PUBLIC TRANSPORTATION AND OPTIMISATION

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1. Introduction

Many modern metropolitan areas, especially in central districts suffer from the congested traffic of pedestrians and vehicles (UNHABITAT 2013, SCATTER 2003). Traffic congestion is a very adverse phenomenon with

negative influence, particularly on society and the environment. The authors of this paper try to demonstrate that transport integration may lead to the reduction of traffic congestion. They concentrate their research on presenting transport integration solutions for an urban public transportation system as tools for improvement of travelling standards in the cities and enhancement of the public transportation systems' efficiency. They claim that only efficiently functioning public transportation system can effectively compete with individual transport vehicles.

The term of "transport integration" is used in different contexts in many publications. Several detailed definitions and areas of integration are presented by different authors, including: (Dydkowski G. 2005, Givoni M., Banister D. 2010, Hine J. 2000, Hull A. 2005, Ibrahim M. 2003, Janic M., Reggiani A. 2001, May et al 2006, May T. 1993, Potter S., Skinner M. 2000, Starowicz W. 2000, Stead D. 2003, Underdal A. 1980, Vigar G.). In general, transport integration denominates such technical, economic, organizational, policy – based and informational concepts and solutions that assure the continuity of travels from door to door (Janic M., Reggiani A. 2001). Transport integration is focused on: connecting different transportation modes operating in a certain transportation system, providing solutions to facilitate passengers' / goods transfer between the modes and assuring safe, smooth and efficient flow of passengers / goods from their origins to their destinations (GUIDE 1999, Ibrahim M. 2003). Based on the results of the EU projects (Hilferink P., Roest Crollius A., Van Elburg J. - C. 2003, Żak J., Fierek S., Kruszyński M. 2014) integration of an urban public transportation is defined as an organizational process by which elements of the passenger public transportation system (network and infrastructure, fares and ticketing systems, information and marketing components) and a variety of carriers who serve different transportation modes, interact more closely and efficiently, to generate an overall improvement in service quality level and enhanced performance of the combined public and individual transportation. In general, the implementation of different transport integration solutions may result in the following benefits (Prospects 2003): reduction of travel times, transportation costs, traffic congestion and environmental pollution. Transport integrating solutions may improve the urban public transportation system accessibility and overall competitiveness as well as assure better utilization of different transportation means and infrastructure.

One can distinguish different types and forms of transport integration in the urban areas, described by different authors and presented in various reports (Starowicz W. 2008, Rudnicki A. 1999, (Hilferink P., Roest Crollius A., Van Elburg J. - C. 2003, Dydkowski G. 2005, May A. 1993, Hine J. 2002, Hull A. 2005, Stead D. 2003, Underdal A. 1980, Solecka K. 2013, Fierek S. 2013). These include:

- Integration of different modes of public transportation.
- Integration of public and individual transportation.
- Integration of transportation policy with other policies concerning spatial planning and city management.
- Spatial integration based on the application of efficient land use strategies (e.g. multimodal terminals and interchange platforms, shared lanes for means of public transportation).
- Infrastructural integration based on development of different technical solutions in transportation infrastructure. (e.g. passageways connecting public transportation stops, overpasses, underpasses, shared stops for public transportation).
- Organizational integration (e.g coordinated timetables; metropolitan tickets for different transportation modes).

x Economic integration focused on introduction of different measures supporting sustainability and efficiency of the public transportation systems (e.g. integrated tariffs). x Informational integration (e.g. passengers' information systems; web pages; electronic travel planners).

The article consists of five sections. The introduction presents the purpose and scope of work, and explains the main idea of transport integration. The second section describes the applied research methodology. In the next one the current status of integrating solutions in a certain public transportation system is characterized and its alternative, prospect development – variant is proposed and simulated. The fourth chapter compares the designed variant of integration with the existing public transportation system based on a set of parameters derived from the traffic simulation carried out in the Visum computer package. Section five is a summing up chapter.

2. Research Methodology. Design, simulation and evaluation of an integrated public transportation system.

The project focuses on the design / development, analysis and evaluation of an integrated urban transportation. Thus, the pillars of the proposed research methodology are as follows:

x The heuristic design of a concrete variant of integration.
x The macro-simulation of the designed variants. x The comparative analysis and evaluation of the variants.

The 1st pillar consists in applying the expert knowledge to design and construct heuristically a concrete variant of integration of an urban public transportation. The construction of transport integrating solutions has been initiated by the analysis of its strengths and weaknesses, based on which the redesign of the urban transportation system has been proposed. The development of an integrated public transportation system has included such elements as:

x Reconfiguration of the transportation network (eliminations, extensions, modifications of routes); x Introduction of new, railway-based transportation modes and reduction of others (buses, trams); x Design of the integrating infrastructure: multimodal terminals; common stops and tracks; x Changes in the distribution and location of bus/tram stops. Redefinition of distances between stops. x Changes of speed limits, boundaries of the limited traffic zones, headways on certain routes.
x Introduction of integrated passengers' information systems and coordinated timetables; x Introduction of a shared multimodal ticket with a common fare for a multimodal travel.

The implementation of these changes in a simulation package have consisted in:

x Adding, editing or removal of:

- selected segments and nodes of the transportation network combined with the redefinition of their characteristic parameters (e.g. type of vehicles, capacity),
- traffic zones combined with the redefinition of their boundaries and centroids as well as introduction of connectors of the new traffic zones to specific transportation nodes,
- selected stops combined with the redefinition of their locations and specific features, (e.g. introduction of a joint platform for a common bus and tram stop),
- public transportation routes combined with the redefinition of their characteristic parameters. x Redefinition of the passengers' transfer time between different transportation modes (changes of parameters for specific connectors) based on the concept of a „penalty for transfer" (Rudnicki A. 1999). x Designing a common track for buses and trams and redefinition of their speed.
- Applying the mechanism of the above mentioned „penalty for transfer" to differentiate travel costs in cases when an integrated ticket with a common fare is introduced and when it is not applied.

The redesign process has been supported by traffic simulation (Szarata A. 2008, Papaioannou P., Politis I., Basbas S. 2009) – **2nd pillar of the applied methodology**. The essence of simulation is to carry out a computational experiment while using the simulation model that expresses the operations of a certain system in real conditions. A specific form of simulation is traffic simulation. The traffic simulation model expresses the transportation needs of travelers' between predetermined points (origins and destinations) and allows the fulfillment of those needs thanks to the model description of road infrastructure and representation of means of transport (Żak J., Fierek S. 2007).

The traffic simulation can be carried out with the emphasis on different level of detail, represented by corresponding simulation models from macroscopic through mezoscopic to microscopic (Lieberman E., Rathi A. 1997). In this research the macrosimulation has been applied to support the design and development of certain variants of integration of an urban transportation system. The traffic macrosimulation software package Visum has been used to simulate the behavior of the designed variants. In general, Visum is a computer based traffic simulator that can be applied to design and analyze transportation projects, systems and solutions that involve both collective and individual traffic flows (PTV 2000). Designing alternative transportation solutions for an urban transportation system with the application of Visum is based on constructing a traffic model, adding, eliminating and changing basic components of the transportation system, such as: traffic zones, network nodes and links, routes, and others. Traffic model generated in Visum is based on activity chains and an origin-destination matrix (Żak J., Fierek S. 2007). To carry out the traffic simulation of the designed variant of integration of a public transportation system a 4stage model (Henscher D., Button K., 2000) has been applied. This model includes the following subsequent components that consequently address the associated questions:

- Trip generation (production and attraction) – How many travel movements will be made?
- Trip distribution – Where will the movements /travelers go to?
- Modal split – What mode will the travel be carried out by?
- Traffic assignment – What routes will be taken during specific travels?

The **trip generation** stage focuses on the prediction of the number of trips entering (attraction) and leaving (production) each predefined traffic zone in a certain time period. In this stage the traffic potential of each zone is defined, based on the survey research of travellers' behaviour and habits. In general, the analytical models used for assessing / prediction of trip production / attraction are expressed in the following form:

$$O_i^k = f(X^k, C_i^k) \tag{1}$$

where: k – index of the segment of the population; segmentation is carried out based on the recognition of travel purposes, household characteristics, mobility patterns; i – origin or destination of a travel;
X^k – vector of characteristics for segment k of the population; C_i^k – "composite" cost of traveling from the origin or to a destination.

The **trip distribution** stage consists in spatial distribution of trips based on the traffic potential (production and attraction) of particular traffic zones. During this stage the origin – destination (O-D) matrix and its graphical representation – traffic grid - are constructed. They characterize the values of traffic flows T_{ij} between origins i and destinations j in a certain area, expressed in terms of flows as a number of vehicles or number of passengers per time unit (day, hour). This spatial distribution of travels is generated with the application of a "gravity" model in the form:

$$T_{ij} = a_j \cdot P_i \cdot f_{ij}(x) = A_j \cdot p_i \cdot f_{ij}(x) \tag{2}$$

where: T_{ij} - number of movements / trips per time unit or the level of traffic flows between origin i and destination j;
a_j – the share of travel demand attracted by the destination/ attraction zone j in the total travel demand generated at all destinations / attraction zones j in the considered area;
A_j – the level of travel demand (attraction) absorbed by zone j; p_i – the share of travel demand produced at the origin / production zone i in the total travel demand generated at all origins / production zones in the considered area;
P_i – the level of travel demand (production) generated in the origin i;
$f_{ij}(x)$ – the "separation" or generalized costs function for a travel between zones i and j; the most endured form of $f_{ij}(x)$ is the negative exponential "deterrence function" (Henscher D., Button K., 2000).

Certain parameters of this model are calibrated in the TFlowFuzzy Module of the Visum software. The adjustments of the traffic flow levels generated in the Visum simulation package are compared with the real life measurements performed in the existing urban transportation system.

In the **modal split** stage the shares of travels carried out by particular transportation modes in the overall number of travels are determined. Due to the fact that modal split has a local character the analysis is performed for a specific time period (day, hour) and in a predefined area. The modal split is generated based on the mode choice models, including the most popular and well known multinomial logit model and nested logit model (Henscher D., Button K., 2000). In the analyzed case the following logit function has been applied to generate the modal split:

[illegible] (3)

and [illegible] (4)

where: [illegible] – probability of choosing public transportation as the mode of travel; *y* – the ratio of travel times by an individual / private car and public transportation;

f, *g* – parameters of the model dependent of the travellers' behaviour in the analyzed metropolitan area;

[illegible] – probability of choosing the individual / private mean of transport.

The **traffic assignment** stage consists in searching for an equilibrium between travel demand and transportation supply. In this stage modal O-D trip matrices are loaded on the modal networks, usually under the assumption of deterministic or stochastic user equilibrium. The basic user equilibrium is obtained by the Frank – Wolfe algorithm (Hillier S., Lieberman G. 2005), which involves the computation of minimum paths and all-or-nothing assignments to these paths. In the analyzed case, while designing the integrated public transportation system the headway – based traffic assignment procedure has been applied (PTV Vision 2000). This algorithm takes into account the detailed characteristics of the public transportation routes, travel times on the routes (between stops and overall) and routes' performance parameters, such as: headways and capacities of vehicles. The application of Visum allows computing a set of measures that characterize and evaluate the proposed transportation solutions. This evaluation is the final pillar of the described methodology. The generated variants of the integrated public transportation system can be evaluated by a set of parameters usually used in the evaluation of public transport systems (Cascajo R. 2005, Giorgi L., Tandon A. 2000, Hilferink P., Roest Crollius A., Van Elburg J. - C. 2003). The literature survey (Dydkowski G. 2005, Rudnicki A. 1999) reveals that many authors use similar parameters to evaluate transportation projects, solutions and systems, including: number of vehicle – kilometers, number of passenger – kilometers, travel, riding and waiting times, transportation costs, transferring frequencies and others.

The 3rd pillar of the applied methodology is the evaluation and comparative analysis of the proposed transportation solutions. Within this pillar the existing public transportation system (variant V0) is compared with the newly designed public transportation system (variant V1). Both variants are assessed based on the parameters and characteristics generated by the Visum simulation package and usually used in the evaluation of the public transportation systems (Żak J., Fierek S. 2007). The major aspect of this comparison is the **integration of the public transportation system.** The 3rd pillar of the methodology involves traffic simulation experiments that result in the computation of selected parameters presented in tables 1 and 2. These parameters can be split into two categories: those that can be applied to the overall evaluation of the public transportation system and those that are suitable for the analysis of its integration. The latter category includes, among others, such measures as: travel times and their components, average speed in a network, the number of transfers. In addition, the application of traffic macro simulation may result in the computation of other parameters, such as: number of integrated terminals, improvement of the overall travel time and transfer time, improvement of waiting time.

3. Development and simulation of variants.

The object of the real life case study is the medium-sized urban public transportation system in Cracow, Poland, for which different variants of transport integration have been proposed. The applied approach is based on traffic surveys carried out sequentially in Cracow in 2003, 2007 and 2010. The traffic model takes into account traffic conditions of the afternoon peak hour in an average week day. It covers 321 traffic zones (regions) in the Cracow metropolitan area, including 265 zones in the city and 56 zones at the suburbs. 18 different types of road/ street segments have been used in the model, including 12 and 6 categories characteristic for the city and suburban areas, respectively. Both regular inner city public transportation routes, suburban routes and adjustable mini bus routes operating in the metropolitan area have been included in the model. This model has been adapted to construct specific integrating transportation solutions and develop different variants of transport integration in the analyzed Cracow metropolitan area. The following methodological rules proposed by K. Solecka (2013) have been applied to develop the transport integrating solutions:

- The construction of variants should be based on the application of a 4 – stage traffic model (Szarata A., 2008) and its adaptation to specific variants (as described in section 2).
- The proposed variants should be designed and simulated in the traffic macro simulation package Visum.
- The evaluation of variants should be based on the application of measures and parameters generated in a traffic macro simulation package Visum.
- The construction of variants should take into account the principles of transport sustainable development and should be consistent with the local land use and transport policy documents.

In the next section two of the designed variants have been presented. One of them – variant V0 describes the existing public transportation system in Cracow, while the second one – variant V1 corresponds to the introduction of two additional transportation modes to the public transportation system, i.e.: Light Express City Train (LECT) and subway, and development of its integrating solutions.

3.1. Characteristics of variants

3.1.1 Variant V0 – the existing public transportation system (current level of integration)

The existing urban public transportation system in Cracow consists of bus and tram networks managed by public and private operators. It provides service for roughly 1 mln people. The system is composed of 190 routes, including 24 tram routes (including 2 fast tram routes), 79 urban bus routes, 65 commuter bus routes and 22 mini bus routes. The system is operated by several service providers, including: public operator - Cracow Urban Transportation Company (MPK – Krakow), private operator - Mobilis Ltd. Co. and several small private carriers. The railway network within the Cracow metropolitan area amounts to 127 km of train lines. There are 19 passenger stops, 4 passenger – fright stations and 7 active sidings in this network. The rail way network has not been utilized for local urban traffic. Suburban public transportation in Cracow metropolitan area is supplemented by microbus transportation serviced by private operators and Regional Operator (National Road Transportation – PKS). Variant V0 is featured by limited transport integration focused in the areas of: spatial – infrastructural, economic, informational and organizational integration. The following integration tools of the public transportation system are characteristic for this variant:

- 11 km of separated, shared bus – tram tracks and 27 common bus-tram stops.
- 6 integrated transfer nodes - interchanges, including 3 in the city center (numbers 1, 2, 3 in figure 1a), 1 in the northern, 1 in the south – western and 1 in the west – northern part of the city (numbers 4, 5, 6 in figure 1a, respectively). In these transfer nodes the passengers have access to: 4 – 10 bus routes and 3- 10 tram routes.
- Common, multimodal public transportation fare combined with the integrated ticket that covers all public transportation modes and 5 major railway entry lines. The ticket introduces 2 traffic zones, including: Zone 1 - City of Cracow; Zone 2 – Suburban areas. It is estimated that 30% of transferring passengers are covered by a common fare / integrated ticket.
- 30% of the stops and 35% of the vehicles are equipped in a common, integrated passengers' information system that includes: timetables, transfer points and riding times.
- Common headways on principal and major subordinate tram / bus routes resulting in a certain (limited) coordination of the timetables of different public transportation modes at the initial and ending stops. The introduced rules imply that the basic intervals equal 10 min on the principal tram / bus routes during peak hours and its multiplication on the subordinate routes and / or in the off-peak period (usually 20 min). Unfortunately, many bus and tram routes operate with the headways of 8, 12 and 15 minutes.

The graphical representation of the existing public transportation system – variant V0 is presented in figure 1a) The picture displays the existing bus and tram network, including major bus and tram routes, common / shared bus – tram tracks and integrated, multi-modal interchange nodes (terminals). It also presents the traffic flows / volumes on main routes of the public transportation system.

a) b)

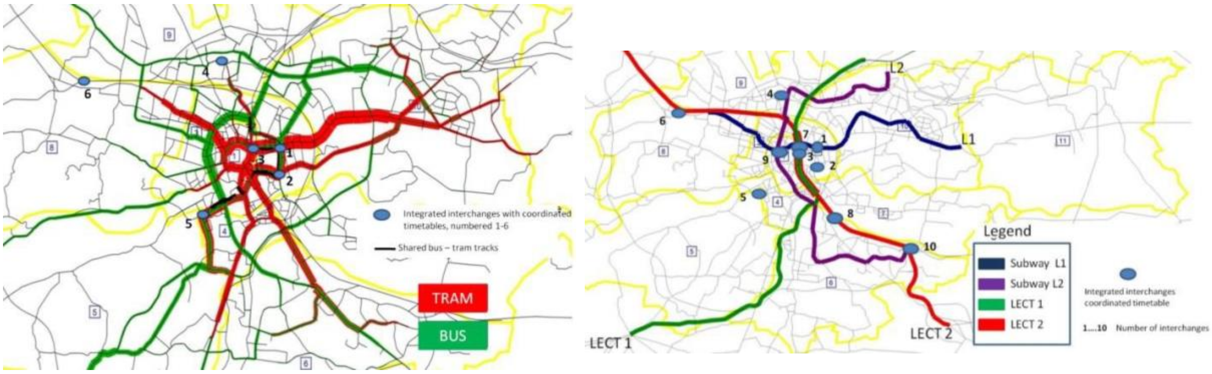

Fig. 1. The graphical representation and major features of the: (a) existing public transportation system (bus and tram network) – variant V0 and (b): the redesigned public transportation system (the course of LECT and subway lines) – variant V1.

3.1.2 Variant V1 – radical, railway-oriented integration

Variant V1 is a radical, investment intensive, railway-oriented modification of variant V0. It is based on the existing urban and suburban public transportation systems and the introduction of 2 lines of the Light Express City Train (LECT), servicing Cracow and its adjoining areas as well as 2 subway lines L1 and L2, crossing the Cracow metropolitan area horizontally and vertically. The LECT line 1 – LECT 1, 47 km long, runs from southwest (Skawina) to northeast (Zastow), while LECT line 2 - LECT 2, 37 km long from south (Wieliczka) to northwest (Krzeszowice), as presented in figure 1 b). Both LECT lines operate with headways of 15 minutes. 10 and 12 stops are located on LECT lines 1 and 2, respectively. The average distance between stops on these lines is 5.2 km and 3.5 km, respectively. The subway lines, presented in figure 1 b), run: from east (Bronowice) to west (Nowa Huta) – L1 and from south (Biezanow) to north (Piastow) – L2. Their respective lengths are 16 km and 22 km. There are 18 and 25 subway stops on lines L1 and L2, respectively, resulting in an average distance between stops of 0.9 km for the whole subway system. The subway lines operate with headways of 4 minutes. In variant V1 several bus routes (e.g. 243 and 143) are either closed or shortened to eliminate duplication between the introduced LECT and subway lines and the existing bus system. In some cases new bus routes (e.g. 195) are introduced as feeder connections from suburbs to interchanges. The designed variant includes the following transport integrating solutions:

- 11 km of separated, shared bus – tram tracks and 39 common bus-tram stops (increase by 12 stops);
- 10 integrated transfer nodes – interchanges. Six of the interchanges are the same as in variant V0. However, one of the transfer nodes (number 4) is extended and reconstructed – due to provision of connections between the existing public transportation modes and one of the introduced subway lines (L2). The newly introduced transfer nodes (numbers 7, 8, 9, 10) have multimodal character. In node 7 the passengers have access to 19 bus routes, 12 tram routes, 2 LECT routes and 1 subway route. In node 8 they can interchange between 6 tram routes (incl. 1 LECT route) and 4 bus routes. In nodes 9 and 10 passengers have access to 2 subway and 5 tram routes, and to 1 subway and 1 LECT route, respectively (figure 1 b).
- Common, multimodal public transportation fare combined with an integrated ticket that covers 3 modes, including: subway, buses and trams. The proposed zonal system is the same as in variant V0. It is estimated that roughly 30% of the transferring passengers are covered by a common fare / integrated ticket.
- 40% of the stops and 45% of the vehicles are equipped in a common, integrated passengers' information system that includes: timetables, transfer points and riding times. Roughly 10% increase of the information integration is proposed in variant V1.
- Further integration of timetables is proposed in variant V1. In addition to the rules introduced in variant V0 the following timetable coordination mechanisms are introduced: individual adjustments of headways on selected bus routes, fixed headways on LECT and subway of 15 and 4 minutes, respectively. The timetable coordination in variant V1 has been extended beyond the initial and ending stops to cover all the interchanges with the subway connections (4 subway interchanges).

Figure 1 b) presents major characteristics of variant V1, including the course of LECT and subway lines with the introduced integrated, multimodal interchanges.

4. The overall comparison of variants

Based on the parameters generated in the Visum simulation package the comprehensive comparison of variants has been carried out. Tables 1 and 2 include a set of parameters based on which the comparison between variants V0 and V1 has been performed. All average values enclosed in table 1 are computed for an average travel / trip of a statistical, single passenger. In addition, the table presents the total number of trips / travels, including those carried out with and without transfers.

Table 1. The overall comparison of variants based on the generated
Table 2. The level of ridership, the resulting modal split and the in the
traffic simulation package Visum. parameters average passenger

Evaluation parameters	Variant 0	Variant 1
Average travel time	45.30	42.29
Average riding time	33.58	31.25
Average time spent in a vehicle of a public transportation system	26.05	23.16
Average transfer time	7.53	8.09
Average waiting time at the transfer stop	1.42	1.16
Average waiting time at first stop	3.36	3.23
Total number of trips / travels	127 465	134 174
No. of passenger trips / travels without transfers	58 869	57 943
No. of passenger trips /travels with transfers	68596	76231
No. of passenger trips/ travels with 1 transfer	25 899	25 287
No. of passenger trips/ travels with 2 transfers	5 301	7 711
No. of passenger trips/ travels with >2 transfers	222	629

speed for variants V0 and V1 computed with the application of the traffic simulation package Visum.

Means of transport	Ridership [pass-hour]	Ridership [pass-km]	Modal split	Average passenger speed [km/h]
Variant 0				
Subway	-	-	-	-
LECT	-	-	-	
Bus	15 899	306 277	32%	
Tram	9 716	173 447	18%	
Minibus	18 549	476 931	50%	
Total	44 164	956 655	100%	22,66
Variant 1				
LECT	4 793	159 357	16%	
Bus	10 787	209 156	21%	
Tram	5 193	89 638	9%	
Minibus	15 580	408 352	41%	
Subway	3 595	129 478	13%	
Total	39948	995 981	100%	24,93

It is worth noticing that due to introduction of 2 new transportation modes in variant V1 the modal split in both variants differs substantially. The newly introduced modes absorb roughly 29% of the ridership, which results in the noticeable decrease of the ridership shares of the major transport modes (bus and tram) in variant V0. This drop reaches the level of 9 – 11 percentage points for trams and buses, respectively. As presented in tables 1 and 2 the changes in the modal split do not have negative impact on two important parameters of the comfort of travel, i.e. average passenger speed and average travel time. Both of them are improved in variant V1, by 10% and 7%, respectively. In absolute terms an average trip in variant V1 is 3 minutes shorter than its equivalent in variant V0. This reduction produces an overall saving of 4216 hours (ridership in pass-hours) in the whole public transportation system. At the same time the efficiency of the system in terms of ridership expressed in pass-km increases by 4%. These results could be achieved thanks to the introduction of separated tracks for public transportation (LECT and subway) and infrastructural integration of different transportation modes proposed in variant V1.

The above mentioned data provide some indications concerning transport integration in both variants. The above mentioned improvements on passengers' speeds (10%) and passengers' travel times (7%) in variant V1 prove that this variant is better integrated in general terms. The cited numbers indicate that passengers should be more satisfied with the overall standard of travel in variant V1 resulting from the reduction of the time spent in the public transportation system. Based on these figures one may conclude that introduction of new transportation modes facilitates passengers' transportation in the considered metropolitan area. Thus, the 5 transportation modes proposed in variant V1 must be better integrated than their 3 equivalents characteristic for variant V0. This conclusion is strongly supported by the comparison of the values of such parameters as: average riding time, average time spent in a vehicle of a public transportation system and average waiting time at the transfer point in both variants. All of them are improved (reduced) in variant V1 by 7%, 11% and 18%, respectively. The latter figure is a measure of particular importance for the evaluation of transport integration. It indicates that passengers' transfers are much easier in variant V1 than in variant V0. The reduced waiting times at transfer points result from better coordination of timetables of different transportation modes, increased availability of transportation means and better integration of the information system. At the same time the average transfer time in variant V1 increases by 7%, which is an evident weakness of the transport integration process. This means that integrating infrastructural facilities are not sufficiently developed and do not provide satisfactory facilitation for passengers to transfer between transportation modes.

Another important characteristic of transport integration is the share of trips with transfers in the total number of trips / travels carried out in a certain public transportation system. These numbers are 53.8% and 56.8% in variants V0 and V1, respectively. In the analyzed case the increase of the share of trips with transfers by 3 percentage points in variant V1 may have an ambiguous interpretation. On the one hand it may correspond to a natural feature of the public transportation system based on 5 transportation modes in which the number of transfers must be larger due to increased statistical chances of transfer events than in a public transportation system based on 3 transportation modes. On the other hand it may be also interpreted as the passengers' willingness to change transportation means more frequently and with more desire when transfers are easy and conveniently arranged. Unfortunately, this interpretation is not valid in the analyzed case due to the fact that the average transfer time in variant V1 increases. It is worth mentioning that comparative analysis of variants V0 and V1 in terms of the number of trips with transfers reveals that the most drastic difference concerns trips with at least 2 transfers. In that category the number of trips / travels increases in variant V1 by 51%. This figure can be also interpreted in two contradictory ways: as the passengers' natural inclination towards transfers due to their convenience or as a natural obligation resulting from the arrangement of the public transportation system.

5. Conclusions

The paper presents the methodology of designing transport integration solutions for a public transportation system with an application of macro simulation. The authors present how the redesign of the public transportation system can influence on its integration. They carry out a real life case study presenting the interrelation between the introduction of new railway – oriented transportation modes into the public transportation system and its integration. They show how various transport integrating solutions can be modelled in a macro simulation package Visum and how to measure the overall level of transport integration. The paper includes a multidimensional comparison of two variants of the public transportation system V0 and V1 and the analysis of their integration. Several measures of transport integration are proposed. The discussion concerning transport integration and the overall standard of travel is presented based on the comparative analysis of the existing public transportation system – variant V0 and its modification – variant V1. In both variants various transport integrating solutions / tools are considered.

The major output of this research is twofold: methodological and practical. From a methodological point of view the contribution of the paper includes the following issues: the application of macro simulation package Visum to the design of transport integrating solutions and construction of several measures / parameters that can be applied in the evaluation of transport integration. From a practical point of view the essential element is the comparison of two variants of public transport integration. The authors show how this comparison can be carried out and which of the variants can be considered more or less integrated. They also discuss the ambiguity of such an evaluation.