Towards the Best Public Transport in Suburban Areas on the Example from One Polish Agglomeration

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The aim of this paper is to find the best public transport system suitable for suburban areas. Two measures of evaluation are developed, in sense of spatial and temporal accessibility. Three options of transport system are evaluated with the use of these measures, with consideration of different time horizons. The first option was the existing bus system. The second option concerns the modification and development of the bus system with the addition of rail transit. A futuristic "dial-a-ride" system is studied in the third option. The ranges of residences from past, present and future are shown for selected time horizons in relation to transportation network. The study concludes that only advanced "dial-a-ride" system can offer good conditions for people who choose public transport means compared to private car transport. The analyses were conducted for an exemplary village located within one Polish agglomeration. The conclusions could be adopted in other cities and countries due the similarity of urbanisation and transportation processes around the whole world.

Keywords: Accessibility, Dial-a-Ride, Measures of quality, Public transport, Suburban areas.

1. INTRODUCTION

1.1. POSSIBLE PUBLIC TRANSPORT SYSTEMS IN SUBURBAN AREAS

The group of villages adjacent to the larger city will be called a “suburban area” in this paper. This term is not commonly used in scientific publications, but it corresponds to the classification of different areas. For example, Smith et al. (2012) produce some classes of areas based on the population size of settlements and the population density. These are: urban, rural town/town and fringe, village, dispersed/hamlet and dispersed. The area named “fringe” could be identified with suburbia. The agglomeration consists of a bigger city (the centre of agglomeration) and neighbouring communities (suburban areas).

Conditions appropriate to both urban and rural areas are observed in suburban areas. Density of population and buildings in suburbia is smaller than in a city. Transportation network is not very expanded there. Traffic jams are not so visible like in a city and they occur in a specific periods and on the specific directions. Derivation of this phenomenon is that the big number of people live in suburbia and they work in a city. It creates particular problems with planning and managing transportation systems for suburban areas, especially in public transport mode. The important fact is, that suburban areas develop dynamically, but their density decreases. Maksim (2012) describes the changes and continuities in the coordination of urban and transport planning on the example from Geneva. Important definitions inter alia of catchment area and a spatio-temporal delimitation of mobility have been studied recently by Gerber (2012).

Traditional and popular public transport systems based on suburban bus lines are not enough to create good quality for travellers, especially in competition with private cars. Cheng and Agrawal (2010) indicate that *transit agencies have never had an accurate indicator of the extent of their service area based on riders’ door-to-door travel time*. Dell’Olio et al. (2012) remind, on behalf of earlier studies, that it is more efficient to use smaller buses at higher frequencies. Although, often it is not possible due to large operating costs in comparison to poor number of passengers. The suburban rail systems are expanded with an addition of "Park and Ride" facilities. Role of these elements are recently studied by Holguı´n-Veras et al. (2012). According to quality's classification of Lovetta et al. (2002) even the integrated bus – rail – park and ride system could not offer a good service (where at least 90% of the residents should have four or more return daytime services every workday).

1.2. THE MEASURES OF ACCESSIBILITY

Specific methods and measures are necessary to evaluate the quality of public transport system in suburban areas. "Accessibility" is a commonly used term for such evaluation. For example, Moniruzzaman and Páez (2012) indicate, that *accessibility by transit is a significant predictor of modal share in their case study*. But Lei and Church (2010) remarked, that *accessibility is a concept that is not entirely easy to define*. Similarly, O'Sullivan et al. (2000) indicate, that *accessibility is generally agreed to be hard to define but critical to any serious understanding of transport issues*. Kuby et al. (2004) showed the importance of land use and accessibility. Employment, population, and percent renters within walking distance, as well as bus lines, park-and-ride spaces, and centrality, were significant. Velaga et al. (2012) examine the context for accessibility and connectivity in rural communities highlighting key transport and technology challenges.

Curtis and Scheurer (2010) wrote that *accessibility is a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index*. Accessibility should relate to personal access to travel and land use opportunities. These Authors introduce a measure, that uses average travel time along a route segment divided by the frequency of the service (number of departures per hour per direction) approximated a path distance. They collected the measures of accessibility: spatial separation, contour, gravity, competition, time-space, utility, network. Cheng and Agrawal (2010) developed the tool to analysing transit service coverage integrates all segments of a complete, door-to-door transit trip into the trip time calculations. Lei and Church (2010) took into consideration ratio of bus and car travel times.

Mavoa et al. (2012) describe two measures of access to public transport. The first is combined public transit and walking accessibility index, which measures potential access to destinations via public transit and walking modes. The sequent is a measure of transit frequency which is a measure of transit service level in an area. Travel time is used also as a measure of access. Burns and Inglis (2007) create a cost surface to determine the travel time to supermarkets and fast food outlets. The new models have combined distance and travel time measures for one or more transport mode. For example, an accessibility planning tool developed in Perth, Australia by Curtis and Scheurer (2010) adopted a minimum service frequency standard. The second approach includes all public transit trips when assigning a measure of service frequency. Mondou (2001) categorizes transit service frequency by how often a bus or train arrives. Lovett et al. (2002) use a combination of service frequency and population size. Accessibility to buses is classified based on the percentage of the population with access to a certain number of bus services per workday.

1.3. AIM AND CONTENT OF THE RESEARCH

The main aim of executed research is the evaluation of possible forms of public transport systems appropriate to suburban areas. Two measures of evaluation are developed, in sense of spatial and temporal accessibility. One example of a village located near the bigger Polish city is chosen as a case study. Three options of public transport system and three time horizons are taken into consideration. The options are evaluated based on assumed values of measures. Conditions to introduce the best option are described in the last part of paper.

2. MATERIAL AND METHODS

2.1. LOCALISATION OF STUDY AREA

The area considered in this study consists of two villages (separated rather administratively than functionally) named: Chrząstawa Wielka and Chrząstawa Mała. These settlements will be called further shortly as the "Village C". Village C is located near one of the bigger Polish cities – Wrocław (see Figure 1). Wrocław has about 630,000 and Village C about 1,800 inhabitants. However, this second number isn't representative due the settlements of some people without registration (there exists a group of people who do not appear in official statistics for smaller villages, but in fact live there). From this reason, only the number of residences (houses) will be adopted in the further calculations, with an assumption, that similar number of people live in one house.

Connections between the Village C and the centre of agglomeration (main railway station in Wrocław) will be analysed. This is the distance of about 20 km (in a straight line). In fact, the transport lines are a little longer. Road transport (bus or car) uses a route with length of about 23 km. Railway distance is about 25 km. Nowadays, in mode of public transport, only the bus connection functions. Railway line running near the Village C is used only for freight transport. Due to this reason, railways located near Wrocław and not used in passenger traffic are marked with no stations on Figure 1. It is possible to reactivate passenger traffic between the Village C and Wrocław. This possibility will be taken into consideration in the next part of this study.

relation to transportation network. Three time horizons of years: 2002, 2012 and 2022 are selected. Residences existing in year 2002 and 2012 are counted with the use of internet maps (with personal control in place). The number of possible buildings for year 2022 are forecasted with assumption that the number of buildings constructed between 2012 and 2022 will be at the same level like the number of buildings constructed between 2002 and 2012 (in correlation with observed and forecasted value of GDP). Localisation of possible buildings is derived from local plans, partially on the areas already today equipped with energy and water systems.

Road network is presented on the figures, with form characterising the year 2012 (it is assumed that each house is connected to road network), but public transport network is studied in three options. The first option is an existing bus system involving one line connecting the Village C and Wrocław. The second option concerns the modification and

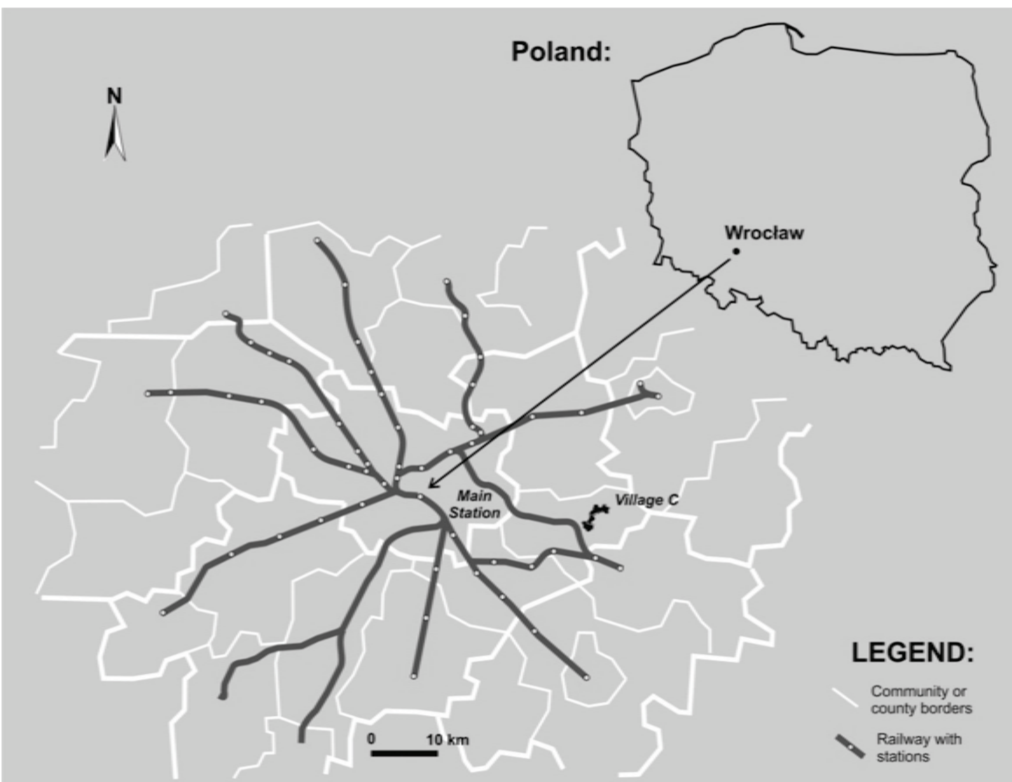

Fig. 1. Localisation of considered Village C as a part of suburban area of Wrocław.

development of the bus system with the addition of rail transit. More bus stops (plus slightly different bus route than today's) and combined bus – rail travel possibility are considered. A futuristic "dial-a-ride" system is studied in the third option.

2.2. TIME HORIZONS AND OPTIONS OF TRANSPORT SYSTEM

The range of residences from past, present and future are shown for selected time horizons in

The advanced dial-a-ride type of public transport system is described in Paquette et al. (2009) for example. They wrote, that *dial-a-ride systems may function very differently from one place to the next. Generally, users of dial-a-ride services must phone a call centre to reserve a trip*. They have provided a synthetic view of the wealth of research in the area of quality of service in dial-a-ride services. Three principal approaches, commonly employed to define quality were discussed: the customer-based approach (customer perceptions), the technical approach (specifications), and the philosophical approach (excellence).

A "catchment area", called in other studies as a "service zone", will be a field with acceptable walking distance between a residence (home) and stop or station. The number of residences located inside and outside the catchment area will be considered in further calculations.

2.3. ASSUMPTIONS AND VALUES USED IN SIMILAR STUDIES

The concrete values used to evaluation of quality of public transport system in sense of spatial and temporal accessibility are important to the further calculations. Curtis and Scheurer (2010) define the *walkable catchment* as a 10-min radius (800 m) around rail stations and a 5-min linear corridor (400 m) around bus routes. Similar values are adopted by Currie (2010). Mavoa et al. (2012) indicate, that researchers have typically used walking distances similar to *planners' rule of thumb* of 400 m (0.25 mile) and 800 m (0.5 mile) for estimating the distance people will walk to a transit stop or station. Estupiña´n and Rodrıguez (2008) used a 250 meter *station buffer*.

Jiang et al. (2012) examine BRT station walk access patterns in rapidly urbanizing China and the relationship between bus rapid transit (BRT) station context and corridor type and the distance people will walk to access the system (i.e., catchment area). The results suggest that people walk farther to BRT stations when the walking environment has certain features (median transit-way station location, shaded corridors, busy and interesting).

Curtis and Scheurer (2010) adopt a minimum service frequency standard of 30 minutes (or longer) during a workday. Mondou (2001) categorizes transit service frequency by how often a bus or train arrives (e.g. at least every 15 min, at least every 30 min, and 30 min and more). Lovett et al. (2002) define a moderate level of bus accessibility, as at least 50% of residents having one or more return daytime services each workday. Dell'Olio et al. (2012) wrote, using of earlier studies, that the value of the headway between buses should oscillate between 40 min maximum and 9 min minimum. Perugia et al. (2011) introduce a multi-objective model in which, among others, equity is considered by time windows on the arrival time of a bus at a stop.

Currie (2010) uses a combined measure of service frequency (vehicle trips per week) and access distance according to the formula (1).

$$SI_{CCD} = \sum N\left(\frac{Area_{Bn}}{Area_{CCD}} \cdot SL_{Bn}\right) \tag{1}$$

where:

SI_{CCD} is the supply index for the census collector districts (CCD),

N is the number of walk access buffers to stops or stations in each CCD,

Bn is the buffer n for each stop or station in each CCD,

$Area$ is the square kilometre spatial area of the CCD,

SL is the service level measure (number of bus/tram/train vehicle arrivals per week).

Jiang et al. (2012) analyse a measure called directness (d_s), for stations (2).

$$d_s = \frac{1}{N}\sum_i^N \frac{w_s^n}{l_s^n} \tag{2}$$

where:

w_s^n is the walking distance from the reported origin/destination of user n to station s,

l_s^n is the associated straight-line distance from the origin/destination of user n to station s,

N is the total number of survey respondents at the station.

Koopmans et al. (2012) construct an accessibility indicator following a simple gravity approach (3).

$$ACC_{i,t} = \frac{POP_{i,t}}{T_{ii,t}^{\beta}} + \sum_{j \neq i} \frac{POP_{j,t}}{T_{ij,t}^{\beta}} \qquad (3)$$

where:

$ACC_{i,t}$ is the accessibility of municipality i,
$POP_{i,t}$ is the population level,
$T_{ii,t}$ is the average internal travel time.

3. EVALUATION OF OPTIONS OF PUBLIC TRANSPORT SYSTEM (THEORY AND CALCULATION)

3.1. PROPOSED MEASURES TO EVALUATE THE QUALITY OF PUBLIC TRANSPORT SYSTEM IN SUBURBAN AREA

Two simple measures to evaluate the quality of public transport systems in the Village C are constructed. First measure corresponds to number of people who living near the stops or stations. It is called: "index of spatial access" and is described by formula (4).

$$I_1 = \frac{N_I}{N} \qquad (4)$$

where:

I_1 is the index of spatial access to stops or stations,
N_I is the number of residences inside the catchment area,
N_0 is the number of residences outside the catchment area,
N is the total number of residences calculated by formula (5).

$$N = N_0 + N_I \qquad (5)$$

Second measure to evaluate the quality of public transport system is connected with journey time between the Village C and agglomeration centre with consideration of waiting time on stops. This measure is called: "index of connection's to city centre quality" and is expressed by formula (6).

$$I_2 = \frac{t_{opt}}{t_0 + t_1} \qquad (6)$$

where:

I_2 is the index of connection's to city (agglomeration) centre quality,
t_{opt} is the travel time by a car [min],
t_0 is the average time of waiting on stop or station [min],
t_1 is the ride time inside a public transport (with addition of waiting time by a transfer) [min].

Developed measures are simple in form, but it is easy to collect the data needed to calculation. These measures don't describe the accurate accessibility to public transport system, but could be enough for comparison of different options of transport system with the use of similar data and assumptions.

3.2. DATA TO CALCULATIONS (OBTAINED ASSUMPTIONS AND VALUES)

Values of data to further calculations are collected in Table 1. The catchment area is here the circle with radius of 300 m. Such area encloses all bus stops and rail stations. Only in option 3, the catchment area has a form of a linear corridor, due to specificity of dial-a-ride bus system. Buses in this system use almost all roads in a village and can stop without official stops. Dimension (width) of this corridor is smaller than the radius in previous options and equals 200 m. The range of catchment areas are shown on Figures: 2 ÷ 6.

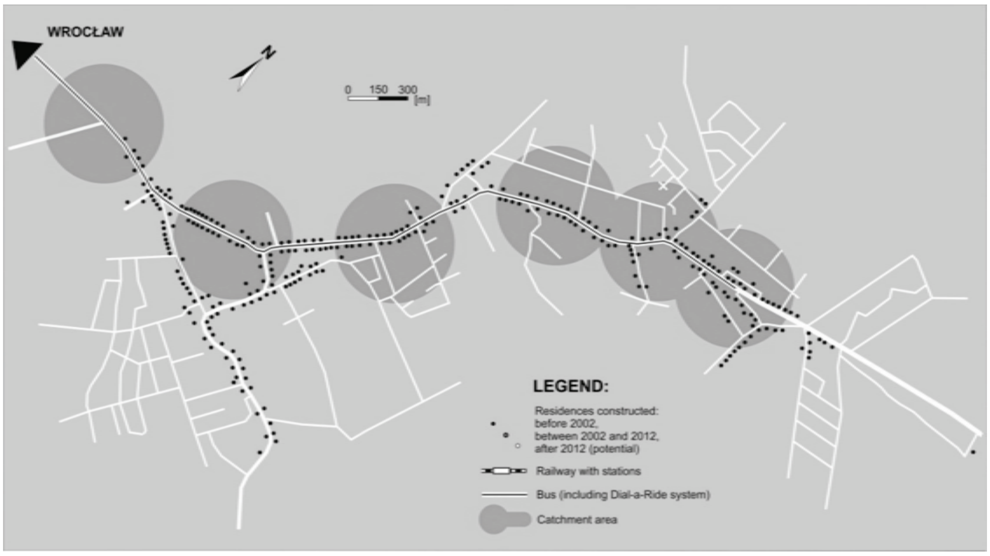

Fig. 2. Residences in year 2002 and catchment area of option 1.

Fig. 3. Residences in year 2012 and catchment area of option 1.

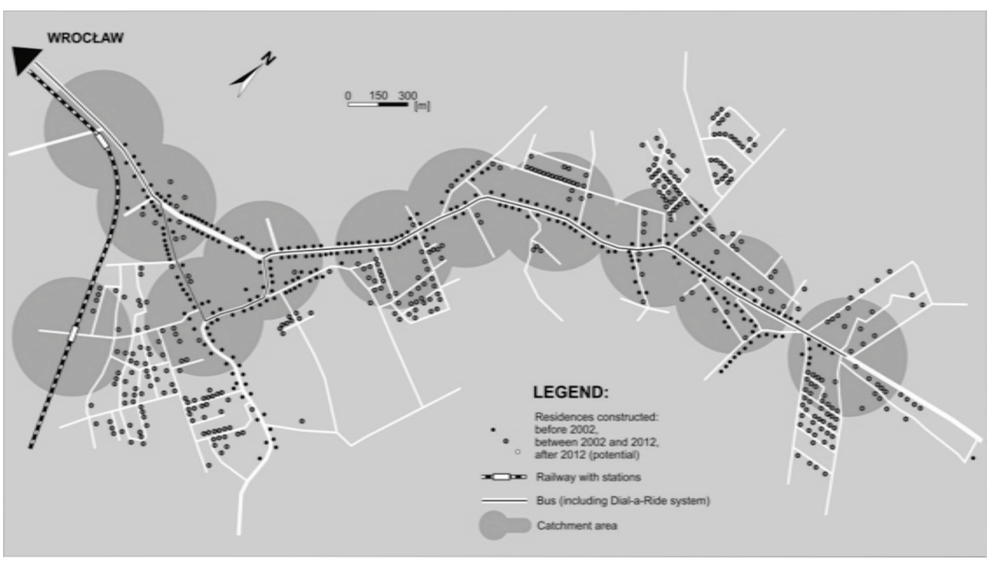

Fig. 4. Residences in year 2012 and catchment area of option 2.

Fig. 5. Residences in year 2022 and catchment area of option 2.

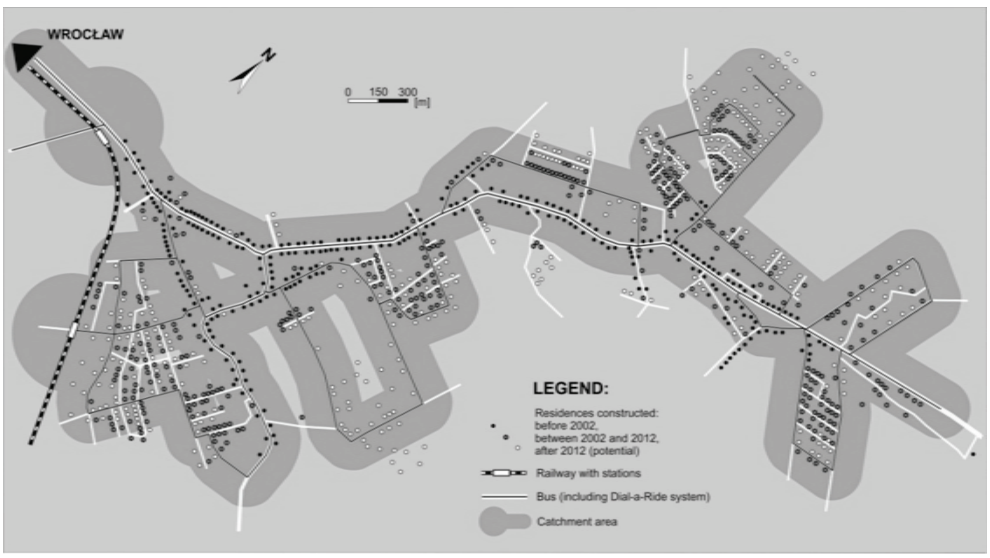

Fig. 6. Residences in year 2022 and catchment area of option 3.

The average time of waiting at a stop or a station, t0 is calculated as a half of the headways. Significant is, that in option 1 the bus operator must keep a connection between the Village C and agglomeration centre. Thus, the practical bus headway in option 1 equal two hours. In options 2 and 3 buses connecting the villages with rail network operate only in the suburban area. From this reason, the bus headways can be smaller there than in option 1. The bus headways are correlated to possible train headway. In option 2, the train headway is assumed like 60 min, as a starting value to a new public transport mean in agglomeration. In option 3, this headway is changed to 30 min (in a rush hour) according to possible growth of popularity of public transport system in the next years, partially as a effect of the use of a dial-a-ride system.

Table 1. Data to calculations.

Year	Option	N_I	N_0	N	t_0	t_1	t_0+t_1	t_{opt}
	1	171	123		60	55	115	
2002	2	268	26	294	30	45	75	55
	3	285	9		15	45	60	
	1	283	381		60	60	120	
2012	2	451	213	664	30	45	75	60
	3	649	15		15	45	60	
	1	353	647		60	65	125	
2022	2	578	422	1000	30	45	75	65
	3	953	47		15	45	60	

It is observed, that the travel time on the road network increases in subsequent years. Thus, the value of t_{opt} (according to car travel time) is 55 minutes in the year 2002, 60 minutes in the year

2012 and approximate 65 minutes in the year 2022. The ride time, t_1 by a bus in option 1 has the same values like the travel times in a car because buses use the same road network in this option (and the streets have only one carriageway). Operating times on stops located between the Village C and Wrocław are approximated in the same values like delays (time lost) of cars. Ride times, t_1 in option 2 and 3 are calculated with assumption that ride time to rail station in the Village C by bus equals 10 minutes, waiting time for a train is 10 minutes and ride time to agglomeration centre by rail equals 25 minutes. These times are constant in all time horizons due the lack of traffic jams in small Village C and due to separation of the rail network from the road network.

Moreover, the travel time (the sum of rides and waiting times) of public transport means in option 1 is greater than travel time by car and will be growing in the upcoming years.

4. RESULTS AND DISCUSSION

The values of author's indexes (calculated by formulas 4 and 6) are collected in Table 2. A car travel is recognized as a "reference level". It is assumed that all residences are located in the car catchment area, thus the index of spatial access (I_1) equals one hundred in the car transport mode. By the definition of the index of connections to city (agglomeration) centre quality (I_2), the value of this index equals one hundred in car transport mode too. In fact, the "maximum" (ideal) value of sum of both indexes equals always two hundred. The public transport system evaluated in value near 200 can really be competitive against private car transport.

Table 2. Values of measures.

Option	Year	I_1	I_2	$I_1 + I_2$
1	2002	58,2	47,8	106,0
	2012	42,6	50,0	92,6
	2022	35,3	52,0	87,3
2	2002	91,2	73,3	164,5
	2012	67,9	80,0	147,9
	2022	57,8	86,7	144,5
3	2002	96,9	91,7	188,6
	2012	97,7	100,0	197,7
	2022	95,3	108,3	**203,6**
car	(independent)	100,0	100,0	200,0

The option 1 receives worst marks (values of indexes) in all time horizons. The values of measure I_1 decrease in subsequent years for this option due developing of built-up areas far away the main street. The sum of both measures decreases over the subsequent years, although, the values of measure I_2 increasing due the longer travel time by a car.

The values of both indexes in option 2 are greater than in option 1. However, the values of I_1 decrease in coming years and the sum of indexes decreases too. This sum is distinctly smaller than the "reference level" (e.g. for the year 2022 for public transport system equals 144.5 in comparison to optimal 200).

The option 3 receives the best values of indexes. The values of index I_1 stay on the close level for all time horizons according to the specify of dial-a-ride system. In fact, by efficient organisation of public transport system, the values of this index could equal maximal one hundred in all time horizons. To the above, the sum of both indexes increases in the upcoming years and might be greater than "reference level" (200) in year 2022.

Results of calculations show that today's option of public transport system (option 1) will be not appropriate for developed suburban areas. The summarized value of both indexes in that option is greater than one hundred only in the past time horizon (year 2002). The option 2 could be appropriate for today's building condition (year 2012). But, due to further development of villages it must be treated only as a transitional stage to more advanced transport systems. Only the option 3 can be adaptive to developing suburban areas and competitive to private car transport.

5. CONCLUSIONS

The study shows that conventional (traditional) public transport system, based on bus lines connecting suburbia with agglomeration centre offers unattractive travel conditions in opposition to the private car transport system. The specific development of suburban areas with sparse residences located away from main roads and bus stops is the main reason of low quality of bus transport system. The second reason is the growth of traffic volume and travel time.

Some countries introduce combined public transport systems with the use of railway and buses. Railway is the main means of transport to connect suburbia and agglomeration centre. Bus becomes the additional means of transport to connect villages and rail station. This form of transportation system is studied and partially initiated now in Poland. Combined travel must work in the integrated fare system and must be fitted with a functional connection points (hubs) and integrated schedules. Also important is the high frequency (low headway) on rail and bus lines. These elements are introduced in Poland, too.

However, in the next decade, the combined bus – rail public transport system will not be competitive to car travel likewise. There is the need to search and plan more advanced public transport forms. It is possible to use of dial-a-ride system. Current research indicate some problems to be considered before introducing such solutions. Also the development of street network according to a new localisation of residences will be necessary to make possible the access of bus to all houses.

Velaga et al. (2012) explore barriers and opportunities to bring together transport and technology solutions to enhance rural accessibility and connectivity. They focus specifically on two issues of current research. At first, they discuss the role of information and associated technologies in supporting rural passengers on public transport. Secondly, they study the use of technologies to support flexible and demand responsive transport services in rural areas. They refer to the main architectural components of any technology-based flexible transport system such as: *control centre, customer devices, in vehicle on-board unit and equipment and communication devices*. Fu (2002) studies a variety of technology-oriented dial-a-ride systems operated in an urban environment and discusses the general concepts, models and computational techniques applied in the simulation system.

Diana and Dessouky (2004) present a heuristic attitude to solve a dial-a-ride problem with time windows. A new route initialization procedure is implemented that takes into account both the spatial and the temporal aspects of the problem. Paquette et al. (2009) collect quality of dial-a-ride system specifications used by researchers: *difference between actual and desired time, time windows, waiting time during the ride, waiting time before pickup, total waiting time, maximum ride time, mean ride time, excess of maximum ride time, ratio of actual ride time on direct ride time, excess ride time over direct time, total ride time, total time (between the call and the delivery time), maximum number of stops while a user is on board*.

Realisation of combined and integrated public transport system in Poland to connect suburbia with agglomeration centre is really urgent today. Local conditions indicate the realisation of bus - rail system as a transitional stage first. However, more advanced dial-a-ride systems should be studied and introduced right now. Presented examples could be adopted to other cities and countries due to similarity of urbanisation and transportation processes around the world.

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