Regional Public Transportation Services Modelling

Model usluga regionalnog javnog transporta

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Summary

This paper has discussed the issue of public transportation services. These services are essential part of social welfare and their providing is accepted in all developed economics without any doubts. The discussion pops up once their extent is doubted. The aim of this paper is to introduce the model describing the extent of public transport services as the support needed for the decision about the structure and extent of public transport services. There hasn't ben such a general model described yet. The idea of general model describing the public transport services that could be used as the comparation base for comparing chosen regions hasn't been realized yet due to the regional differences in characteristics of certain villages, regions and their public transport services. The output of the analysis is the advanced model constituted of multidimensional linear regression function that serves to describe the public transport services in chosen regions.

KEY WORDS

regional public transport services
public transport services model
regression analysis

Sažetak

Ovaj članak razmatra pitanje usluga javnog prijevoza. Te su usluge bitan dio društvene dobrobiti i njihovo je osiguravanje prihvaćeno u svim razvijenim ekonomijama bez ikakve sumnje. Diskusija se nastavlja kada je u pitanju opseg. Cilj je ovog rada uvesti model koji će opisati opseg usluga javnog transporta kao podršku potrebnu za odluke i strukture i razmjera usluga javnog prijevoza. Takav općeniti model još nije bio opisan. Ideja generalnog modela kojim se opisuju usluge javnog transporta koji bi se mogao upotrijebiti kao usporedna baza za poredbu odabranih regija, još nije ostvarena zbog regionalnih različitosti i karakteristika određenih sela, regija i njihovih usluga javnog prijevoza. Ishod je analize napredni model koji se sastoji od multidimenzionalne linearne funkcije regresije i služi da bi se opisale usluge javnog prijevoza u odabranim regijama.

KLJUČNE RIJEČI

regionalne usluge javnog prijevoza
model usluga javnog prijevoza
analiza regresije

INTRODUCTION / *Uvod*

The public transport services are organized in every region of the European Union and all the competent authorities are subsidizing the operation of transport connections to fulfill the transport needs of their inhabitants. Although the system directly influences the life conditions in the region and in the same moment it is significant cost of the regional government, there is no general model describing the extent of public transport services, which could be used as a benchmarking tool.

The issue of public transport services in the Czech Republic is legally defined in the Act No. 194/2010 Coll., on passenger public transport services and on amendment to some acts. This Act defines the public transportation services as essential part of the regional harmonious development as the part of sustainability and specifies the extent of public transport services that shall provide transportation in all weekdays primarily to schools and education institutions, to the public authority bodies, to the employment places, to health care institutions providing primary health care and to satisfy cultural, recreational and social needs, including transport back.

The pioneer work in the issue of regional public transport in the Czech Republic is the study introduced by Bulíček and Mojžíš. "The mathematical expression of this relation (in the form of functions) is able to be reached in the way of multiple linear regression based on results of the survey." (Bulíček, Mojžíš 2009). This idea of multiple linear regression model is adopted into the presented model. The model is designed to evaluate the sufficiency or insufficiency of public transport in certain region and to enable the comparison among regions. The presented model identifies the key elements determining the public transport services in Czech regions.

The question of the sustainability is widely discussed especially in the last decade, the transport problems connected with unlimited increasing of car ownership and the needed infrastructure are more relevant lately. "Transport authorities, especially those in developing countries where rising income stimulate increased car ownership rates, are often concerned with maintaining or increasing levels of public transport use. Therefore, the ability to identify clients at risk of abandoning the system can be valuable for remedial measures, allowing for more focused quality improvements." The travelers are very sensitive to any kind of change in public transport, the careful preparation respecting all the needs of the travelers is needed. The model discussed in this paper could be accepted as a benchmarking tool to find out the harmonious equilibrium. The remedy of previous nonsensitive changes can last long time. All the problematic is described in Bass, Donoso, Munizaga (2011).

The evaluation process that would measure the quality of public transport services is complicated as the other ones when involving interactions among soft factors. These factors are set of social, political, demographical and economic variables. "Operational extent of regional public passenger transport is depended on character of solved region, especially on the number of inhabitants. Number of passengers is also able to be influenced by some other socio-economic characteristics like structure of industry, unemployment rate or average income of inhabitants in the region." (Bulíček, Mojžíš 2009).

This paper is focused on the problematic of public transport services from the social point of view, the aspect of fulfilling transport needs on sufficient basis is respected when creating the model. The other analysis of transport services don't usually discuss the problem from this point of view, the usual ones are the technological, mathematical, for example fuzzy mathematic applications introduced by Ralević, Gladović, Pamučar, Dobrodolac, Đorović (2012) or a model of moving collectives interaction by Regirer, Smirnov, Chenchik (2007). The combination of technological-mathematical issue usually leads to the vehicle routing problem, the routing problem applied on the region is discussed in Pacheco, Caballero, Laguna, Molina (2013), the literature review in area of this tasks is done by Drexl (2012). The other point of view is economical one, this one is closer to the discussed model and it is on the opposite side, the cost reducing very often is the criteria function. Nice overview of economic aspects is done by Ljungberg (2010). The social issue isn't discussed deeply enough and the question of sufficiency of certain level of public transport services isn't solved.

The issue of social aspect in public transport comes more into the focus when discussing the urban public transport, but the need of deeper involvement of these factors is generally accepted. "There is still room for improvement in aspects of spatial coverage and for a greater focus on the factors which explain the social need for transport which are not usually considered within planning." (Jaramillo, Lizárraga, Grindlay 2012). The sustainability of public transport services must include the social sustainability too. "Public transport and government agencies must balance the sometimes competing objectives of economic and social sustainability. In general, more frequent, higher quality, and financially efficient public transport also helps achieve social sustainability. However, in some circumstances financial efficiency and social equity might not be fully compatible." (Buehler, Pucher 2011).

THE MODEL / *Model*

The idea of the model is based on the presumption that the number of public transport connections serving certain unit

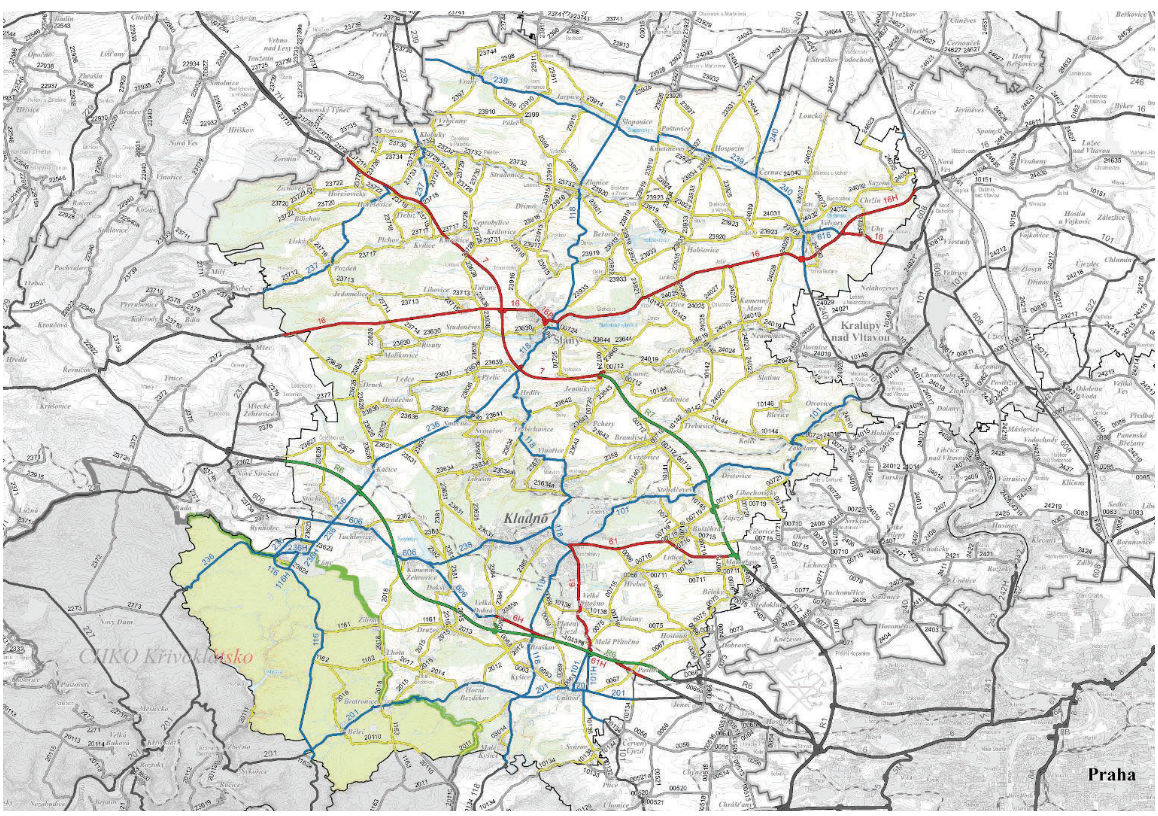

Figure 1 Kladno region (area of the region colored)
Slika 1. Karta oblasti Kladnog (područje u boji)

Source: Road and Motorway Directorate of the Czech Republic (2014) http://www.rsd.cz/sdb_intranet/sdb/img/kraje/st.png

Table 1. Critical values of parameters b_0 to b_{12} for t-test

Tablica 1 Kritične vrijednosti parametara b_0 do b_{12} za t-testiranje

Parameter ***Parametar***	***Shortened description of the variable with its assigned parameter*** ***Skraćeni opis varijable sa njenim pripadajućim parametrom***	***Critical value*** ***Kritična vrijednost***
b_0	Absolute parameter of the regression model	8,633
b_1	x_1 – population	17,364
b_2	x_2 – distance to a municipality with an extended authority	2,212
b_3	x_3 – sum of distances to Kladno and Slaný	- 4,978
b_4	x_4 – amount of units with population of 4 000 within 5 km distance	3,549
b_5	x_5 – amount of units with population of 2 000 within 5 km distance	3,117
b_6	x_6 – station or stop on a nationwide or a regional railway line	5,540
b_7	x_7 – primary school	2,437
b_8	x_8 – road with intensity over 10 000 vehicles / day	5,742
b_9	x_9 – road with intensity over 5 000 vehicles / day	2,669
b_{10}	x_{10} – intersection of frequented roads	9,045
b_{11}	x_{11} – exit from a motorway or an expressway	4,601
b_{12}	x_{12} – radial road from Prague to a district city	12,668

Source: author

during weekdays can be used as the mark of level of public transportation services. Every unit represents residential units (villages, independent parts of villages) according to the parcelling of the Czech Statistical Office. The statistical methods are used for calibrating and validating of the model. The calibration is proceeded on real data from the district of Kladno in Středočeský region. The model consists of a multiple linear regression function generally describable as:

$$y=b_0+b_j \cdot x_j$$
$$\text{for } j=1,2,\ldots 12.$$

Multiple linear regression function with one dependent variable y and 12 independent variables x_1 to x_{12} is the base of the model. The independent variables x_1 to x_{12} represent particular factors where a statistically significant influence was proven on the amount of transport service connections in the observed units on a weekday.

The dependent variable y is an estimation of above described regression function. The estimation is counted for the amount of all public transport service connections in all stops and stations in certain unit's area during a weekday (typical weekday without the holiday restrictions). The traffic mode isn't important for the estimation, all the public transport connections (buses as well as train connections) have the same value. The quality of the estimation is compared to the real situation in Kladno district; data of the amount of bus connections and trains were obtained from valid timetables on 31st October 2013[1].

[1] The exception is the unit of Čabárna, particularly road III/2388, since the closure of its part in a section of Velvarská street in Kladno-Hnidousy due to sewerage construction and the unit of Netřeby, particularly street III/00716 that is closed for bus transport in a section between Netřeby and Dolany due to a damage by floods in June 2013. In these sections, timetables valid before the restrictions were used.

The coefficients b_0 to b_{12} are bounded with certain independent variable x_1 to x_{12} and their value is the outcome of the model. The coefficient b_0 symbolises the basic amount of public transport connections for imaginary unit when all the other variables are equalled to zero.

The independent variable x_1 is given by the populations of certain unit. Czech Statistical Office's Statistical lexicon of municipalities 2013 issued by 31st October 2013 is used to get the exact number of inhabitants in every unit.

Next variables x_2 to x_5 are based on the geographic location of the unit in relation to other units in the region. The presumption says that closer location to the regional centre brings stronger connection to that centre. Distances of the observed unit and two centres of the region (two largest units and the only municipalities with extended authority in this region), Kladno and Slaný, determine the independent variables x_2 and x_3. The hypothesis of stronger connection on the routes between the largest municipalities of the region than between comparable cities on interregional basis sets the variable x_3 as the sum of distances to Kladno and Slaný from observed unit. Another assumption says that more public transport connections are provided in densely inhabited areas, so the information about the density of population surrounding the observed unit is added in next variables. Variable x_4 determines the number of units with population of 2 000 to 3 999 (Buštěhrad, Libušín, Tuchlovice, Unhošť, Velvary, Vinařice) in the distance to 5 km. Variable x_5 determines the number of units with population of 4 000 and more (Nové Strašecí, Stochov and Kralupy nad Vltavou in Mělník district, too) in the same distance.

The precondition that rail transport results in a higher level of public transport services includes the artificial variable x_6. This variable equals 1 if there was a railway station or a stop on a nationwide or a regional railway line in the unit's area that serves to a regular passenger transport[2]. If there was not, then $x_6 = 0$.

Similar precondition is applied on artificial variable x_7. This variable deals with the existence of primary school in the unit's area. The value of the variable reaches 1 if there was primary school in that area. The value equals zero in other case. The idea is based on the hypothesis that the children from other units have to travel with public transport to the school located in the unit's area.

Block of variables x_8 to x_{11} follows. The existing road network in the region determines the values of these variables in the same way like the existence of the station or stop on the railway line in the unit's area. The most important factors are the frequented roads and the intersections of frequented roads. Artificial variables x_8 and x_9 are focused on trafic intensity on roads going through the unit. These variables equal 1 in case that there is a road with traffic intensity higher than 10 000 vehicles / 24 hours, or with traffic intensity from 5 000 to 9 999 vehicles / 24 hours, respectively. Artificial variables x_{10} and x_{11} are focused on important road intersections. Variable x_{10} equals 1, if there was an intersection of two roads in the unit or in its immediate proximity and the traffic intensity on the less frequented road exceeded 2 000 vehicles / 24 hours and it was not a motorway or an expressway. Variable x_{11} equals 1 if there was an exit from a motorway or an expressway in the unit's area or in its immediate proximity. In case a motorway exit is situated in an area between units, it is added to the closer one.

The specification of the region is represented by the artificial variable x_{12} The region Středočeský surrounds the capital city of Prague and Prague is also the real regional centre despite its location outside the region. All transport to Prague goes through the region and these connections go also through the area of district of Kladno. The variable equals 1 for units situated on a main road from a city in region Středočeský with population exceeding 15 000 to Prague. In case of Kladno district, the affected cities are Kladno and Slaný, and furthermore the city of Rakovník (in its own district of Rakovník), out of which a road to Prague is placed through the area of Kladno district.

After a software calculation was made, based on data for 162 units that create the area of Kladno district, following regression function was determined:

$$y=44{,}422\,019+0{,}021\,741\cdot x_1+1{,}415\,214\cdot x_2-1{,}485\,283\cdot x_3+16{,}375\,680\cdot x_4+7{,}531\,673\cdot x_5+20{,}473\,253\cdot x_6+8{,}219\,191\cdot x_7+30{,}650\,374\cdot x_8+12{,}125\,150\cdot x_9+63{,}128\,034\cdot x_{10}+25{,}928\,550\cdot x_{11}+75{,}469\,785\cdot x_{12}$$
where:

where:

y - estimate of the amount of connections creating the transport service in the observed unit on a working day [-],

x_1 - population of the unit [-],

x_2 - distance to a municipality with an extended authority the unit belong to [km],

x_3 - sum of distances to the two largest municipalities in the region [km],

x_4 - amount of units with population of more than 4 000 in distance up to 5 km from a unit except for units observed in factor x_3 [-],

x_5 - amount of units with population of more than 2 000 and less than 4 000 in distance up to 5 km from the unit [-],

x_6 - artificial variable representing the existence of a railway station or a stop on a railway line with regular service [-],

x_7 - artificial variable representing the existence of at least one primary school in the unit [-],

x_8 - artificial variable representing the existence of a road with intensity exceeding 10 000 vehicles / 24 hours going through the unit [-],

x_9 - artificial variable representing the existence of a road with intensity from 5 000 to 9 999 vehicles / 24 hours going through the unit [-],

x_{10} - artificial variable representing the existence of an intersection of main roads in the unit [-],

x_{11} - artificial variable representing the existence of a motorway exit or an expressway exit in the area of the unit [-],

x_{12} - artificial variable representing the location of the unit on a radial road heading out of Prague serving as a connection of a city with population exceeding 15 000 and Prague [-].

Confidence of the model appears to be sufficient; regression function describes the reality very well; confidence value R^2 equals 94,628 %.

Several factors, that were supposed to have a significant influence on the amount of public transport connections provided in the observed municipality, were put under the test. The original set included more variables, but only 12 of them proved their statistically important influence on the transport service level.

At all of the parameters of the final regression function, it is reached such t-test criterion values that in the confidence level of 95 %, their influence on y variable is proven. Critical value of student distribution for 95% level of confidence and number of observation higher than 120 is $t_{0,975;>120} = 1{,}96$. Parameters b_0 to b_{12} equal the values of the t-test testing criterion presented in the table No. 1.

The confidence of the model is proven by the Fishers complete F-test, too. The critical value gained from the Fisher distribution tables for the 95% level of confidence is as following: $F_{0,95\,(12;>120)} = 2{,}185$. Testing criterion equals 218,702 902.

Parameter values of artificial variables clearly show that the level of transport service of a unit is higher if they are located in more densely populated area near to larger municipalities. Even more important is their location in relation to the transport infrastructure, place at a frequented road or intersection results in an important increase of amount of connections serving in the unit. Equally, the location at a railway station or a stop results in an increase of 20 connections on a working day in comparison to similar municipalities without location at a railway line.

The highest parameter values are at variable x_{12}. Connections to the capital city of Prague are in the observed district very intense and the location of a municipality on a way from an important centre to Prague results in an increase of 75 connections on a working day.

Factors resulting out of distribution of transport infrastructure can have a higher influence on the final transport service than factors resulting out of transport service definition

[2] Railway lines 095 and 121 are not regarded as railway lines with regular passenger service in the area of Kladno district. Operation on the line 095 in section Zlonice – Straškov is muted on a long term basis and its near cease is expected; nowadays, there are only 2 pairs of trains in operation during the working days. Railway line 121 serves for Cyclotrain „Cyklohráček" operation in range of 2 pairs of trains on Saturdays, Sundays and national holidays from the end of March to the end of October.

Table 2. Model applications for 40 chosen units
Tabela 2 Primjena modela za 40 odabranih jedinica

The name of the unit Naziv jedinice	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	y	Real amount of connections Stvarni iznos veza
Bakov	00 104	5	23	0	0	0	0	0	0	0	0	0	019,632	026
Blahotice	23	3	18	0	0	0	0	0	1	0	0	0	34,565	21
Budihostice	118	15	39	0	1	0	0	0	0	0	0	0	17,821	3
Buštěhrad	02 863	7	21	0	0	0	1	1	0	0	0	1	199,743	175
Byseň	50	4	20	0	0	0	0	0	0	0	0	0	21,443	24
Čabárna	43	5	17	0	1	0	0	0	0	0	0	0	34,701	27
Čeradice	64	11	33	0	0	0	0	0	0	0	0	0	12,366	17
Drnov	88	6	19	0	0	0	0	0	0	0	0	0	26,627	15
Horní Kamenice	46	13	38	0	0	0	0	0	0	0	0	0	7,379	19
Hospozín	00 503	12	35	0	0	0	0	0	0	0	0	0	020,355	027
Hospozínek	34	16	29	0	0	0	0	0	0	0	0	0	24,731	0
Kačice	01 244	11	23	1	1	1	1	0	1	0	0	0	117,599	109
Kamenné Žehrovice	01 729	7	24	0	1	1	1	0	1	1	0	1	243,212	232
Kokovice	112	14	39	0	0	0	0	0	0	0	0	0	8,744	9
Kováry	104	13	29	0	0	0	0	0	0	0	0	0	22,008	26
Křovice	66	9	30	0	0	0	0	0	0	0	0	0	14,035	6
Kutrovice	106	8	27	0	0	0	0	1	0	0	0	0	48,596	52
Kvílice	80	9	29	0	0	0	1	0	0	0	0	0	24,030	27
Lány	01 765	13	30	1	1	0	1	0	0	0	0	0	088,761	088
Libochovičky	58	11	26	0	1	0	0	0	0	0	0	0	30,165	32
Libušín-u dolu	70	7	18	0	1	0	0	0	1	0	0	0	48,765	69
Líský	85	14	38	0	0	0	0	0	0	0	0	0	9,642	10
Lisovice	83	8	29	0	0	0	0	0	0	0	0	0	14,468	9
Lotouš	46	6	23	0	0	0	0	1	0	0	0	0	50,416	37
Luníkov	57	7	24	0	0	0	0	0	1	0	0	0	32,081	21
Makotřasy	00 373	9	25	0	1	0	0	1	0	0	1	1	167,752	167
Nabdín	78	11	33	0	1	0	0	0	0	0	0	0	20,203	15
Netovice	39	3	14	0	0	0	0	0	0	0	0	0	28,701	12
Netřeby	38	5	23	0	1	0	0	0	0	0	0	0	25,680	14
Nová Studnice	92	12	24	0	0	0	0	0	0	0	0	0	27,758	21
Nové Uhy	89	15	38	0	1	0	0	0	0	0	0	0	18,676	13
Osluchov	74	8	24	0	0	0	0	0	0	0	0	0	21,706	17
Otruby	90	3	19	0	0	0	0	0	0	0	0	0	22,432	9
Otvovice	00 793	17	34	1	0	1	1	0	0	0	0	0	080,290	030
Skůry	87	9	29	0	0	0	0	0	0	0	0	0	15,977	20
Slaný[4]	13 986	0	13	0	0	1	1	0	1	1	0	1	508,600	511
Stradonice	119	10	33	0	0	0	0	0	0	0	0	0	12,168	9
Tmáň	100	8	29	0	0	0	0	0	0	0	0	0	14,859	18
Vítov	77	5	21	0	0	0	0	0	1	0	0	0	34,113	21
Želevčice	115	4	21	0	0	0	0	0	0	0	0	0	21,399	43

Source: author

by law. Many municipalities can exploit their advantageous location in relation to transport infrastructure that ensures a lot higher transport service level for them than what they would have reached if there would only had applied the transport service by the definition of law.

The model confidently predicts the amount of transport service connections in the evaluated unit after the input of

[3] The unit of Slaný is understood as the sum of the amounts of inhabitants in two city parts of Slaný – the main part Slaný (Czech Statistical Office code 40207 9) and the city part of Kvíček (Czech Statistical Office code 30416 5).

necessary variables, determines the amount of transport service connections for 139 out of 162 evaluated units with deviation ± 20 connections, for 97 out of them with deviation ± 10 connections. I show the demonstration of use of the model for randomly selected 40 units in the table no. 2.

The model works for the above mentioned units with different rate of reliability, for most of them it works very reliable. The biggest difference between the real situation and the situation predicted in the model in the whole set of analysed units appears in the information to the unit of Otvovice, which is also described in the Table no. 2. This unit is located on the eastern border of the district of Kladno. Otvovice is served only by the railway transport on the regional line no. 093 that provides the connection between Kladno and Kralupy nad Vltavou[4]. Although the amount of inhabitants in Otvovice reaches almost 800 and the village is located less than 5 kilometres from Kralupy nad Vltavou with the population of 18.472 inhabitant, the village is served only by 30 trains per weekday. The model expects about 80 public transport connections for this kind of village. The assumption for so significant difference is the location of the unit on the edge of the district of Kladno, the northern-east end of the unit forms the border with the district of Mělník. Another reason is the strong link to the mentioned city of Kralupy nad Vltavou, which is local centre of that area. The cross border interregional transport is unfortunately common problem. Otvovice is located in the valley of Zákolanský stream, this valley creates the natural corridor for the railroad no. 093 as well as for the road no. II/101. The only other road in the unit is the road no. III/24010 which ended in Otvovice by the main road no. II/101, this road leads outside the district of Kladno in the direction to Holubice (the district of Prague-West). There is no other road connection to the area of district of Kladno because of the rugged terrain. The variable representing the location of the unit on the edge of the district as well as the one representing geographically rugged terrains were put into the original set of variables. The t-testing of statistical influence on y variable hasn't been proven.

CONCLUSION / *Zaključak*

The paper has presented the creation of public transportation services model calibrated for the district of Kladno. Although only the first use of that model has been presented in the paper, the model describes the real situation with statistically significant reliability. The differences have been given by the imperfection of the model as well as by the soft factors related to the decisions about the extent of the public transportation services. The model with 100% of reliability is purely hypothetic possibility. The differences are the discussion topics for the future and they may lead to the optimization of the public transport services in the described district of Kladno. Every difference should be analyzed individually and the higher ones have to be discussed with the competent authorities and the explanation which can lead to the development of the model or the remedy of the public transport system should be done.

The next development of the model is possible in précising to describe the real situation more reliable, the proper information about the population density or including of walking distance that shall be the next steps. The model is only descriptive in the present-time form, but next development, calibration and validation could lead to its use as the normative model. The including of economic factors on the level of certain regions can lead to the development of effective tool for benchmarking of public transport services in different regions.

[4] The bus services were stopped on 1st July 2005 when the operation on bus line no. 220006 Kladno – Zákolany – Kralupy nad Vltavou was stopped.

REFERENCE / *Literatura*

[1] Bass P, Donoso P, Munizaga M. (2011) A model to assess public transport demand stability. Transportation Res. Part a-Policy and Practice 45(8): 755–764.

[2] Buehler R, Pucher J (2011) Making public transport financially sustainable. Transport Policy 18(1): 126–138.

[3] Buková B, Brumerčíková E (2011) Vplyvy globalizácie na prepravný trh. Horizonty železničnej dopravy 2011 = Horizons of railway transport 2011 (Žilinská univerzita, Žilina, Slovakia), 32–35.

[4] Bulíček J, Mojžíš V (2009) Regional Public Passenger Transport Service in Macroscopic Transport Models. Scientific Papers of the University of Pardubice, Series B 15(1): 117–127.

[5] Drexl M (2012) Synchronization in Vehicle Routing—A Survey of VRPs with Multiple Synchronization Constraints. Transportation Science 46(3): 297–316.

[6] Häll CH (2011) Modeling and Simulation of Dial-a-Ride and Integrated Public Transport Services. Dissertation, Linköping University, Institute of Technology.

[7] Jaramillo C, Lizárraga C, Grindlay AL (2012): Spatial disparity in transport social needs and public transport provision in Santiago de Cali (Colombia). Journal of Transport Geography 24(1): 340–357.

[8] Kampf R, Lizbetin J, Lizbetinova L (2012) Requirements of a transport system user. Komunikacie 14(4): 106–108.

[9] Ljungberg A (2010) Local public transport on the basis of social economic criteria. Research in Transportation Economics 29(1): 339–345.

[10] Melichar V, Drahotský I (2007) Support of Transport Services in the Czech Republic. Scientific Papers of the University of Pardubice, Series B 13(1): 47–58.

[11] Pacheco J, Caballero M, Laguna R, Molina J (2013) Bi-Objective Bus Routing: An Application to School Buses in Rural Areas. Transportation Science 47(3): 397–411.

[12] Ralević P, Gladović P, Pamučar D, Dobrodolac M, Đorović B (2012) Mathematical Model for Evaluating the Effectiveness of Urban and Suburban Public Transport. Metalurgia International 17(11): 194–202.

[13] Regirer SA, Smirnov NN, Chenchik AE (2007) Mathematical Model of Moving Collectives Interaction: Public Transport and Passengers. Automation and Remote Control 68(7): 1225–1238.

[14] Sui Y, Shao F, Sun R, Li S (2012) Space evolution model and empirical analysis of an urban public transport network. Physica A 391(14): 3708–3717.

[15] Stopka O, Kampf R, Kolář J, Kubásková I, Savage Ch (2014) Draft guidelines for the allocation of public logistics centres of international importance. Komunikacie 16(2): 14–19.

[16] Tirachini A, Hensher DA, Jara-Diaz SR (2010) Restating modal investment priority with an improved model for public transport analysis. Transportation Res. Part E-Logistics and Transportation Review 46(6): 1148–1168.

[17] Trpišovský M, Rýc T, Průša P (2013) Villages Public Transportation Service Modelling. International Masaryk Conference For Ph.D. Students And Young Researchers. (MAGNANIMITAS, Hradec Králové, Czech Republic), 765–774.

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