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Full Length Research Paper

Influence of vehicle headway irregularity in public transport on in-vehicle passenger comfort

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This paper performs an analysis of the influence of headway irregularity in public transport on the quality of the transport service, in the domain of in-vehicle passenger comfort. The influence of vehicle headway irregularity along a route on the in-vehicle passenger comfort has been analysed on urban bus routes that operate in a mixed traffic flow. Based on the research conducted on 2,800 bus departures, the headways and capacity utilizations have been determined for every individual vehicle along a route. On the recorded departures, the capacity utilizations have been analyzed in real working conditions. Based on the real recorded capacity utilizations (with headway deviations) and simulated capacity utilizations (without headway deviations), a comparative analysis has been performed on the influence of headway irregularities along a route on the capacity utilizations, that is, on in-vehicle passenger comfort.

Key words: Transport service quality, headway irregularity, capacity utilization, in-vehicle comfort.

INTRODUCTION

The quality of a public passenger transport service can be defined as the general effect of the service's features that determines the degree of satisfaction of the service user's needs. At the same time, it is important to emphasize that the quality of the transport service is determined by a set of quality features. The transport service quality features include organizational service support, convenience of the service, service availability, service reliability, system production capability, and technical exploitation reliability (Filipović and Stanković, 1996).

Passenger comfort represents a part of service convenience. Service convenience can be defined as a service quality feature that enables and facilitates successful and easy usage of the public transport system. In addition to in-vehicle comfort, the other service convenience features include the passenger information system, the comfort characteristics at the bus stops, the tariff system, payment system, and ticket system.

Research has shown that the headway irregularity phenomenon on public transport routes has an array of negative effects which can cause consequences, such as: passenger uncertainty regarding the waiting time at a bus stop (Dziekan and Kottenhof, 2007), passenger uncertainty in terms of the necessary planned travel time from the place of departure to the destination (Dziekan and Kottenhof, 2007), and increased passenger discomfort due to overcrowding in certain vehicles caused by irregular and inaccurate arrivals, etc.

Headway irregularity and bus route unreliability can be caused by different operational problems. The primary causes of unreliability have been attributed to route characteristics (e.g. the length of the route, the number of signalized intersections, the characteristics of on-street parking, distance between the stops, etc), operating

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conditions (e.g. traffic volume, service frequency, passenger's activities, and driver's behaviour), and the vehicles (e.g. departure delays and different behaviour of operators) (Paliska and Kolenc, 2008).Numerous authors have analysed the headway irregularity problem along the route from various aspects. A certain number of authors have elaborated models for headway management, while others have studied the influence of headway irregularity on capacity utilization, the influence of vehicle delays at stops on headway irregularity, passenger waiting time depending on the interval, and integration of the transit offer at interchange stations.

Chien and Ding (2001) developed a model for real-time headway management which maintains headway regularity and reduces the average waiting time. Wei and Randy (2009) in their paper, utilize linear regression as a model for determining passenger waiting time on bus routes depending on headway irregularity. Gershenson and Pineda (2009) presented a model for achieving equal headways, and they stated that in their future work they shall apply their model onto various public transport subsystems in Mexico City.

Chang and Chu (2005) present a way of determining the minimum costs of a public transport system whilst taking into consideration external influences, and at the same time analyzing the optimal length of individual routes and the optimal headway on the corridor. Strathman et al. (2003) analysed the influence of headway irregularity on the number of passengers, and concluded that vehicles which achieve a longer than planned headway carry larger passenger loads and vice versa. Hill (2003) in his paper analyses the cause of headway irregularity and brings it into connection with passenger accumulation at bus stops. The paper presents a model with three phase diagrams showing different regimes of unstable behaviour that a bus system can enter. Simeunović (2001), in his Master's dissertation thesis, utilizes a real system to analyze the influence of headway irregularity on bus routes onto service quality, in the domain of passenger waiting time and in-vehicle comfort. Nagatani (2004) studied the influence of bus stop dwell time on delays, and determines a dependency between the number of passengers and bus delays. Chang and Hsu (2003) developed a mathematical model for the analysis of passenger waiting time at an interchange station where the intermodal intercity transport system is served by feeder buses. They also take into consideration passenger behaviour, namely, whether they arrive at the station randomly or in accordance with a known time schedule.

Gershenson and Pineda (2009) stated the manner in which headway irregularity causes inefficiency of the public transport service, which performs best when the headways are equal. Shorter headways lead to shorter waiting times. Longer headways lead to longer waiting times and more delays, so several vehicles will start platooning, that is, travelling together.

Ruan and Lin (2008), in their paper, presented the results of a research conducted on a bus route in Chicago. Based on the research, they concluded that expected headway irregularities have occurred on the observed route. During the study, bus platooning had occurred, while some buses even overtook the buses in front of them. They also stated that this phenomenon usually causes longer headways and longer passenger waiting times until the arrival of the next bus.

Vučić (1981, 2005, 2007) in his books provided recommendations for determining the capacity of a route and its bus stops, as well as various combinations of interchange stations and headway regularity as a key segment for passenger interchange.

Based on the papers from the aforementioned authors, it can be concluded that headway deviations from the determined regimes along a bus route are inevitable, which also causes deviations from the designed parameters of transport service quality. Based on the conducted research, this paper analyses the influence of headway irregularity on bus routes onto capacity utilization, that is, on in-vehicle passenger comfort.

During this research, 2,800 bus departures were recorded on bus routes without an independent route, which operate within the general traffic flow. Since the presentation of the results of all departures that were included in the research would represent a volume of data that would significantly exceed the framework of this paper, the authors have decided to present one bus route during peak traffic.

Based on the authors' own research regarding the quality of service in public transport, a starting hypothesis has been established: "It is possible to provide the desired quality of service in the segment of in-vehicle passenger comfort by eliminating headway irregularity, or reducing it to an adequate value."

MATERIALS AND METHODS

Capacity utilization on a route

The vehicle seat utilization coefficient, k_{ik} represents the capacity utilization on the most loaded section of the route, that is, at the characteristic section of the route. A characteristic route section is the inter-stop distance at which the maximum passenger flow, $q_{\max}$ occurs, meaning that the vehicle seat utilization coefficient represents the most unfavourable utilization of the transport capacity, Q, which can be expressd by the Equation 1:

$$k_{ik} = \frac{q_{\max}}{Q} \tag{1}$$

where $q_{\max}$ is the maximum passenger flow [distance/h] and Q is the transport capacity of the route [seats/h].

In the reference literature, the dominant opinion is that the vehicle seat utilization coefficient is provided as a norm for traffic peak periods and off-peak periods, where the recommended coefficient values are as follows:

(1) For peak periods $k_{ik} = 0.9$
(2) For off-peak periods $k_{ik} = 0.5 - 0.6$ (Banković, 1994).

The vehicle seat utilization coefficient, in the manner defined in the literature, represents the average hourly utilization of the existing number of seats on the most loaded section of the route. It is realistic to expect that the seat utilization on the most loaded route section will be different for each individual vehicle and each half-cycle route. Considering this fact, the vehicle seat utilization coefficient can serve to provide a general image of the quality of the offer in the segment of comfort. The passenger flow on a route presents the transport demands of the route, while the route's transport capacity expressed through the flow of seats represents the route's transport capabilities. The utilization coefficient of the route's transport capacity represents a ratio between the total performed transport work expressed in the number of passenger-kilometres, and the total input work expressed by the offered number of seat-kilometres (Banković, 1994):

$$k_i = \frac{q_1 \cdot l_1 + q_2 \cdot l_2 + \ldots + q_n \cdot l_n}{Q \cdot L} = \frac{\sum_{i=1}^{n} q_i \cdot l_i}{Q \cdot L} = \frac{q_{pr}}{Q} \quad (2)$$

Since the utilization coefficient of the route's transport capacity provides information on the average capacity utilization, it cannot be used for evaluating the transport service quality in the segment of comfort. Due to the previously mentioned, the comfort parameter analysis in this paper has been performed for each individual vehicle on one of the bus routes that were included in the research.

Methodology

The conducted research for this paper is presented at the afternoon peak period from 1 p.m. until 3:30 p.m. During this time period, 7 vehicles operated on the observed route with an equal headway of 8 min.

The research concept is structured into four units that include the following:

(1) Recording the departure times of all vehicles on bus stops along the route;
(2) Passengers accumulation per minute on every bus stop along the route;
(3) The number of passengers boarding and alighting the vehicles at every bus stop;
(4) A passenger survey regarding suitable routes, performed on all bus stops along the route.

The researches for the first three data groups covered the main set in the observed period. The passenger survey was performed on a randomly selected sample, and it included over 74% of all of the passengers arriving at the bus stops during the research period.

For the real recorded situation, the utilization capacity has been determined for each individual vehicle on each inter-stop distance along the bus route. Based on the research data, a simulation of the capacity utilization for equal headways was performed. A comparative analysis of the simulated and real-time capacity utilization was used to quantify the influence of headway irregularity on passenger comfort.

RESULTS

By analysing the obtained data, one can observe certain specificities in the unequal headways of vehicles along the route. The determined mean value of the realized headway in the first two half-cycles was around 9.0 min, while the projected headway for the research period was 8.0 min. Out of the total recorded 273 headways along the observed route, only 25 headways were realized according to the designed time schedule of 8.0 min, which percentagewise represents only 9.16%. All other headways demonstrated a smaller or larger deviation. A significant piece of data is that a large percentage, 29.67% out of the total number of recorded headways for this route, had a realized headway of up to 5 min, while 15.38% displayed headways of over 20 min. This clearly indicates a connection between the headways of consecutive vehicles, that is, a strong interaction of headway irregularity between the vehicles along the same route.

The presented data show that a certain number of vehicles were enormously late, which consequently lead to consecutive vehicles following each other at a shorter interval, or even vehicles catching up to each other along the same route. The connection between headways and capacity utilization will represent a key factor in the analysis of the observed problem.

Characteristics of passenger flows

Passenger accumulation was recorded every minute at all bus stops along the observed route, and on a basic set of 8,437 passengers (all passengers arriving at the bus stops during the research period were recorded).

The number of passengers boarding and alighting the buses in two half cycles was used to determine the passenger flow per vehicle at all inter-stop distances. The capacity utilization values were obtained as the ratio between the passenger flow per vehicle and the capacity of the vehicle units.

Considering the fact that on the investigated bus routes there are also other public transport routes, a public transport passenger survey was conducted to determine which routes suit the passengers for their given trips. The survey included 74.52% of the total number of passengers that arrived at the bus stops during the research periods, that is, 6,288 passengers. The obtained results showed that the investigated route suited only 19.79% of the respondents; both the investigated and some other route suited 35.45%; while 44.76% of the respondents claimed that the investigated route does not suit their needs. The survey data was expanded onto the

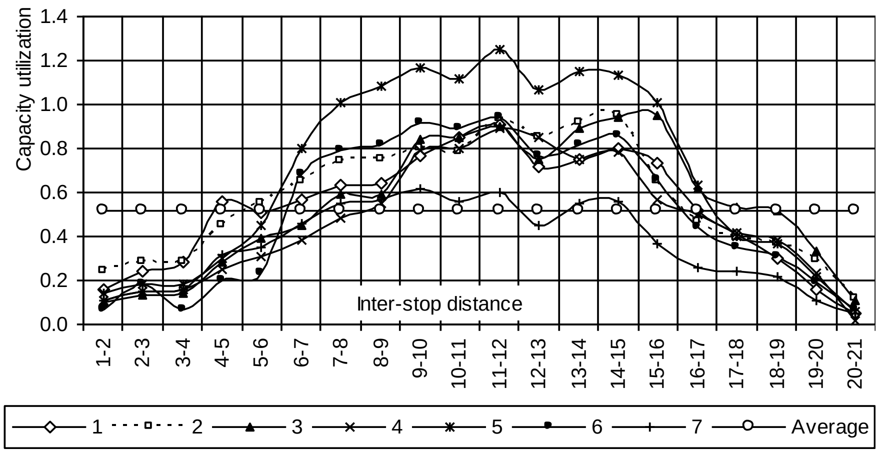

Figure 1. Capacity utilization for vehicles along the route in the first half-cycle.

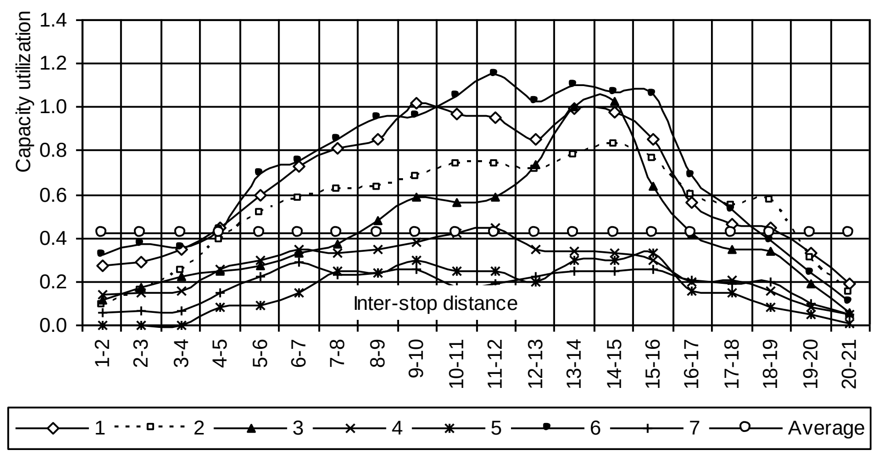

Figure 2. Capacity utilization for vehicles along the route in the second half-cycle.

main set, during a vehicle unit load simulation for equal headways.

The comfort parameters for every vehicle obtained in the research

In order to describe comfort, it is necessary to determine the parameters for evaluating the quality of a transport service. Since the utilization coefficient on a characteristic route section and the route capacity utilization coefficient cannot provide a clear picture on the in-vehicle comfort, this paper proposes parameters that can be used to draw conclusions when it comes to in-vehicle passenger comfort.

To describe comfort, this paper has selected the utilization coefficient for every inter-stop distance per vehicle, as well as the number of passengers (ridership) in the flow that has endured the intensity of the vehicle unit utilization for designed pre-chosen value.

The previously listed comfort parameters have been determined for the real recorded situation, while they were simulated for equal headways per minutes in the range between 5 and 12 min. For the real recorded situation, based on the data obtained by this research, the headways for each vehicle were determined, as well as the intensity of passenger boarding and alighting for each individual vehicle at every bus stop. From the data obtained in such a manner, real values of the passenger flows have been calculated for every inter-stop distance along the route. By providing a ratio between the obtained flow and the vehicle capacity expressed in the number of seats, data was obtained on the capacity utilization for every inter-station distance and every vehicle. Figures 1 and 2 present the previously described results.

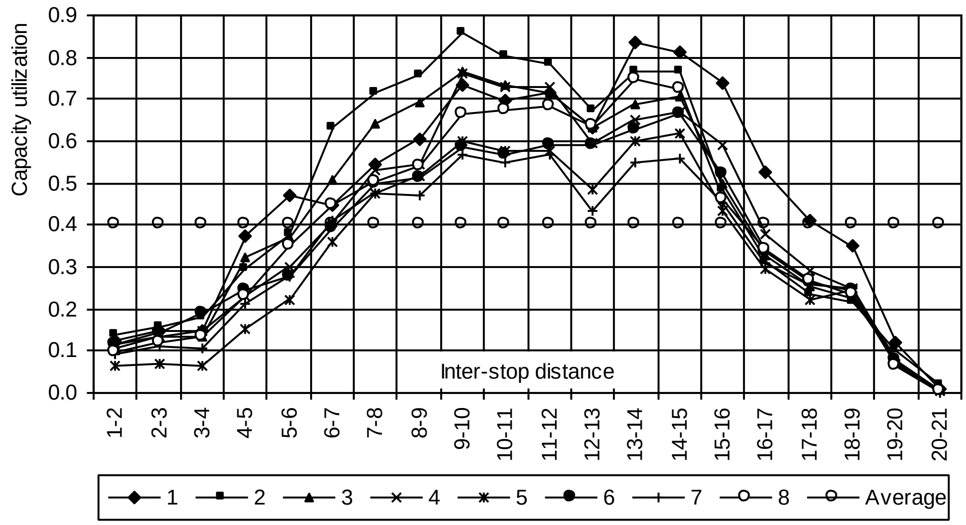

Figure 3. Simulated capacity utilization for equal headways of 8 min in the first half-cycle.

The obtained results show the following:

(1) The average value of the route capacity utilization for each of the half-cycles is satisfactory and equals 52%, that is, 42% of the offered capacities;
(2) The value of the capacity utilization coefficient on the characteristic sections of the route is satisfactory, and equals 0.91 and 0.68, respectively;
(3) An unsatisfactory realization of capacity utilization has been recorded for certain individual vehicles.

If one was to use the realized headways, number of vehicles per route and maximum flow values in order to evaluate the passenger comfort for the research period, or a period of 1 h, one will conclude that the comfort is satisfactory. The vehicle frequency is close to the planned, thus the route transport capacity is close to the planned one as well. Therefore, passenger comfort during the peak traffic period is not threatened. However, when observing the comfort for each individual vehicle, one can conclude that the threat of discomfort is clearly expressed, especially in vehicles arriving with longer headways than designed. An analysis of the capacity utilization values for every vehicle shows the existence of significant inequalities of vehicle capacity utilizations, observed according to inter-stop distances. Such large differences in capacity utilization are expected, because if a connection is made between the realized headway and the at-stop passenger accumulation and capacity utilization, it can be concluded that these values are interconnected.

Simulation of comfort parameters for each vehicle

The simulation was performed based on the data on at-stop passenger accumulation and the data obtained through the survey. The determination of at-stop passenger accumulation intensity was performed by the minute, so the number of passengers arriving at the bus stops is known for every minute. In the existing research conditions, the number of passengers boarding each individual vehicle on the route was determined, while a passenger survey was performed regarding the routes that the passengers find suitable. Based on these data, it was possible to simulate the passenger accumulation and the passenger boarding per vehicle, depending on the accumulation for any given headway. The simulation was performed for equal headways ranging between 5 and 12 min. Figures 3 and 4 show the vehicle unit capacity utilization for the, according to the time schedule, planned headway of 8 min. The performed simulation analysed the same comfort parameters as in the real recorded conditions, thus it is possible to perform their comparative analysis.

DISCUSSION

A comparative analysis of the real and simulated values of capacity utilization provides the conclusion that, for the conditions of equal headways, the obtained in-vehicle comfort is significantly more satisfactory than the one actually realized. The difference in capacity utilization of consecutive vehicles is extremely expressed in the conditions of headway irregularity, while with equal headways the different degree of utilization at the same stop is relatively small. Therefore, large differences in capacity utilization occur exclusively as a result of headway irregularity.

It has already been stated that in the real conditions,

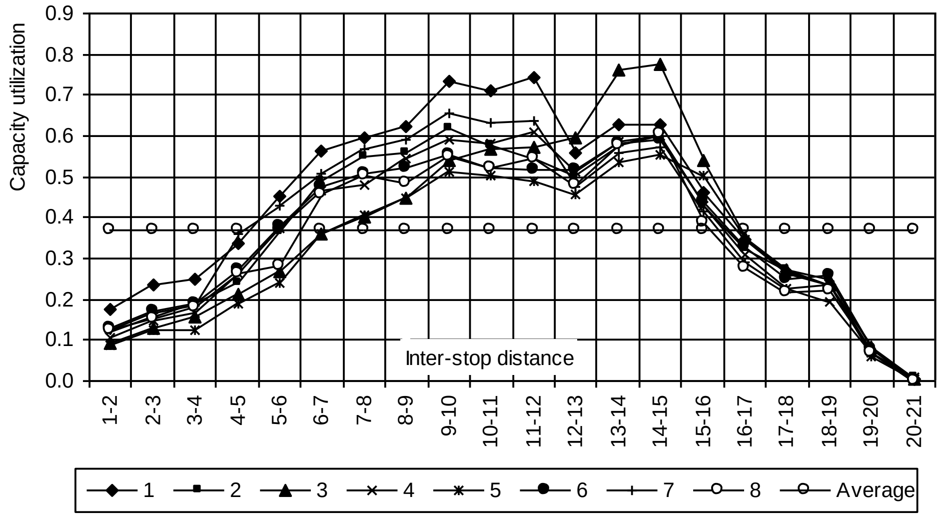

Figure 4. Simulated capacity utilization for equal headways of 8 min in the second half-cycle.

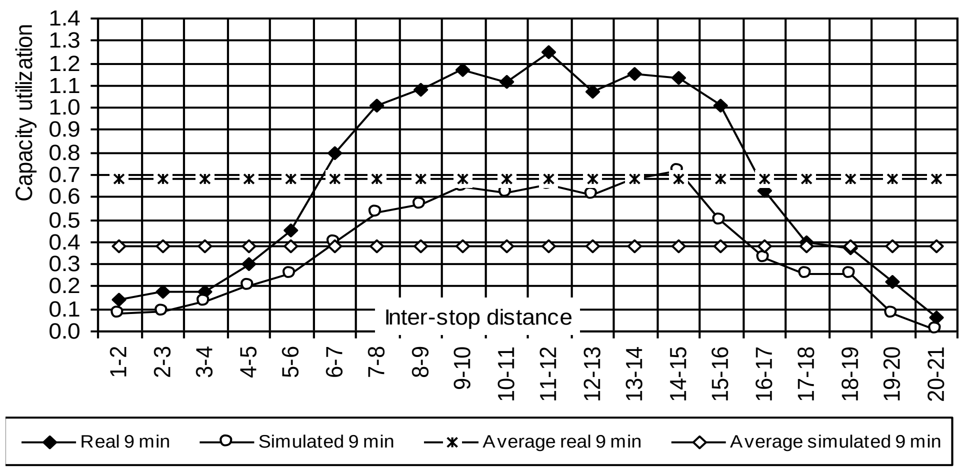

Figure 5. A comparative presentation of the vehicle capacity utilization in real and simulated conditions.

the determined mean value of the realized headways is 9.0 min. In order to perform a comparative analysis, a simulation of the capacity utilization of every vehicle along the route has been performed for this headway. Figure 5 shows the comparative presentation of the capacity utilization of the vehicle that had the largest capacity utilization in both the real and simulated working conditions.

It can be noted from the previous Figure 5 that the difference in capacity utilization is clearly expressed for the equal and irregular headways, which clearly shows the impact of headways irregularity on in-vehicle passenger comfort.

Vehicle capacity utilization is definitely the absolute indicator of comfort. However, other parameters (relative indicators) can also be applied to describe comfort, based on which an evaluation can be made of the quality of the transport service. It is very important to state which number of passengers in the flow are experiencing discomfort of certain intensity. Various capacity utilization thresholds can be established as discomfort intensities, depending on the set objectives during the design of the transport system.

The analysis includes discomfort intensities expressed

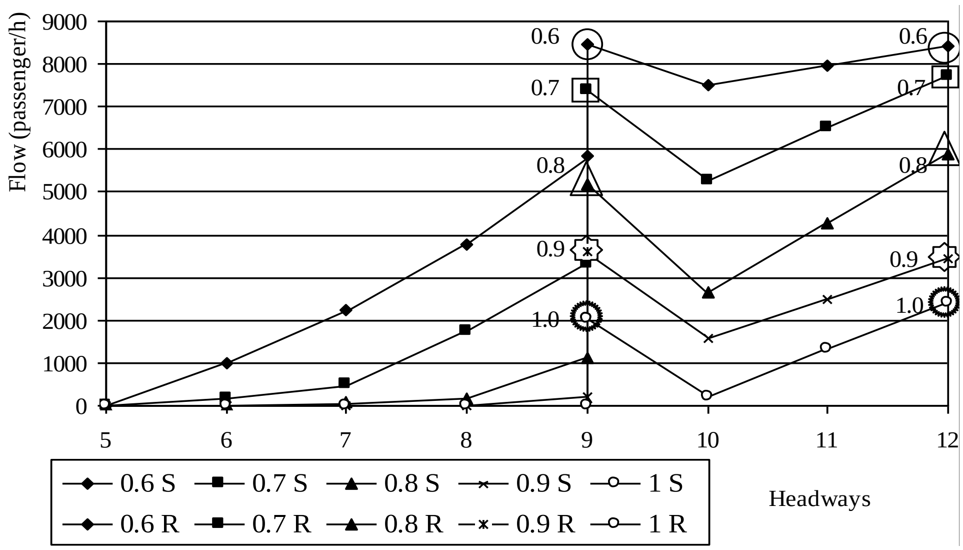

Figure 6. The number of passengers in the flow who are experiencing a certain discomfort intensity for the simulated headways.

Table 1. Cumulative number of passengers in vehicles for various degrees of capacity utilization, presented according to headways.

Capacity utilization	Simulated headways from 5 to 12 min								Recorded headway (9 min)
	5	6	7	8	9	10	11	12	
0.6	0	981	2253	3765	5855	7507	7959	8411	8441
0.7	0	160	496	1734	3327	5288	6491	7694	7371
0.8	0	0	88	182	1139	2672	4276	5879	5199
0.9	0	0	0	0	204	1570	2499	3428	3604
1.0	0	0	0	0	0	228	1317	2405	2036

in the capacity utilization of 0.6 as the lowest limit (maximum comfort) over to 1.0 as the highest limit (minimum comfort). Figure 6 presents the number of passengers in the flow who are experiencing discomfort (0.6, 0.7, 0.8, 0.9, and 1.0), for all of the simulated headways.

Figure 6 shows that for the stricter comfort conditions (lower capacity utilization), an increasing number of passengers experience discomfort. If the condition on the investigated route were set for the capacity utilization not to exceed 90% (0.9), Figure 6 clearly shows that the headways should not exceed 9 min. For the realized headway value of 10 min, 228 passengers in the flowbear a discomfort intensity of 1.0, this occurs only at one inter-stop distance, and in two out of the total of six vehicles operating on the route. Since the designed headway according to the existing conditions in the time schedule is 8 min, it is possible to conclude that the allowed headway deviation that could be tolerated, from the aspect of comfort, would be 2 min.

If the number of passengers bearing discomfort in the existing route conditions (Table 1) is compared to the simulated values, the consequences that the headway irregularities have on capacity utilization can be clearly seen. Approximately, the same number of passengers experienced the same intensity of discomfort in the existing conditions when the mean realized headway was 9 min (when 7 vehicles operated on the route), and in the simulated results for a headway of 12 min (with 5 vehicles operating on the route). From the aspect of capacity utilization, the investigated route would achieve approximately the same level of transport service quality as in the existing conditions, if there were 5 vehicles operating with equal headways of 12 min.

The average capacity utilization in the real and simulated conditions is similar, as expected. The completed analyses demonstrated that the comfort parameters for each individual vehicle significantly differ.

Therefore, it can be concluded that the determined mean comfort parameter values cannot represent a reliable manner for making conclusions regarding passenger comfort, nor can they be used to evaluate the quality of the transport service. In order to evaluate quality, it is necessary to determine certain parameters for every vehicle and for every individual inter-stop distance. In such a manner, the transport service quality, from the aspect of comfort, would be expressed at the level of each individual trip instead of the average values.

Conclusion

On the basis of the illustrated analyses, it can be concluded that there is a high correlation between the realized headways and vehicle capacity utilizations, that is, the capacity utilization is greatly conditioned by the intensity of the headway irregularity.

According to the real analytical comfort analyses, and based on the selected parameters, the following conclusions can be derived:

(1) The capacity utilization coefficient on a characteristic route section cannot fully demonstrate the comfort situation on a route;
(2) The mean values of comfort parameters cannot serve to evaluate comfort either, thus it is necessary to observe the transport service quality in this domain for every trip individually;
(3) The comfort parameter values differ for each individual vehicle;
(4) The diversity of comfort parameters is mostly conditioned by headway irregularity and passenger flow characteristics;
(5) Changes in comfort parameters that are conditioned by passenger flows are predictable and can be compensated by the flow instability factor at rush hour, but only in the case of equal headways;
(6) Changes in comfort parameters in the case of headway deviations are unpredictable, and they cannot be compensated without limiting the intensity of the headway irregularity;
(7) The sensitivity of the comfort parameter change is high even for small headway irregularities;
(8) In the case of equal headways, the change in comfort parameters occurs exclusively as the result of passenger flow irregularities.

The described analytical procedure of evaluating comfort as a transport service quality parameter, demonstrates the existence of a very large difference between the planned service quality, from the aspect of comfort, and the one realized. This paper has shown that this difference occurs due to vehicle headway irregularities. This paper demonstrates that the quality of the transport service in the domain of comfort can be significantly improved by decreasing the headway irregularities along a route. This fact confirms the starting hypothesis of the paper, which states that it is possible to provide a desired quality of the service in the segment of in-vehicle passenger comfort, by eliminating headway irregularities, or by reducing them to an adequate value.

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