THE CONCEPT OF COMPUTER APPLICATION SUPPORTING THE WORK OF THE ORGANIZERS OF RAILWAY TRANSPORT AND RAILWAY UNDERTAKINGS IN THE CONSTRUCTION OF TRAINS TIMETABLE

GOŁĘBIOWSKI Piotr[1], JACYNA Marianna[2]

[1]*Warsaw University of Technology, Faculty of Transport, Warsaw, Poland, EU*
[1]*pgolebiowski@wt.pw.edu.pl*, [2]*maja@wt.pw.edu.pl*

Abstract

Every year a new annual timetable is being prepared. Under the work on its preparation the organizers of transport together with railway undertakings determine the shape of the transport offer, which will be best suited to the needs of passengers. A multitude of factors which should be taken into account can cause some mistakes. The article presents the concept of computer application supporting the work of the rail transport offer construction and its visualization on the graphic trains timetable. The paper presents the mathematical model of transport offer and its display on the graphic timetable. The article also shows example of using the application to construct the timetable for the selected railway line.

Keywords: Computer application, construction of trains timetable, organizers of railway transport

1. INTRODUCTION

Organization of railway traffic is a very important issue, because it allows for arranging of trains displacement in time and space on the railway network. Its introduction guarantee movement in a timely, fast, safe and secure manner. Expression of the correct method of its preparation is the timetable, which should meet the needs of different groups of stakeholders. On the development of timetable consists shaping the transport offer and its visualization on a graphic train timetable [6]. Shaping the transport offer consists of properly determination of customer expectations and capabilities of service providers in terms to meet the needs [13]. Process in detail was presented in paragraph 3 of this article. For the preparation of rail transport offer are responsible railway undertakings and organizers of the transport. At present, this process is supported by text editors, spreadsheets and commercial software: packages for the analysis of traffic flow distribution in the communication network (e.g. PTV VISUM) or information systems for railway undertakings (e.g. DPK Railways or city Line Designer). There is a lack of tools to support the shaping of the offer and its visualization on a graphic timetable.

In Polish literature the issues of shaping the transport offer relates generally to public transport [13]. It was also pointed to one of the most important elements of shaping which is timetable [12]. In the field of railway transport offer were discussed factors influencing the shape of the offer [15]. In addition, presented approach to the mathematical modelling of the transport offer [6], [18] together with the characteristics of the application used to this [7]. An important part of problems of shaping the offer is also distribution of traffic flow in the transport network [1], [10], [11]. It should be also ensure that that the offer allowed for the implementation of services in a reliable and effective way [9].

In world literature a lot of space devoted to mathematical modelling of the transport offer, where the problem is referred to as the "Line Planning Problem" [3]. Mathematical formulation of various researchers is as close to each other. The differences are mainly in terms of indicators to assess the quality of solutions and methods of solving the problem. Used, among others, branch-and-bound method [5], [14], tools of integer *linear programming (ILP) [2],* nonlinear mixed integer model [4], branch-and-cut method [8] or Lagrangian relaxation and heuristic methods [16]. As an objective functions assumed among others number of transported passengers [2], [5], the cost of implementation of transport tasks [4], [8], [14] and the number of transfers between train sets [16].

The article presents the concept of application BEERJ supporting the work of transport offer designers: railway undertakings and transport organizers. We introduced the concept of the application and the mathematical model being the basis of its action. At the initial version of the computer application we conducted the trial of methods works - we prepared the transport offer and it illustration on a graphic timetable for the railway line 285: Wrocław Główny - Świdnica Przedmieście.

2. CONCEPT OF APPLICATION SUPPORTING TRANSPORT OFFER CONSTRUCTORS

As mentioned above, the application [7] is designed to support the designers of railway transport offer: transport organizers and the railway undertakings. Through the utilization of this application, responsible for the preparation of the offer, after the introduction of input data will be able to shape it and illustrate using graphic train timetable. Display the transport offer in graphical form allow for its more accurate development and eliminating of potential errors. Comprehensive preparation of the transport offer will also facilitate the work of the constructors of graphic timetable (who are the representatives of the infrastructure manager), who receive input data much more accurate.

BEERJ application will allow for a solution of three problems. The first is allocating of the volume of traffic flow to transport on previously designated communication lines. The second problem is to assign for each communication line, on the basis of the specified volume of the traffic flow, the type of train set to support and frequency of running. The third problem is to develop graphic timetable for the previously prepared transport offer. Problems have been characterized in detail at point 3 of this article. **Figure 1** shows the main BEERJ application window and **Figure 2** an example screen shot.

The BEERJ application is prepared in the programming language C# (C Sharp) [17] in a free Microsoft Visual Studio 2015. This environment supports the designing in visually manner - objects and elements are at first placed on the form and then are programmed their behaviour. Editor on an ongoing basis indicates errors in the code and suggests how to fix them. BEERJ application will be available for Windows. The application is prepared in the technology Windows Forms Application.

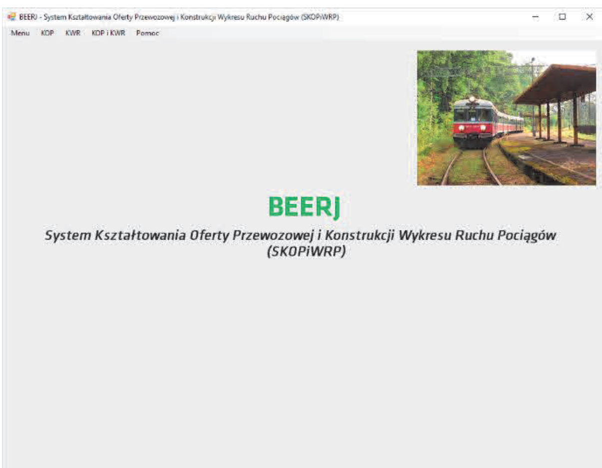

Figure 1 Main application window

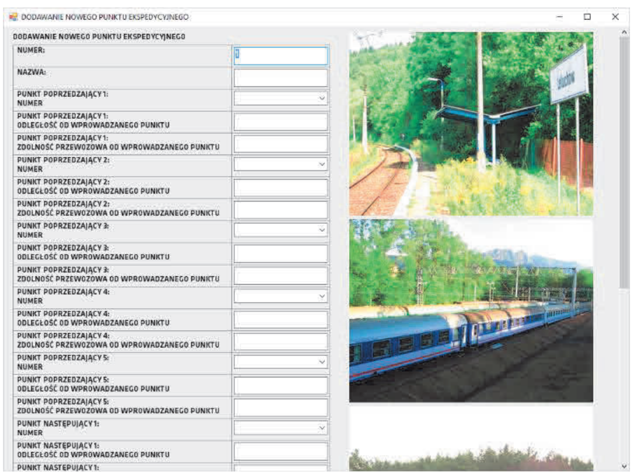

Figure 2 Example screen shot

3. MATHEMATICAL MODEL OF TRAIN TIMETABLE CONSTRUCTION WHICH IS THE BASIS OF THE APPLICATION

BEERJ application will allow for solution of three problems. The first one is allocating to the designated communication lines appropriate volume of the traffic flow which will be transported over them. We look for the volume of traffic flow $d(t_{kat}^{okrdob}*, kat, okrdob)$, which should be transported in a direct relations along the route $t_{kat}^{okrdob}* \in \boldsymbol{T}_{kat}^{okrdob}*$ by the trains category $kat \in \boldsymbol{KAT}$, in a specified period of the day $okrdob \in \boldsymbol{OKRDOB}$ record as a vector **D**:

$$\mathbf{D} = \left[d\left(t_{kat}^{okrdob}*, kat, okrdob \right) \right] \tag{1}$$

The set $\boldsymbol{T}_{kat}^{okrdob}*$ is developed separately for the specific periods of day *okrdob* and for each category of trains *kat*. To this set are classified all train routes $t_{kat}^{okrdob} \in \boldsymbol{T}_{kat}^{okrdob}$ - these are the routes, which beginning and / or end is not included in operating offices where it is possible to begin and terminate of trains run.

To solve the first problem is also needed to define additional input data. The railway network should be presented using graph **GK** = <**WK**,**LK**> consisting of a set of operating offices **WK** ($wk \in \boldsymbol{WK}$) and a set of connections between these operating offices **LK** ($lk \in \boldsymbol{LK}$). In addition, for each period of the day *okrdob* and each category of train *kat* should be defined matrices $\mathbf{P}_{kat}^{okrdob}$ determining the demand for transport between all operating offices.

As an indicator of assessing the quality of solution $f_1(\mathbf{D})$ we used the demand for transport, which was transported in direct relations:

$$f_1(\mathbf{D}) = \sum_{t_{kat}^{okrdob}* \in \boldsymbol{T}_{kat}^{okrdob}*} \sum_{kat \in \boldsymbol{KAT}} \sum_{okrdob \in \boldsymbol{OKRDOB}} d\left(t_{kat}^{okrdob}*, kat, okrdob \right) \longrightarrow \max \tag{2}$$

In the model should be apply the boundary conditions as: the volume of the traffic flow transported in direct relations should not be negative, should not exceed the flow to transport on the given route, and be less than the supply of seats on the route.

The second problem is the allocation to the routes $t_{kat}^{okrdob}*$, the type of train set $po(t_{kat}^{okrdob}*) \in \boldsymbol{PO}(t_{kat}^{okrdob}*)$, which can handle the trains for this category in a given part of the day, and the frequency of running $f(t_{kat}^{okrdob}*)$ for a specific period of the day *okrdob* and specific category *kat*, so we need to determine the values of the elements of vector **X**:

$$\mathbf{X} = \left[x\left(t_{kat}^{okrdob}*, po\left(t_{kat}^{okrdob}* \right), f\left(t_{kat}^{okrdob}* \right), kat, okrdob \right) \right] \tag{3}$$

The frequency of running $f(t_{kat}^{okrdob}*)$ should be selected from the interval $\langle \lfloor f(t_{kat}^{okrdob}*) \rfloor, \lceil f(t_{kat}^{okrdob}*) \rceil \rangle$ specified for given category *kat* and the day period *okrdob*. In addition, to solve the problem, it is neccesary to define a parameter indicating the train capacity $c(po(t_{kat}^{okrdob}*))$, their numbers $l(po(t_{kat}^{okrdob}*)$, number of running hours on the route $t_{kat}^{okrdob}*$ - $lh(t_{kat}^{okrdob}*)$, travel time of the vehicle type $po(t_{kat}^{okrdob}*)$ along the route $t_{kat}^{okrdob}*$ - $tp(t_{kat}^{okrdob}*, po(t_{kat}^{okrdob}*))$, the average stop time at a operating offices *wk* of the train category *kat* - $\Delta(wk, kat)$ and the amount of operational costs of ride the trainkm by train type $po(t_{kat}^{okrdob}*)$ - $ko(t_{kat}^{okrdob}*)$.

To assess this problem we used two indicators for assessing the quality of solutions. Indicator first $f_1(\mathbf{X})$ describes the operational costs associated with running of all trains:

$$f_1(\mathbf{X}) = \sum_{t_{kat}^{okrdob}* \in \boldsymbol{T}_{kat}^{okrdob}*} \sum_{kat \in \boldsymbol{KAT}} \sum_{okrdob \in \boldsymbol{OKRDOB}} \begin{matrix} ko\left(t_{kat}^{okrdob}* \right) \cdot \\ \cdot x\left(t_{kat}^{okrdob}*, po\left(t_{kat}^{okrdob}* \right), f\left(t_{kat}^{okrdob}* \right), kat, okrdob \right) \end{matrix} \longrightarrow \min \tag{4}$$

The second indicator $f_2(\mathbf{X})$ describes the number of train sets required to operate trains in all periods of day:

$$f_2(\mathbf{X}) = \sum_{t_{kat}^{okrdob}* \in \mathbf{T}_{kat}^{okrdob}*} \sum_{kat \in \mathbf{KAT}} \sum_{okrdob \in \mathbf{OKRDOB}} \frac{x\left(t_{kat}^{okrdob}*, po\left(t_{kat}^{okrdob}*\right), f\left(t_{kat}^{okrdob}*\right), kat, okrdob\right) \cdot 2\left(lh\left(t_{kat}^{okrdob}*\right) \cdot \left[\frac{60}{f\left(t_{kat}^{okrdob}*\right)}\right]\right) \cdot \left(tp\left(t_{kat}^{okrdob}*, po\left(t_{kat}^{okrdob}*\right)\right) + \Delta(wk, kat)\right)}{60 \cdot lh\left(t_{kat}^{okrdob}*\right)} \longrightarrow \min \quad (5)$$

In the model should be apply the boundary conditions: each line should be handled by only one train set, and that the assigned number of train sets should not be greater than at the disposal. An important issue is also the fact that we need to determine the number of train of each category *kat* to run $poc(t_{kat}^{okrdob}*,kat) \in \boldsymbol{POC}(t_{kat}^{okrdob}*,kat)$ on specific routes $t_{kat}^{okrdob}*$ and leading hours for them $gw(poc(t_{kat}^{okrdob}*,kat))$.

The third problem is to develop graphic timetable for prepared transport offer. We look for relative positioning of train paths $poc(t_{kat}^{okrdob}*,kat)$ in time and space $lr(lk,poc(t_{kat}^{okrdob}*,kat))$, which can be presented as vector **Y**:

$$\mathbf{Y} = \left[y\left(lr\left(lk, poc\left(t_{kat}^{okrdob}*, kat\right)\right)\right)\right] \quad (6)$$

For the preparation of a graphic timetable it should be presented in the form of a graph ***GR*** = <***WR***,***LR***> consists of a set of time moments ***WR*** ($wr(lk,poc(t_{kat}^{okrdob}*,kat)) \in \boldsymbol{WR}$) and a set of states ***LR*** ($lr(lk,poc(t_{kat}^{okrdob}*,kat)) \in \boldsymbol{LR}$). In addition, it is necessary to define the parameters: length of station time spacing *lrns*(*wk*), length of open line time spacing $szl \in \boldsymbol{SZL}$ - *lrnsz*(*szl*,*kat*) and the length of time needed for transport connections *lrsk*(*wk*).

To assess this problem we used indicator for assessing the quality of solution $f_1(\mathbf{Y})$ describing the volume of differences between time taking into account and not taking into account the principles of proper conducting the railway traffic $p(lr(lk,poc(t_{kat}^{okrdob}*,kat)))$:

$$f_1(\mathbf{Y}) = \sum_{lr\left(lk, poc\left(t_{kat}^{okrdob}*, kat\right)\right) \in \boldsymbol{LR}} p\left(lr\left(lk, poc\left(t_{kat}^{okrdob}*, kat\right)\right)\right) \cdot y\left(lr\left(lk, poc\left(t_{kat}^{okrdob}*, kat\right)\right)\right) \longrightarrow \min \quad (7)$$

In the model should be apply the technical and security boundary conditions. To technical boundary conditions we can include, among others, that the train should have one moment of appearance and leave on a chart, and the intermediate nodes only one predecessor and one successor. To security boundary conditions we include the need to maintain station and track spacing and time needed for transport connections.

4. CASE STUDY OF TRAIN TIMETABLE CONSTRUCTION FOR SELECT RAILWAY LINE

We prepared in application BEERJ transport offer and its presentation on the graphic train timetable for a railway line 285: Wrocław Gł. - Świdnica Przedmieście. As part of the testing procedure, we assumed that will be launched the agglomeration trains in relation Wrocław Gł. - Wrocław Klecina, regional trains in relation Wrocław Gł. - Sobótka Zachodnia and freight trains in relation Wrocław Brochów - Świdnica Przedmieście (on line 285 from junction signal box Tarnogaj).

Presenting the line 285 as a graph we identified 22 operating offices (vertices) and 21 edges. Timetable will be prepared for the one period of day (whole day) for three segments of demand (agglomeration, passenger and freight trains). For each segment we prepared demand matrices.

After collecting the data for each trains category and for each period of the day we searched the communication lines (e.g. for the first category - six routes). Then we conducted aggregation of lines to those that are between points where it is possible to begin and terminate of trains run (for all categories are two routes) and assigned to them volume of traffic flow to transport. Then we assigned the type of train to service from pre-defined (we adopted to use rolling stock owned by the Lower Silesia Province) and the frequency.

The effects of the work are as follows: to handle the 12 pairs of agglomeration trains we assigned rail-bus SA106 and frequency 120 min., to handle the 6 pairs of regional trains in relation we assigned rail-bus SA135 and frequency 240 min., to handle the 2 pairs of freight trains in relation we assigned locomotive SM42 and frequency 720 min.

For prepared transport offer we developed a model graphic train timetable (**Figure 4**)

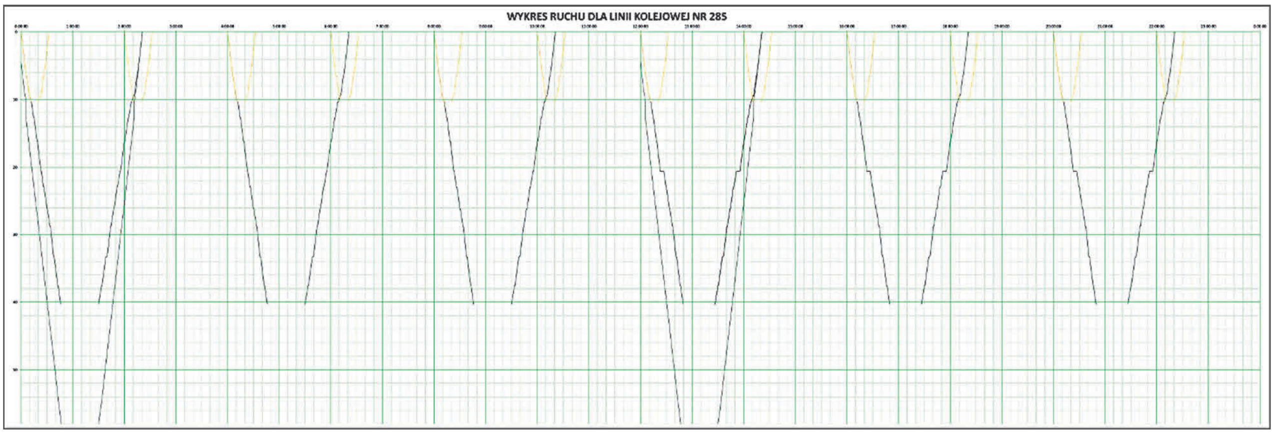

Figure 4 Model graphic train timetable for railway line 285 Wrocław Główny - Świdnica Przedmieście

On model graphic timetable there are many collisions between trains. There are not preserved times spacing. Included are only leading hours for trains. It should be removed all problems threatening safety of traffic. Removal of the conflict should be carried out under the supervision of the constructor. Through experience of the researcher timetable becomes more adapted to the needs of customers. After removal of collisions and application of experience of constructor it is preparing a real graphic timetable (**Figure 5**).

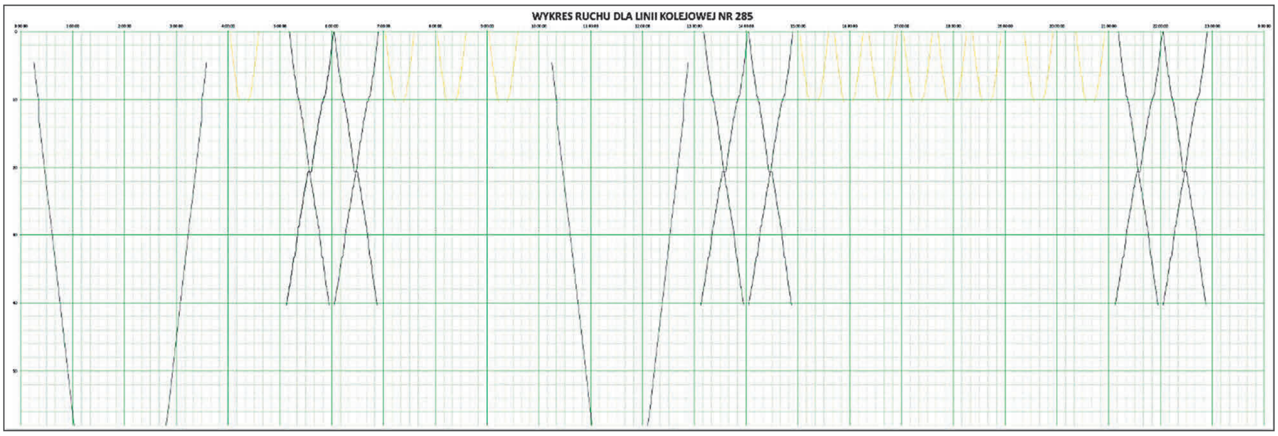

Figure 5 Real graphic train timetable for railway line 285 Wrocław Główny - Świdnica Przedmieście

5. SUMMARY AND CONCLUSIONS

A well-constructed timetable allows for conducting of movement smoothly and safely. In prepared timetable should be taken into account the time associated with any determinants - e.g. adequate time to change of the passengers, the time required to realize train announcing by train dispatchers, time of non-simultaneous arrival etc. Timetable should take into account satisfying the needs of all participants of movement - mostly passengers, so capacity of train sets and frequency of running should be adjusted accordingly.

The aim should be to develop applications to support the work of timetable constructors (both transport offer and graphic timetable). Use of application will reduce the risk of error, which can have more or less serious consequences. Article presents the author's assumptions about the computer application BEERJ, which is intended to support railway undertakings and transport organizers in preparing the transport offer, together with its presentation on the graphic train timetable. Graphic form of presentation of the transport offer will allow the constructor for a holistic look and possible correction of plan in places generating problems and ensure accurate implementation of transport needs.

REFERENCES

[1] AMBROZIAK T., JACHIMOWSKI R., PYZA D., SZCZEPAŃSKI E. Analysis of the traffic stream distribution in terms of identification of areas with the highest exhaust pollution. The Archives of Transport, vol. 32, iss. 4, 2014, pp. 7 - 16.

[2] BUSSIECK M., KREUZER P., ZIMMERMANN U. Optimal lines for railway systems. European Journal of Operational Research, 1997, vol. 96, p. 54-63.

[3] CAPRARA A. KROON, L.; MONACI, M.; PEETERS, M.; TOTH, P.: Passenger Railway Optimization. In: Barnhart C., Laporte G.: Handbooks in Operations Research and Management Science - Vol. 14: Transportation. Elsevier, 2007, pp. 129-188.

[4] CLAESSENS M., VAN DIJK N., ZWANEVELD P. Cost optimal allocation of passenger lines. European Journal of Operational Research, 1998, vol. 110, p. 474-489.

[5] DIENST H. Linienplanung in Spurgeführten Personenverkehr mit Hilfe eines Heuristischen Verfahrens. PhD thesis, Technische Universität Braunschweig, 1978.

[6] GOŁĘBIOWSKI, P. Mathematical Model of Shaping the Railway Transportation Offer. In CLC 2013: Carpathian Logistics Congress. Ostrava: TANGER, 2013, pp. 397-402.

[7] GOŁĘBIOWSKI, P. Założenia do aplikacji komputerowej BEERJ wspomagającej konstrukcję rozkładu jazdy pociągów. Logistyka, No. 4, 2015, pp. 281-292.

[8] GOOSSENS J., VAN HOESEL C., KROON L. A branch-and-cut approach for solving railway line-planning problems. Transportation Science, 2004, vol. 38, p. 379-393.

[9] JACYNA M., LEWCZUK K., SZCZEPAŃSKI E., GOŁĘBIOWSKI P., JACHIMOWSKI R., KŁODAWSKI M., PYZA D., SIVETS O., WASIAK M., ŻAK J., JACYNA-GOŁDA I. Effectiveness of national transport system according to costs of emission of pollutants. In: Safety and Reliability: Methodology and Applications. CRC Balkema, 2014, pp. 559-567.

[10] JACYNA M., MERKISZ J. Proecological approach to modelling traffic organization in national transport system. The Archives of Transport, vol. 30, iss. 2, 2014, pp. 31 - 41.

[11] JACYNA-GOŁDA. I., ŻAK J., GOŁĘBIOWSKI P. Models of traffic flow distribution for various scenarios of the development of proecological transport system. The Archives of Transport, vol. 32, iss. 4, 2014, pp. 17 - 28.

[12] KRÓLAK M., SENKO J., GROMADZKI M. Rozkład jazdy jako element oferty przewozowej. XXXI Krajowy Zjazd Komunikacji Miejskiej, Gdańsk, 2006, s. 129 - 150

[13] KWAŚNIKOWSKI J., GRAMZA G. Kształtowanie oferty przewozowej w publicznym transporcie pasażerskim. Logistyka, 2011, vol. 6, p. 2133 - 2139.

[14] LINDNER T. Train schedule optimization in public rail transport. PhD thesis, Technische Universität Braunschweig, 2000.

[15] POLIŃSKI J. Oferta przewozowa najważniejszym dla klienta elementem działalności nowoczesnego zarządu kolejowego. Problemy Kolejnictwa, 1998, vol. 128, p. 98-116.

[16] SCHOLL S. Customer-oriented line planning. PhD thesis, University of Kaiserslautern, 2005.

[17] SHARP, J. Microsoft Visual C# 2013 Krok po kroku. Promise: Warszawa, 2013.

[18] WOLFENBURG A. New version of the bbs method and its usage for determining and scheduling vehicle routes. The Archives of Transport, vol. 31, iss. 3, 2014, pp. 83 - 91.