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## EVALUATION OF QUALITY PUBLIC TRANSPORT CRITERIA IN TERMS OF PASSENGER SATISFACTION

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This article presents a detailed description and explanation of the methodology for evaluation of quality public transport criteria in terms of passenger satisfaction. In 2011-2014 this method was applied in an assessment of passenger satisfaction with the urban public transport system in Ostrava. In order to assess passengers' satisfaction, traffic survey has been chosen utilizing questionnaire and student inquirers. The results achieved by application of the method have been processed to evaluate time accessibility criteria of a public transport system. Time accessibility criteria group (accessibility of stops, waiting for a connection and transferability in the public transport network) evaluates physical and psychological aspects of the passenger during his arrival at the station, while leaving the station, in the course of waiting for a connection and during the transfer. The time accessibility criteria are considered the most significant criteria that impact a passenger's decision to utilise public transport options.

**Keywords:** Public transport quality evaluation, passengers' satisfaction, time accessibility criteria, accessibility of stops, waiting for connection, transferability in transport network

### 1. Introduction

Providing high-quality transportation services to passengers travelling on all types of national routes as well as in urban public transport is one of the objectives of Czech national passenger transportation policy (Ministry of Transport CR, 2014). The public transport is used as a leisure transportation mode in the Czech Republic as well. The objective is to supply the passengers in the Czech Republic with quality public transport services as well as to make it efficient competition to private car transportation (Olivkova, 2009).

Until recently, Czech Republic lacked both compilation and verification of customer satisfaction evaluation methods as well as studies dealing with status and characteristics of public transport and its users. This is caused mainly by absent theoretical processing of these issues because there were no methods and approaches defined to characterize and evaluate the quality from passengers' perspective in a complex way. The approach applied until now was that individual transport organizations conducted their own independent quality surveys and had no option of using complex methodology for comprehensive evaluation of offered services' quality.

These reasons resulted in proposal of a method for complex journey and journey alternatives' quality evaluation from the passengers' perspective in 2009 (Olivkova, 2009). This methodology has been certified by the Ministry of Transport of the Czech Republic and it can be used for quality evaluation of the public transport services offered in the Czech Republic.

Experimental verification of practical applicability of the proposed method and questionnaire was carried out by complex journey and journey alternatives quality evaluation in the public transport system in the city of Ostrava that was based on the traffic survey made in a selected group of passengers (Olivkova, 2009). The traffic survey of passengers (urban public transport users in Ostrava) took place from April to September 2008; the passengers in all Ostrava city districts were questioned. The respondents were approached at their workplaces and they filled the questionnaire in the presence of trained person (i.e. myself or a student of the Institute of Transport at the VŠB - TU Ostrava) who supervised correct and complete filling of the questionnaire. The questionnaire was filled by total of 635 respondents.

Public transportation quality evaluation methodology has been expanded in the following years with the methodology for passengers' satisfaction assessment and urban public transport quality evaluation. Supplementing the quality evaluation methodology with a measurement of passenger satisfaction emerged from the necessity to be able to objectively describe, compare, and interpret facts collected in a transportation survey.

The methodology was applied in practice in an actual case study of the urban public transport system in Ostrava. Novel findings from practical application of this methodology are processed in this paper by evaluation of time accessibility criteria in urban public transport system.

## 2. Methodology for evaluation of quality criteria

The situation arises while evaluating urban public transport quality criteria that part of the criteria is of quantitative nature (quantitative criteria values are expressed in the metric scale) and another part is of qualitative nature (qualitative criteria values are expressed in ordinal metric scale) (Moreno and Fidélis and Ramos, 2014). Metrization of ordinal scales, i.e. assigning points from five-point scale as a tool for assessing passengers' attitudes and opinions, is the way to achieve possibilities of statistic evaluation, common for metric scales, while using ordinal scales (Carlsson and Fuller, 1996). Each quality criterion level is precisely defined by verbal expression (descriptor) for each degree of the five-point scale. By assigning a point from five-point scale, a passenger determines to what extent a given criterion meets his/her expectations. Nominal values of the qualitative criteria are thus expressed subjectively in the scale values based on passengers' attitudes. Subjectively expressed attitudes can then be statistically objectified (Fotr and Píšek, 1986).

### 2.1. Evaluation of quality criteria

Evaluation of quality criteria of urban public transport is divided into these steps:

- Definition of the domain of the partial utility function

Criterion nominal values interval  $x_i = \langle x_{i \min}; x_{i \max} \rangle$  is the definition domain of the partial criterion utility function. The nominal values have been set objectively based on quantitative data (in metric type of scale) stated by the passengers in the survey. Extreme points of this interval can be labelled  $x_{i \min}$  and  $x_{i \max}$  where:

- $x_{i \min}$  is the lowest (minimal) value of the  $i^{\text{th}}$  criterion
- $x_{i \max}$  is the highest (maximal) value of the  $i^{\text{th}}$  criterion

- Graphical representation of the values detected in the survey using the dot diagram

The passengers assign utility value  $u_i = 1, u_i = 0.75, u_i = 0.5, u_i = 0.25$  or  $u_i = 0$  to certain nominal value of  $x_i$  criterion by means of criterion quality rating equal to 1, 2, 3, 4 or 5 where 1 is the best score and 5 the worst one. Corresponding pairs  $(x_i, u_i(x_i))$  constitute coordinates of the points that can be represented graphically by means of the dot diagram – the nominal criterion values are plotted on the x-axis and corresponding average utility values on the y-axis.

- Determination of the regression functions type (partial criterion utility function) and setting its parameters using least-squares method

The least-squares method can detect regression (approximation) function whose sum of variances of observed (detected by the survey) values and calculated (theoretical)  $y_i'$  values is the lowest possible.

The least-squares method consists in search for regression (approximation) function for which the relation is true (Meloun and Militký, 2002):

$$\sum_{i=1}^n (y_i - y_i')^2 = \min \quad (1)$$

The proposed approach to criteria evaluation will be presented by evaluating time accessibility criteria. The procedure is as follows:

The dot diagram that graphically represents the criteria values detected in the survey (see fig. 2, 3, 4) allows us to conclude that the dependence is quadratic. The  $u_i(x_i)$  function will be monotonically decreasing in its definition domain  $x_i = \langle x_{i \min}; x_{i \max} \rangle$ . Two different types of the  $u_i(x_i)$  function behavior can be expected, i.e. convex (fig. 1 - type a) or concave utility function (fig. 1 - type c).

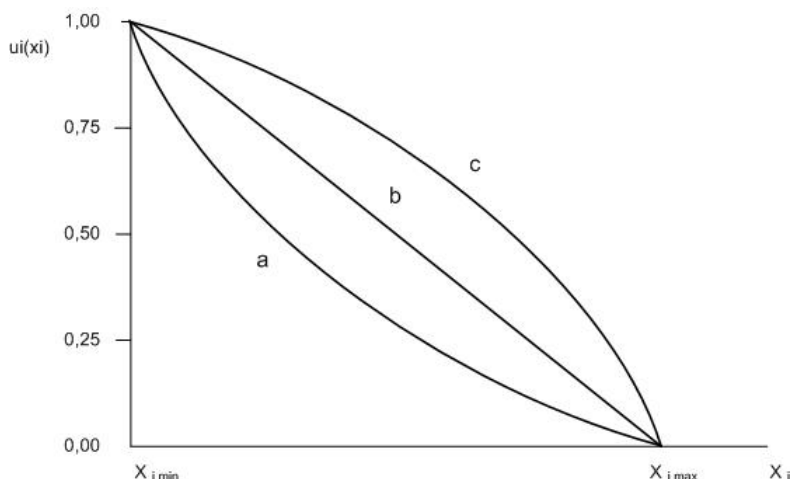


Figure 1. Types of partial utility function  $u_i(x_i)$  behavior (a-convex, b-linear, c-concave)

The values detected in the survey can be thus approximated by parabola (quadratic function, second order polynomial) with the equation  $y = f(x) = ax^2 + bx + c$ . Estimates of its parameters can be obtained by means of the least-squares method, i.e. by using the condition that the sum of variances  $S$  is minimal (Meloun and Militký, 2002):

$$S(a, b, c) = \sum_{i=1}^n (y_i - ax_i^2 - bx_i - c)^2 = \min \tag{2}$$

For this sum to be minimal, its partial derivatives have to be equal to zero:

$$\frac{\partial S}{\partial a} = \frac{\partial S}{\partial b} = \frac{\partial S}{\partial c} = 0 \tag{3}$$

System of linear equations can be derived by the given procedure:

$$\begin{aligned} a \sum_{i=1}^n x_i^4 + b \sum_{i=1}^n x_i^3 + c \sum_{i=1}^n x_i^2 &= \sum_{i=1}^n y_i x_i^2 \\ a \sum_{i=1}^n x_i^3 + b \sum_{i=1}^n x_i^2 + c \sum_{i=1}^n x_i &= \sum_{i=1}^n y_i x_i \\ a \sum_{i=1}^n x_i^2 + b \sum_{i=1}^n x_i + c \cdot n &= \sum_{i=1}^n y_i \end{aligned} \tag{4}$$

If these  $S_m = \sum_{i=1}^n x_i^m$  ( $S_0 = n$ ) are set, a, b, c parameters estimates are:

$$a = \frac{(S_1 S_3 - S_2^2) \sum_{i=1}^n y_i + (S_1 S_2 - n S_3) \sum_{i=1}^n y_i x_i + (n S_2 - S_1^2) \sum_{i=1}^n y_i x_i^2}{\Delta}$$

$$b = \frac{(S_2 S_3 - S_1 S_4) \sum_{i=1}^n y_i + (n S_4 - S_2^2) \sum_{i=1}^n y_i x_i + (S_1 S_2 - n S_3) \sum_{i=1}^n y_i x_i^2}{\Delta}$$

$$c = \frac{(S_2 S_4 - S_3^2) \sum_{i=1}^n y_i + (S_2 S_3 - S_1 S_4) \sum_{i=1}^n y_i x_i + (S_1 S_3 - S_2^2) \sum_{i=1}^n y_i x_i^2}{\Delta} \quad (5)$$

$$\text{Where } \Delta = n (S_2 S_4 - S_3^2) + S_1 (S_2 S_3 - S_1 S_4) + S_2 (S_1 S_3 - S_2^2)$$

Suitability of the regression function can be detected by the **determination index**. Determination index indicates what part of the variability of the dependent variable is explained by the model chosen (Meloun and Militký, 2002):

$$I^2 = \frac{\sum_{i=1}^n (y_i' - \bar{y})^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (6)$$

Determination index (labelled R<sup>2</sup> in Microsoft Excel) takes values in the closed interval <0, 1>.

- Division of the partial criterion utility function's definition domain into nominal value intervals and determination of limit nominal values.

Definition domain of the function can be divided into five partial intervals of nominal values by transformation of criterion quality score by means of partial  $u_i(x_i)$  utility function. The  $u_i(x_i)$  function also provides limit nominal values  $x_i^1, x_i^{0.75}, x_i^{0.5}, x_i^{0.25}, x_i^0$  for whom the  $u_i(x_i)$  shall take the values  $u_i(x_i^1) = 1, u_i(x_i^{0.75}) = 0.75, u_i(x_i^{0.5}) = 0.5, u_i(x_i^{0.25}) = 0.25$  a  $u_i(x_i^0) = 0$ .

## 2.2. Assessment of Passengers' Satisfaction

In order to assess passengers' satisfaction, traffic survey has been chosen utilizing questionnaire and student inquirers. The reasons for this were significant reduction of costs for the entire survey, its fast execution as well as requested high rate of respondents' feedback (high return of questionnaires). This decision has made an impact on the choice of parent population. All current public transport users older than 15 years have been selected as parent population which includes those individuals that can make to certain extent individual decision on the mean of transport they choose. This type of survey thus pre-excludes the possibility to learn about the requirements of potential or occasional passengers.

The selection of respondents in different city neighbourhoods has been made based on proportional representation according to socio-demographic quota characteristics of the city, with reference to similar assessments and our own survey experience. The inquirers will be assigned exact survey area as well as gender, age and level of education quotas. The sample size of 500 and more statistical units is generally recommended based on results and assessments of already executed studies with quota sampling (Nenadál and Petříková and Hutyra and Balcarová, 2004).

Inquiring of responders at a workplace (at school) was chosen specifically for passengers' satisfaction assessment because of the time necessary to fill the questionnaire. Extent of the questionnaire corresponds with inquiry period of c. 10 minutes while maintaining a comprehensive view of the urban public transport services. It can be realized by timetable analysis that most of the passengers are available at stops for 5 minutes at most when travelling to work (to school) during peak hours which is insufficient for correct and complete filling of the questionnaire. On-board inquiring is virtually impossible during rush hours. In these cases, passengers' motivation to fill the questionnaire would decrease as well as the amount of respondents and thus quality of the survey itself would be reduced.

On the other hand, compression of the questionnaire content would be to the detriment of the evaluation itself and assessment goals. As already mentioned, regular public transport satisfaction assessment practically does not take place and even impacts of individual quality components to overall quality are not known. Therefore the extent of inquired urban public transport quality components has to be maintained in the questionnaire.

The traffic survey was focused on the residents of the city and surroundings who use urban public transport means of transport for travelling to work (school). Hence it was not presented to residents of other

cities, or users of an integrated transport system who use other transport systems of public passenger transport (bus and rail passenger transport) to travel from their residence and who switch to the urban public transport system during journey. Focus of the survey on urban public transport passengers' satisfaction evaluation is one reason for this. The other one is possible reduction of objectivity in the urban public transport quality criteria evaluation caused by the use of another transport system during journey. All transport modes operated by the public transport company (bus, tram, trolley) and their combinations - in the case of transfer – are represented.

Although all the results given in this chapter have been acquired by application of the method between 2011 and 2014, derived conclusions and recommendations can be considered even today because some of the findings presented below exhibit the same trend and they basically have not changed since the first traffic survey in 2009 (Olivkova, 2009).

### 3. Results of application of methodology

The traffic survey of the passengers' satisfaction was organized in years 2011-2014. The survey involved 2120 respondents together. The first survey in 2011 consists of 540 respondents, 521 respondents in 2012, 543 respondents in 2013 and 516 respondents in 2014.

#### 3.1. Evaluation of respondent data

Evaluation of respondent data is depicted in Table 1, which presents both absolute and relative frequencies, expressed in percent, both for the individual years 2011-2014 as well as overall.

**Table 1.** Evaluation of respondent data

Resp. data	Class	Absolute frequency [person]					Relative frequency [%]				
		2011	2012	2013	2014	sum	2011	2012	2013	2014	average
sex	man	226	234	216	214	890	42	45	40	41	42
	woman	314	287	327	302	1230	58	55	60	59	58
age	till 26	130	115	152	139	530	24	22	28	27	25
	26-44	221	224	185	175	806	41	43	34	34	38
	45-59	157	135	152	165	615	29	26	28	32	29
	from 60	32	47	54	36	170	6	9	10	7	8
level of education	elementary	113	78	60	72	318	21	15	11	14	15
	secondary	346	401	413	387	1548	64	77	76	75	73
	higher	81	42	71	57	254	15	8	13	11	12
frequency of use of urban public transport system	daily	378	328	353	356	1420	70	63	65	69	67
	3-4 times a week	86	104	114	77	382	16	20	21	15	18
	1-2 times a week	54	47	43	67	212	10	9	8	13	10
	less	22	42	33	15	106	4	8	6	3	5

The proposed approach to criteria evaluation will be presented by evaluating time accessibility criteria. The time accessibility of urban public transport system expresses quality of public transport services in the city. Time accessibility criteria group (accessibility of stops, waiting for a connection and transferability in the public transport network) evaluated in this article relates to passengers' comfort outside of a vehicle. It evaluates physical and psychological aspects of the passenger during his arrival at the station, while leaving the station, in the course of waiting for a connection and during the transfer. These criteria are affected by both the level of traffic organization and management as well as the transport route and transportation network of urban public transport lines.

### 3.2. Accessibility of stops criterion evaluation

Each trip by public transport vehicle starts and ends with walking. Continuity of walking paths and accesses therefore has to be logical, as short as possible, well-arranged and as safe as possible. Urban public transport stops accessibility is determined spatially by the distance and in time by the accessibility period of stops and stations upon entering public transport system. Walking distance is the criterion whose adjustment affects citizens' access to public transport. While setting limit for walking distance to a stop or more accurately to public transportation vehicle, it is necessary to consider the fact that the time spent walking is part of the time spent to reach a destination. This criterion can be characterized as time accessibility of stops.

In order to determine stops' accessibility objectively, it is necessary to consider particular data on the components of walking time (from the journey origin to the departure stop and from the arrival stop to the journey destination) acquired from the passengers in the survey.

The passengers have assigned utility value  $u_1 = \langle 1 ; 0 \rangle$  to a given nominal value of walking time  $x_1$  through criterion quality score from the scale 1, 2, 3, 4, 5. Corresponding pairs  $(x_1, u_1(x_1))$  create coordinates of the points plotted in Figure 2 (nominal walking time values and corresponding average utility values are plotted on the x-axis and y-axis, respectively). The values detected in the survey can be preferably approximated by parabola (quadratic function, second order polynomial).

Partial utility function of the stop accessibility criterion  $u_1(x_1)$  assumes the form:

$$u_1(x_1) = -0.0018x_1^2 + 0.011x_1 + 0.9706 \tag{7}$$

Determination index value  $R^2 = 0.9483$  which indicates good point interlay.

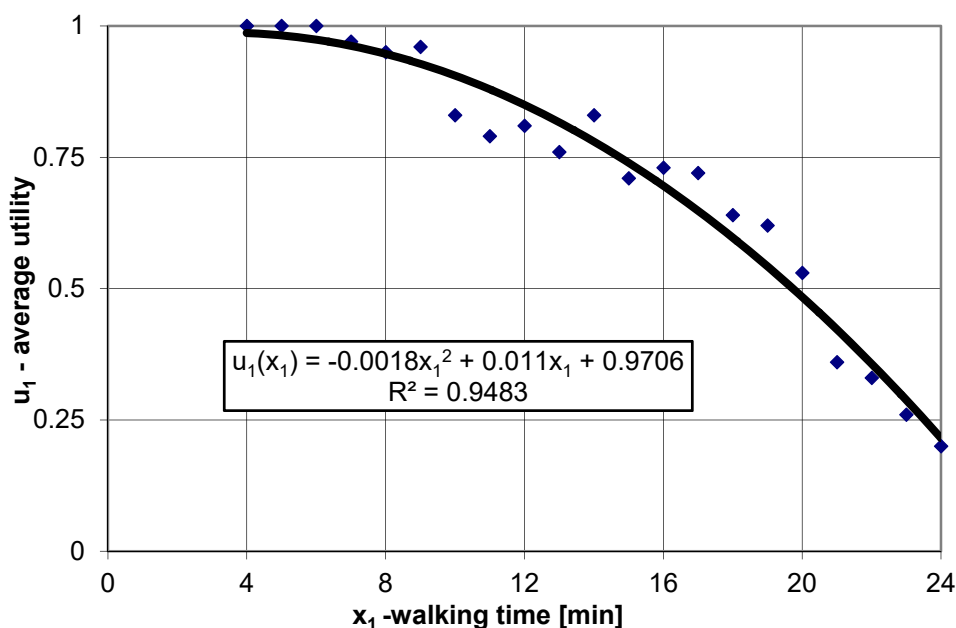


Figure 2. Partial utility function of the stop accessibility criterion  $u_1(x_1)$

The function  $u_1(x_1)$  decreases monotonously in its definition domain  $x_1 = \langle 4; 24 \rangle$  from the functional value  $u_1(x_1^1) = 1$  to the functional value  $u_1(x_1^0) = 0.20$ , graph of the function is concave. Stop accessibility is thus the criterion of decreasing preference, identic increments of the criterion's nominal values bring ever lower benefit to respondents.

Definition domain of the function  $u_1(x_1)$  has been divided to five intervals based on the score assigned by respondents. The  $u_1(x_1)$  function also provides limit values  $x_1^1, x_1^{0.75}, x_1^{0.5}, x_1^{0.25}$ , for whom  $u_1(x_1)$  takes values  $u_1(x_1^1) = 1, u_1(x_1^{0.75}) = 0.75, u_1(x_1^{0.5}) = 0.5, u_1(x_1^{0.25}) = 0.25$ .

The values listed in Table 2 indicate how the passengers evaluates the time spent walking (from their home to departure stop and from arrival stop to workplace) on their journey to work. Passengers have the highest benefit from the stop accessibility of up to 10 minutes, they evaluate walking up to 17 minutes as still "favourable". Extension of walking time to 21 minutes is evaluated in a neutral way as "neither favourable nor unfavourable". Further extension of walking time is unacceptable for the passengers. The

table 2 makes it clear that within the definition domain  $x_1 = <4; 24>$ , it is impossible to transform score 5 (very unfavorable) into interval and value  $x_1^0$  for which  $u_1(x_1)$  shall take value  $u_1(x_1^0) = 0$ . These values are outside of the definition domain detected by the survey.

**Table 2.** Transformation of stop accessibility criterion quality score into intervals and limit values  $x_1$  by means of partial utility function  $u_1(x_1)$

Score	Interval $x_1$ [min]	Limit value $x_1$ [min]	
1	very favourable	4-10	4
2	favourable	11-17	15
3	neither favourable nor unfavourable	18-21	19
4	unfavourable	22-24	23
5	very unfavourable	-	-

The values listed in this table indicate that passengers do not evaluate the time spent by walking overly negatively. Increments of the nominal values at the beginning of the domain bring lower declines of benefit to passengers than increments of the nominal values close to the value  $x_{1max} = 24$  minutes. That can be caused by the fact that the passengers do not consider the walking time to be a part of a journey. They apprehend coming to departure stop and leaving arrival stop to be start and finish of the journey, respectively (eventually even entering and exiting vehicle).

### 3.3. Waiting for connection criterion evaluation

Time of waiting for a connection is measured from passenger’s arrival to urban public transport stop to departure of requested connection vehicle. Average time of waiting for a connection depends on division of passenger’s arrival to a stop and on transportation periodicity, reliability and punctuality. The passengers who travel regularly to work already know the departures set in a timetable and they adjust their arrival to the stop of requested connection in order to reduce time of waiting for it.

Waiting for connection criterion (time of waiting for a connection) has been evaluated by the passengers from perspective of the time spent waiting at a stop on the way to work. Nominal values  $x_2$  have been set based on waiting time data obtained from passengers through the questionnaire.

The passengers have assigned utility value  $u_2 = <1 ; 0>$  to a given nominal value of waiting time  $x_2$  through criterion quality score from the scale 1, 2, 3, 4, 5. Corresponding pairs  $(x_2, u_2(x_2))$  create coordinates of the points plotted in Figure 3 (nominal waiting time values and corresponding average utility values are plotted on the x-axis and y-axis, respectively). The values detected in the survey can be preferably approximated by parabola (quadratic function, second order polynomial).

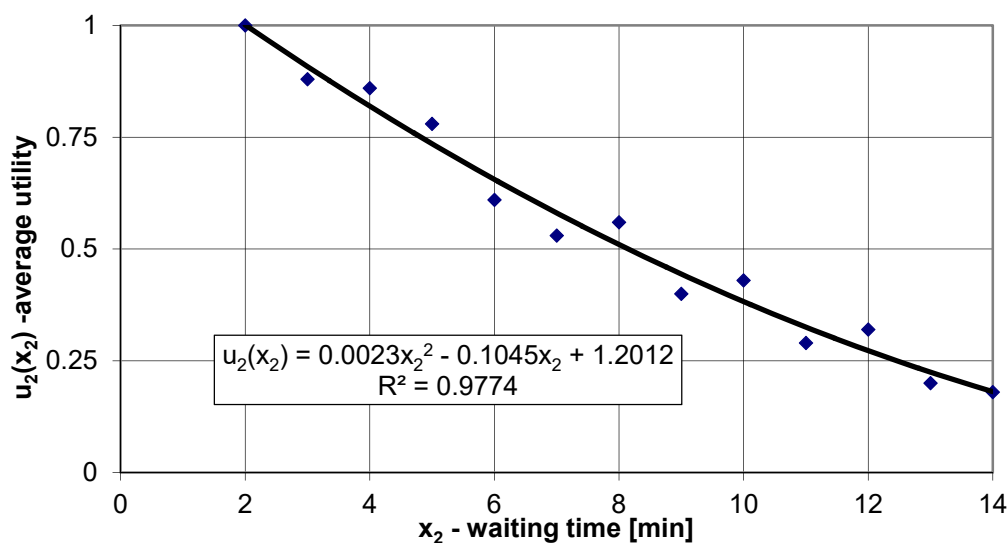


Figure 3. Partial utility function of the waiting for connection criterion  $u_2(x_2)$

Partial utility function of the waiting for connection criterion  $u_2(x_2)$  assumes the form:

$$u_2(x_2) = -0.0023x_2^2 - 0.1045x_2 + 1.2012 \tag{8}$$

Determination index value  $R^2 = 0.9774$  which indicates good point interlay.

The function  $u_2(x_2)$  decreases monotonously in its definition domain  $x_2 = \langle 2; 14 \rangle$  from the functional value  $u_2(x_2^1) = 1$  to the functional value  $u_2(x_2) = 0.18$ , graph of the function is convex. Waiting for a connection is thus the criterion of decreasing preference, identic increments of the criterion's nominal values bring ever lower benefit declines to respondents.

Definition domain of the function  $u_2(x_2)$  has been divided to four intervals based on the score assigned by respondents. The  $u_2(x_2)$  function also provides limit values  $x_2^1, x_2^{0.75}, x_2^{0.5}$  and  $x_2^{0.25}$  for whom  $u_2(x_2)$  takes values  $u_2(x_2^1) = 1, u_2(x_2^{0.75}) = 0.75, u_2(x_2^{0.5}) = 0.5$  and  $u_2(x_2^{0.25}) = 0.25$ .

**Table 3.** Transformation of waiting for connection criterion quality score into intervals and limit values  $x_2$  by means of partial utility function  $u_2(x_2)$

Score	Interval $x_2$ [min]	Limit value $x_2$ [min]	
1	very favourable	2 - 3	2
2	favourable	4 - 6	5
3	neither favourable nor unfavourable	7 - 10	8
4	unfavourable	11 - 14	13
5	very unfavourable	-	-

The values listed in table 3 indicate how the passengers evaluate the time spent waiting at a stop. They evaluate waiting for a connection for up to 3 minutes as very favourable and up to 6 minutes as favourable. Waiting time of up to 10 minutes is still evaluated as neutral, i.e. neither favourable nor unfavourable. Longer waiting time is no more acceptable for the passengers. The table 3 makes it clear that within the definition domain  $x_2 = \langle 2; 14 \rangle$ , it is impossible to transform score 5 (very unfavorable) into interval and value  $x_2^0$  for which  $u_2(x_2)$  shall take value  $u_2(x_2^0) = 0$ . These values are outside of the definition domain detected by the survey.

The passengers evaluate the time spent by waiting at a stop rather negatively. Increments of the nominal values at the beginning of the domain bring higher declines of benefit to passengers than increments of the nominal values at the end of the domain. This can be caused by the fact that the passengers who travel regularly to work already know departures set in a timetable and they arrive to a stop prior to scheduled departure. Therefore they do not expect the time of waiting for a connection to increase.

### 3.4. Transferability in transport network criterion evaluation

Transfer time is the sum of walking time from exiting to boarding stop of the lines to transfer between and of time of waiting for following connection. Necessity to transfer from one vehicle to another in order to reach destination of a journey reduces the quality of transportation. This disadvantage has to be minimized as transfers among various transportation systems cannot be avoided. Good time and space coordination of the transportation system is the precondition necessary for transfer time minimization. The transfer time is affected by adherence to the schedule, i.e. by transportation periodicity, reliability and punctuality.

However, total journey time, i.e. door to door time consumption, remains the basic criterion in this case; in contrast, the total journey time can be reduced by transfer to other means of transport. In order to prevent negative transferability evaluation by passengers, it is desirable to arrange the transfer relations suitably (in both time and space) and to design the route network optimally to avoid multiple transfers that are evaluated very negatively by the passengers.

The passengers have evaluated the transferability in urban public transport network criterion from the perspective of the transfer time on their way to work. Nominal values  $x_3$  have been set based on transfer time data (sum of walking time in transfer between the stops where one gets off and on and time of waiting for following connection) obtained from passengers through the questionnaire.

The passengers have assigned utility value  $u_3 = \langle 1 ; 0 \rangle$  to a given nominal value of transfer time  $x_3$  through criterion quality score from the scale 1, 2, 3, 4, 5. Corresponding pairs  $(x_3, u_3(x_3))$  create coordinates of the points plotted in Figure 4 (nominal transfer time values and corresponding average utility values are



plotted on the x-axis and y-axis, respectively). The values detected in the survey can be preferably approximated by parabola (quadratic function, second order polynomial).

Partial utility function of the transferability in the transport network criterion  $u_3(x_3)$  assumes the form:

$$u_3(x_3) = -0.0018x_3^2 - 0.0092x_3 + 1.0291 \tag{9}$$

Determination index value  $R^2 = 0.9658$  which indicates good point interlay.

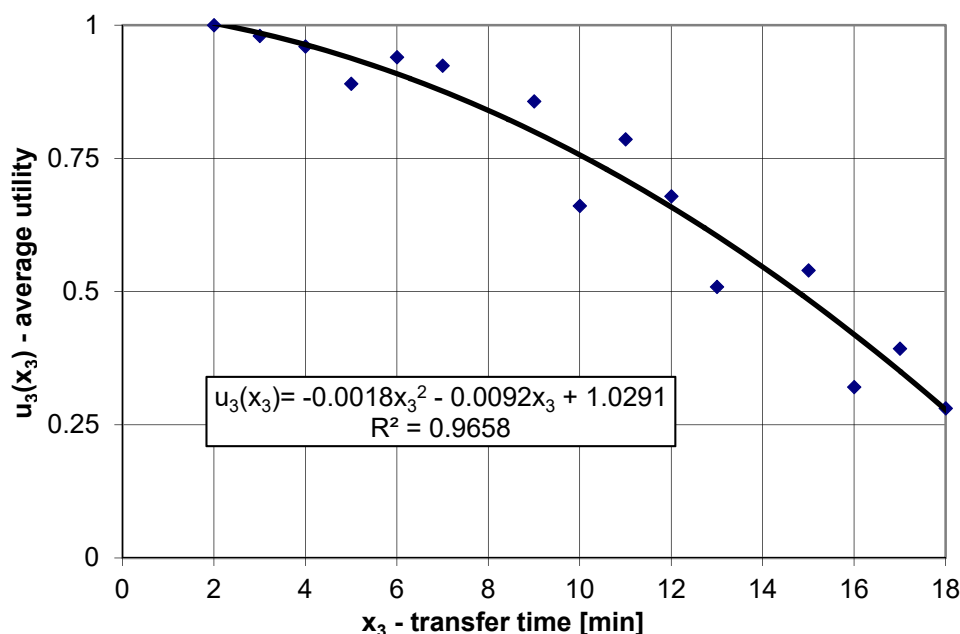


Figure 4. Partial utility function of the transferability in the public transport network criterion  $u_3(x_3)$

The function  $u_3(x_3)$  decreases monotonously in its definition domain  $x_3 = \langle 2; 18 \rangle$  from the functional value  $u_3(x_3^1) = 1$  to the functional value  $u_3(x_3) = 0.26$ , graph of the function is concave. Transferability in the public transport network is thus the criterion of decreasing preference, identic increments of the criterion's nominal values bring ever lower benefit to respondents.

Definition domain of the function  $u_3(x_3)$  has been divided to four intervals based on the score assigned by respondents. The  $u_3(x_3)$  function also provides limit values  $x_3^1, x_3^{0.75}, x_3^{0.5}$  and  $x_3^{0.25}$  for whom  $u_3(x_3)$  takes values  $u_3(x_3^1) = 1, u_3(x_3^{0.75}) = 0.75, u_3(x_3^{0.5}) = 0.5$  and  $u_3(x_3^{0.25}) = 0.25$ .

More detailed results are listed in table 4. Definition domain of the function  $u_3(x_3)$  has been divided to four intervals based on the score assigned by respondents. The  $u_3(x_3)$  function also provides limit values  $x_3^1, x_3^{0.75}, x_3^{0.5}$  and  $x_3^{0.25}$  for whom  $u_3(x_3)$  takes values  $u_3(x_3^1) = 1, u_3(x_3^{0.75}) = 0.75, u_3(x_3^{0.5}) = 0.5$  and  $u_3(x_3^{0.25}) = 0.25$ .

**Table 4.** Transformation of transferability in the transportation network criterion quality score into intervals and limit values  $x_3$  by means of partial utility function  $u_3(x_3)$

Score	Interval $x_3$ [min]	Limit value $x_3$ [min]
1 very favourable	2-6	2
2 favourable	7-12	10
3 neither favourable nor unfavourable	13-16	13
4 unfavourable	17-18	18
5 very unfavourable	-	-

The values listed in table 4 indicate how the passengers evaluate the need to transfer from one vehicle to another during journey. Passengers have the highest benefit from the transfer time of up to 6 minutes, they evaluate journey with transfer time of up to 12 minutes as still favourable. The limit value of passenger satisfaction  $x_3^{0.5}$  for which the partial utility function of the transferability in the urban public transport network criterion  $u_3(x_3)$  takes value  $u_3(x_3^{0.5}) = 0,5$  is  $x_3 = 13$  minutes. The table 4 makes it clear that within the definition domain  $x_3 = \langle 2; 18 \rangle$ , it is impossible to transform score 5 (very unfavorable) into interval and value  $x_3^0$  for which  $u_3(x_3)$  shall take value  $u_3(x_3^0) = 0$ . These values are outside of the definition domain detected by the survey.

The values listed in table 4 indicate how the passengers evaluate the time spent in transfers. Increments of the nominal values at the beginning of the domain bring lower declines of benefit to passengers than increments of the nominal values close to the value  $x_{3\max} = 18$  minutes. This can be caused by the fact that the passengers are not bothered if they have to transfer from one vehicle to another once during a journey given that the time loss is not too big. Multiple transfers when the time loss also increases, however, are evaluated by the passengers as unfavourable.

#### 4. Conclusions

The paper deals with the issues of urban public transport quality evaluation. It focuses especially on description of quality evaluation method for urban public transport and on experimental verification of the proposed method by evaluating time accessibility criteria.

In order to evaluate the proposed method, the results of the conducted survey are of importance as they prove it to be suitable for practical application in the field of evaluating public transport quality and passengers' satisfaction because it allows:

- To identify passengers' expectations related to public transport quality,
- To identify existing quality levels,
- To reveal the causes for passengers' dissatisfaction,
- To provide information and data for quality improvement projects,
- To deliver quantified outputs with the possibility of trends evaluation.

The main advantages of the proposed method comprise the possibility to present the basic results of the survey. Although all the results given in this article have been acquired by application of the methodology in Ostrava, it can be recommend using this methodology for evaluation of quality public transport criteria in other cities.

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