planned time schedule

In the case of main bus terminal there are 698 pairs of transport services (train and bus or bus and train) per day. The portions are: uncomfortable 8.60 %; optimal 11.32 %; with reserve 10.74 %; acceptable 69.34 %.

In the case of bus terminal at the railway station there are 766 pairs of services. Uncomfortable 4.83 %; optimal 12.66 %; with reserve 11.23 %; acceptable 71.28 %.

It is seen that operational stability is preferred before shortening of travel times.

4.3. Stochastic assessment of time schedule stability

Specific indicator is applied for this case - average ratio of holding of planned interchange category within 1000 replications of stochastic simulation. It is based on presumption that different category (with shorter or longer transfer time) is a complication for passengers. Span of values recorded in the simulation are added to the average values in **Table 1** (in brackets).

Table 1 Interchange stability in stochastic simulation – all values are average [own study]

Bus terminal:	Bus terminal at railway station		Main bus terminal	
Interchange category	**Train > Bus (%)**	**Bus > Train (%)**	**Train > Bus (%)**	**Bus > Train (%)**
Uncomfortable	47.33 (20.70 - 80.50)	60.80 (45.80 - 83.10)	55.76 (13.10 - 100.00)	76.67 (50.10 - 91.00)
Optimal	65.46 (29.20 - 100.00)	81.13 (47.20 - 97.90)	70.82 (27.70 - 100.00)	77.66 (48.00 - 97.30)
With reserve	68.07 (30.40 - 100.00)	76.63 (46.30 - 97.80)	65.43 (15.90 - 90.10)	82.26 (47.90 - 97.90)
Acceptable	66.16 (21.80 - 100.00)	91.63 (44.50 - 100.00)	85.43 (15.90 - 100.00)	91.61 (45.20 - 100.00)

4.4. Average transfer time and probability of use of planned connection

Figure 4 shows relation between average transfer time and probability to catch planned bus (according to bus destination profiles). Rising value of transfer time is helpful to improving reliability of that interchange connection at both bus terminals. On the other hand, this relation is not statistically significant (5th degree polynomial functions are applied and the values of coefficient of determination R^2 are about 0.3 only).

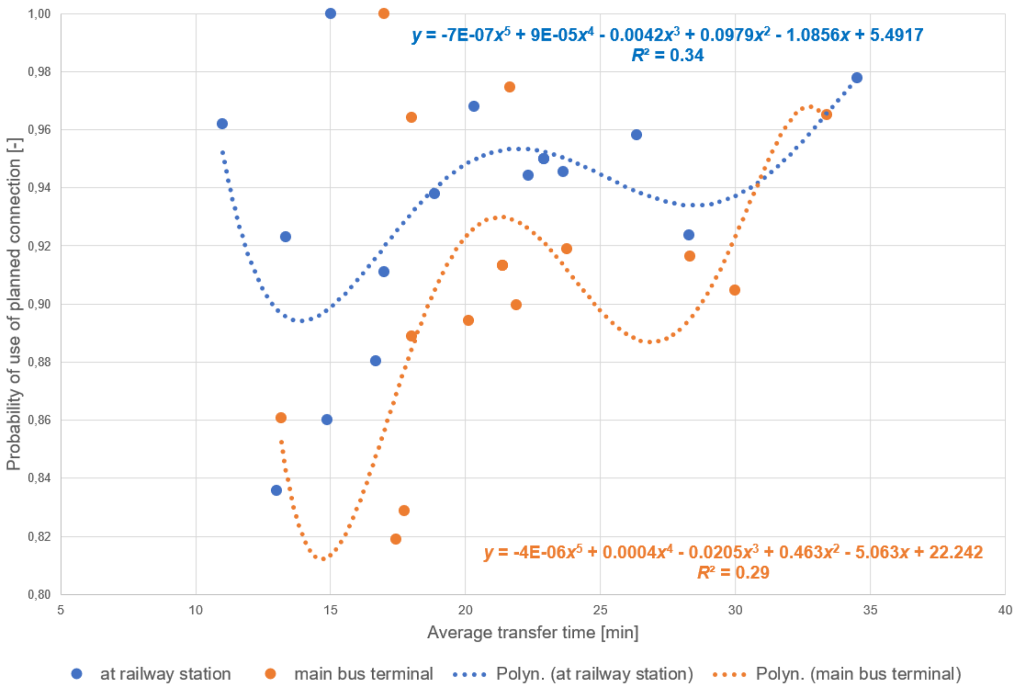

Figure 4 Přelouč: Relation between average transfer time and probability of utilization of planned service [own study]

4.5. Detail analysis by destination profiles

There are 7 railway and 16 bus destination profiles defined in Přelouč. It means that the model allows 224 points of view of different passenger groups changing from each profile to each profile (from train to bus as well as vice versa).

Table 2 shows an example consisted of 16 cases – for passengers coming from the neighbour city and regional centre of Pardubice interchanging to each of bus destination profiles. Passengers can come by express as well as regional trains by travel time of 9 or 14 minutes respectively (13 km). Bus profiles named by line number stands for individual bus lines. Profiles named by municipality name represent profiles where it is possible to travel by more lines in common segment. Dwell time represents time spent in Přelouč (from arrival to departure) in this case.

Table 2 Stochastic simulation for passengers coming from Pardubice - average values [own study]

Bus terminal:	Bus terminal at railway station			Main bus terminal		
Destination profile	Planned dwell time (min)	Simulated dwell time (min)	Utilization of planned service (%)	Planned dwell time (min)	Simulated dwell time (min)	Utilization of planned service (%)
Line 172	34.50	33.99	97.77	33.40	33.68	96.50
Břehy	16.67	18.53	88.02	17.44	19.51	81.89
Line 620	28.30	28.92	92.36	28.31	31.36	91.62
Lázně Bohdaneč	26.33	28.77	95.82	23.75	27.66	91.90
Line 621	13.00	32.88	83.56	16.10	40.18	73.27
L. 623 to West	13.33	42.07	92.30	13.17	41.36	86.07
L. 623 to East	17.00	32.48	91.10	21.67	22.74	97.45
L. 625 to Podhořany	14.88	29.44	86.01	30.00	33.95	90.46
L. 625 from Podhořany	20.33	30.04	96.80	17.75	38.61	82.86
Line 627	22.90	24.64	94.99	21.36	27.26	91.34
Heřmanův Městec	22.33	24.72	94.43	20.11	28.36	89.41
Choltice	22.90	24.64	94.99	21.36	27.26	91.34
Line 628	23.63	26.19	94.56	21.88	30.09	89.95
Rohovládova Bělá	18.86	22.95	93.79	18.00	28.00	88.87
Line 635	11.00	10.30	96.00	18.00	17.14	96.40
Line 638	15.00	13.37	100.00	17.00	15.37	100.00

This analysis should be done also on more detailed level of each pair of transport services to identify possible specific problems. One example for all. Minimal scheduled transfer time in the destination profile of Břehy is 4 min (by interchange at railway station bus terminal).

Probability to catch this connection is 53.90 % only, but due to the fact that backup bus (of other line) runs 7 min later (in this common segment), it is not too much serious problem. Passengers will spend 5.67 min in average in Přelouč only (including those waiting for backup service).

The same bus is a problem for the passengers needed to use the line 621 only (direction Labské Chrčice – profile “Line 621”). Backup bus of this line runs about 243 min later. Need to reschedule this bus is still a question, because passengers from Pardubice can come by previous train about 16 min earlier and the probability to catch planned bus of the line 621 is 100 % as follows from simulated data. This simply example can show, how important is to access this problem in as individual way as possible. On the other hand, this can be also used as an appeal that it is necessary to announce to passengers (by information systems) that it is strongly recommended to use earlier train from Pardubice to Přelouč.

4.6. Discussion

Table 1 and **Table 2** show different ways of assessment using different indicators - time category (expressing passengers’ comfort) in **Table 1** and probability to catch planned connection (of travel by planned transport service) in **Table 2**. It seems that both tables provide quite opposite results by mutual comparison. Planned time span of transfer time is ensured more frequently (in 5 from 8 cases – marked by green) at the main bus terminal. Proportion of using of planned connections (transport services) is higher at the terminal in front of the railway station (in 12 from 16 cases – marked by green). This is due to next important factor, that values of scheduled transfer time are relatively high (20.06 min in average), almost the same as in the main bus terminal (21.21 min). The consequence is that possibility to reduce transfer time (due to missing walk) is replaced by improvement of operational reliability in this case.

5. CONCLUSION

The paper presents application of developed mesoscopic stochastic simulation model for assessment of operational reliability of interchange nodes where railway station and bus terminal are not at one locality and interchanging passengers must walk. On the other hand, model naturally allows assessment of interchange nodes located at the same place as well, e.g. for comparison.

Connections (pairs of transport services) with insufficient stability (reliability) are identified and measures proposed for elimination of problems in this filed should be also checked by this model to keep regularity of the system without transfer of problem to other connections.

The fact that the model has not one simple criterion applied for assessment with the solution is appropriate. Individualized solution is often needed. For instance, insufficient connection of bus to train should be correctly indicated by the model, but transport planners are not obligated to replace it if there is such reason to keep the current state. For example, when it is a bus serving local schools in the municipality and there is no significant demand for interchange to train.

The main contributions of the model are following. Connections are assessed according to destination profiles. what allows extended and more adequate considering than by line-expression. Interchange nodes as potential risky place in the point of public transport quality is highlighted. More variants of time schedule as well as infrastructure of interchange node should be assessed.

Model was tested on the case study of the interchange node in Přelouč served by 344 transport services (trains and buses) per day. All functionalities work correctly.

Related research hypothesis seems that it is not valid for the case of Přelouč. Operation of main bus terminal (with need of walk in the length of ca. 600 m) provides higher reliability than the terminal located in front of railway station at least in some cases. It is due to the fact that transfer time contains often time reserves for walk able to be used also for partial reduction of impact of train delay.

Finally, the operation reliability is influenced by volume of delays and applied time reserves next time schedule composition. Designed simulation model can examine this for each specific case. General recommendation is that it is necessary to hold adequate time reserves by possible moving of bus terminal from distant localities to railway stations. Maximal reduction of transfer time should have negative impact on transport reliability as well. Research in this filed will be continued starting by application of model to more interchange nodes.

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