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THE DYNAMICS OF THE POPULATION FLOWS IN METROPOLITAN AREAS

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ABSTRACT. The article presents an analysis of the dynamics of population flows in the corridors of the metropolitan area, based on the example of Poznan. The aim of these studies was to determine the mobile preferences of the population as well as the possibilities for improving the efficiency of the city transport, mainly in aspects related to the road congestion and its reducing by the better use of the existing railway infrastructure as well as other instruments of the transport policy. The results obtained in multi-methods analysis showed, that such solution is likely to be a successful one as an alternative to the road transport and different strategies and solutions, designed in accordance with articulated preferences of the population, may be more effective than large-scale initiatives issued by a superior. The "difficult" heritage of the poorly used or unused railway infrastructure, occurring in many urban areas, can be often successfully adapted to be a solution for the transportation needs of the inhabitants.

Key words: metropolitan area, city management, congestion, passenger transport, city logistics, transportation, commuting to work, flows of the population.

INTRODUCTION

The spatial development of urban areas and continually growing needs of the population in terms of mobility (to move faster and further) significantly affect the systems of the passenger transport. The fulfilment of these needs and at the same time the minimizing any negative impacts of the transport on the social and economic environment is very difficult and responsible task for many areas of the science. The city passenger transport means not only the transfer of the people in the space, but also a dynamic influence on the entire system of the logistic infrastructure of the city and therefore it became the topic of the interest of researches as well as experts, who optimize the management of city areas. The researches of preferences between means of the transport or traffic routes, the modelling of interactions between users as well as costs and profits analysis make the transport field the research topic mainly for economists and scientists involved in the transport management. The quantitative modelling of transport systems is also an important task for traffic engineers. All these approaches are presented more or less in this paper. The common desire to understand the behaviour and to learn the preferences of the inhabitants, as well as to improve the efficiency of the city transport, mainly in aspects connecting with road congestion, shares all these approaches.

The road congestion is today probably one of the biggest problems of city transport systems. The road congestion, defined usually as the overcumulation of vehicles on the road, could lead to overload of transport network and ultimately to the stop of the flows [Tundys 2008]. One of the proposed solutions for this situation is to provide the alternative public transport system, e.g. rail one, which

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could take over some part of persons travelling by cars. Such solutions, increasing the trouble-free flow, are introduced already in many urban areas all over the world. The introduction of such type of a solution is still not fully examined in cities of former socialist countries, where the sudden political and economical transformation of the end of twentieth century increased the problem of the road congestion to the unprecedented proportions. Therefore the aim of researches made and described in the presented paper, is to determine whether the inclusion of existing railway infrastructure of urban and suburban areas could lead to decreasing of the road congestion and obtaining the improvement of management of population flows in existing transport corridors. The extended area of agglomeration of Poznan, so-called Poznan metropolitan area, was chosen to be the area of this research. It consists of the city of Poznan and 17 surrounding municipalities. The population of chosen area is over 850 000 inhabitants [GUS 2010]. The base study was conducted for the selected city within this area in three main transport corridors, associated with flows of the population and extended in north, east and south directions starting from the centre of the city along the existing roads – in the form of roads and railway lines. The peculiarity of the area covered by the research is the constantly congestion problems of the roads system at peak hours while at the same time the railway lines reveal the big reserves – they are not intensively exploited, since the majority of regional transport connections (mainly due to the lack of the profitability) was cancelled in the mid of 90's last century. The considerable part of flows of the population is realized at present by the use of personal cars (e.g. daily commuting to work). It leads to increasing of the congestion in the city and decreasing the average speed of the travel. The metropolitan area of Poznan has well developed and practically poorly operated railway infrastructure, which could be relatively quickly adapted to the needs of the transport system between urban and suburban areas, similar to an existing system in London, Berlin or Paris. Providing such public transport system, based on the already existing infrastructure, could efficiently improve the conditions of the transport of the population both in city area and practically in the whole metropolitan area.

Hence, this research is characterized by the duality of the scientific aim:

- a congitive aspect – to determine the influence of the population flows in the agglomeration of Poznan on the transport infrastructure of the city,
- a utilitarian aspect – to determine in what context and whether the inclusion of the existing urban and suburban railway infrastructure can reduce the road congestion and consequently improve the management of the population flows.

THE DETERMINANTS OF FLOWS OF THE POPULATION IN METROPOLITAN AREAS

The high tendency to the mobility of the population in urban areas and the passengers' flows and congestion problems resulted from this, are related to every bigger urban agglomeration all over the world. It is practically not depended on the level of economical development of the country. The urban areas are the areas created by humans with the participation of environmental, social and economical factors and characterized by the increased density of building, compared to surrounding areas. It is connected with the constant trend of growing number of inhabitants of urban areas in comparing to rural areas. This trend is expected to be continued in the future.

The congestion of the road traffic in the cities is understood as the situation of the accumulation of vehicles leading to the overload of the transportation network as well as many social, economical and ecological problems connected with this [Pawlak 2007].

The passenger transport has been always one of the key subsystem of urban areas [Tundys 2008] fulfilling the needs of mobility of the population [Matulewski et al. 2007]. The significance of the assurance of the realisation of these opportunities has been identified by Peter Hall, as one of the most important factors influencing the convenient conditions of the life. The possibility to travel gives the chance to discover and meet new people and in turn to develop the conditions of the creative environment, where the innovations, art and science could be dynamically developed. While cities and

metropolitan areas has evolved for long periods of time (some of them creating bigger city-regions and some polycentric agglomerations), the passenger transports will remain an indispensable element of their functionality, providing the connection between the densely populated centres and integrating the various functional areas of the city (residential, commercial or recreational one) into one system [Broll 2004, Hall, Pain 2006]. The transport is clearly called by Pawlak [2007] to be the power keeping the cohesion of the city, while Tundys [2008] points out, that transport allows the city to shape and define its metropolitan area (spheres of influences).

The congestion as an occurrence resulting from the division of the cities into the various functional spheres and the need of population's mobility, resulting from that [Domanski 2006] seems to be treated almost as an axiom in the specialist literature [Rodrigue 2006]. However, what is the extent of the researches of this causality justified by empirical researches? While examining the case of commuting to work in Barcelona, Asesnsio [2002] concluded, that the suburbanization is the main reason of the creation of passengers' flows and not only cars flows. Similarly, Luo [2010] showed in his studies the connection between the development of suburban areas and the increased road traffic. The study published by Forbes journal showed, that American cities with large suburbs areas and no public transport system, experience considerable difficulties caused by the high level of the road congestion [Forbes 2010b]. Pawlak [2008] showed, that within the Poznan metropolitan area, towns located closer to Poznan are characterized by higher proportion of transport flows, caused by the high level of commuting of the population to the work. Nevertheless, the results of the researches conducted in Tallinn metropolitan area [Tammaru 2004] proved, that not only suburbanization but also the social and economical system transformation has led the people to change the preferences of the transport, from the abandonment of the public system in the direction to use their own cars, which resulted in the increase of the congestion. It showed the great complexity of this topic and emphasized the importance of this analysis in the context of the system transformations, which have taken place in last twenty years in all post-socialist countries.

The question arising from the assumption, that the commuting to the work is the dominant factor increasing the road congestion, is how this problem can be solved. It seems, that creating more spatially compact cities could be the best option, although it also seems that the change of the rhythm of working time [Down 2004] reducing the number of rides in peak hours could be the solution. Both solutions seems to be quite radical approaches, which require dramatic changes in the process of shaping the urban space, the transformation of social and economical systems as well as the inversion of advanced processes of the decentralization. In the light of such extreme approaches, the rational adaptation of already existing factors creating the urban areas seems to be more probable. Hence, providing the fast, clean and relatively comfortable public transport, which could compete with cars [Rzeczyński 2007], is considered to be the appropriate and realistic solution.

One of the solutions to solve the problem of the road congestion is clearly to change the preferences of as big as possibly numbers of cars' users in the direction of other (alternative) means of the transport. However such advantages of public transport like the safety, the environmental friendliness and higher transport efficiency are well known, it also seems to be important to hear the voices of sceptics, who claim that the influence of the means of the public transport on the total efficiency of transport network of the city could be limited, e.g. by the level of the development of the infrastructure. However, most of the described in the literature study cases for different sizes of the cities, confirms rather the usefulness of the public transport. It was demonstrated based on the analysis of the metropolitan area of Barcelona [Asensio 2002] that suburban trains are able to take over the significant passengers' flows of people commuting to work and therefore to reduce considerably the intensity of the road traffic. The permanent reduction of the number of connections and closing the whole railway lines in the period of last years were undoubtedly the reasons of big problems connected with the road traffic in British urban areas. The commonly used "emergency" programs, aimed mainly to increase the roads' throughput, proved to be greatly a failure. They caused the mass car mobility, which consequently led to the quick increase of the road congestion. On the other hand, the trials undertaken in many metropolitan areas of the rebuilding of the old railway infrastructure into the modern "light" suburban trains led to an unquestionable success – even in such German cities like Freiburg or Hamburg, which now have one of the most effectively operated city transport networks in Europe. The analysis published by Forbes [Forbes 2010a] shows, that the average speed of the car in

Hamburg is 84 km/h, which is almost four times faster than in London (19 km/h) or in Poznan (21,4 km/h) [Bojarski, Kowalski 2008]. However the experiences of many British cities in the eighties of last century, even the economical recession caused the decline of the share of private cars in the total amount of realized commuting rides may suggest, that the years of economical crises can have paradoxically the positive influence on the improving of the efficiency of urban transport systems. The specialist literature offers various ideas and study cases, while often giving practical examples, where they were implemented with the positive or negative effect. However, a simple application of such types of solutions in the cities of former socialist countries remains a topic not fully explored. The consequences of political and economical transformation of the 90's, manifest, among others, in dynamic processes of the suburbanization and the increase of the level of the road congestion – the situation known so far mainly only in the cities of Western Europe or USA [Parysek, Mierzejewska 2006]. The tools to solve such transport problems are mainly very sophisticated and concern large-scale solutions and therefore they are also very expensive [Fularz 2004]. On the other hand, the possibility to adopt the existing railway infrastructure to solve these problems were practically ignored in the former socialist countries, although such solutions were suggested for Wrocław [Antonowicz, Zielaskiewicz 2004], but only for the transport of goods. According to the author, there are so far underestimated but significant possibilities in the metropolitan area of Poznan, to adopt the existing railway infrastructure for passenger transport within the whole metropolitan area.

Summary, many of practical solutions implemented in cities all over the world implies the search for solutions of problems of the road congestion of urban areas towards the greater usage of the public transport, especially the railway transport.

Providing a well-functioning public transport system can be a very useful tool to improving urban systems of the public transport. Nevertheless, only the presence of buses, trams or suburban trains does not lead automatically to increasing the balance between the systems [Richardson 2005]. The expression "sustainability" includes the multidimensional optimization, being a result of long-term interactions of both economical and non-economical factors. The ignoring of these factors, especially the social ones, can lead to the failure of that policy. For example, the drivers in countries, where there is a strong tradition to use their own car, e.g. in USA, will accept less likely the suggestion to use the public transport only due to the reason, the public transport is available. Consequently, it might lead even to the increase of numbers of vehicles on the roads and thereby to the increase of the road congestion. Such situation, so called Braess paradox (the introduction of the additional possibility of transport connection increases the total social cost of the transport), can be a very serious obstacle to the sustainability of the city public transport [Quinet, Vickerman 2004].

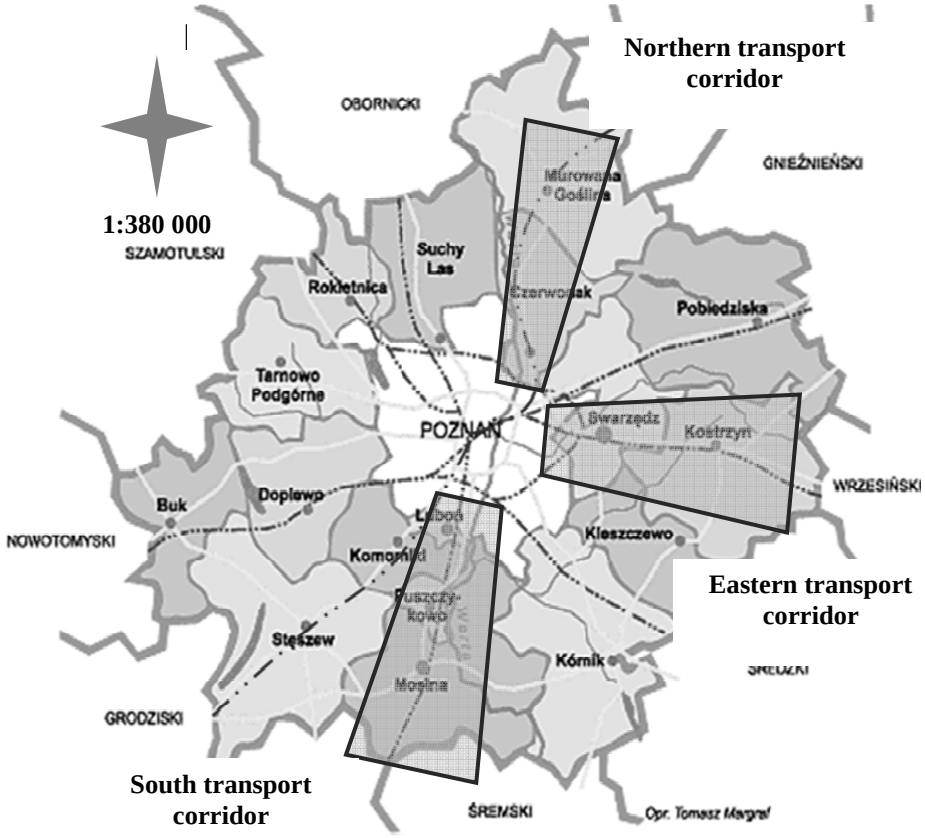
The previous experiences resulted from the rational city management shows, that the public transport is desirable in situations, where the area arrangement minimizes the needs of the mobility of inhabitants, while some researches indicate more the radical vision. The idea of "car-free cities" means that the use of cars is forbidden and only the means of the public transport give the opportunity to travel [Crawford 2000]. It should be pointed out, that if the use of a car is a rational response to existing conditions, it is necessary to provide a rational alternative as well as to inform people about it.

The means of the public transport, despite their abilities to reduce the road congestion, are very expensive projects, even if they are based on the existing infrastructure. The potential failure connected with their wider usage would be significant, and therefore no authority would be willing to accept such situation, especially in the cities of former socialist countries, where the infrastructures resources are still limited. In such case, the post factum analysis of the unsuccessful new projects is unacceptable. The approach ante factum seems to be more appropriate, when the potential users (in this case, commuting to work and schools) are directly asked about their preferences and opinions concerning the proposed transport solutions, including the alternative ones.

THE MANAGEMENT OF INHABINTANTS FLOWS IN METROPOLITAN AREA OF POZNAN

The Poznan metropolitan area is characterized by a very convenient configuration of the transport infrastructure, the high density of the road network and the relatively accessible railway network. Additionally their tracks run often parallel to each other. While the congestion can be observed in the peak hours on the roads, situated along these corridors, the railway lines also situated along these corridors seem to be not used properly. The reduction of local railway connections almost to zero, conducted in 90's of the last century (like in other regions in Poland) is the main reason to the present situation of the lack of the usage of railway lines. Meanwhile, the system of the suburban railway transport, based on existing infrastructure (rail buses, suburban trains), could be certainly a useful alternative to the road system, based on car transport, and consequently leads to the reduction of the road congestion, the unfavourable situation for the whole area.

The research of the dynamics of the population flows were made along three transport corridors of Poznan metropolitan area. These corridors run through the municipalities and towns, where the seats of local governments are located (Fig. 1). There were three reasons for choosing such area of the research: the configuration of the communication infrastructure of the whole region, the availability of data and practical considerations, mainly connected with the possibility of the realisation of further own researches.



Source: own work

Fig. 1. The main transport corridors of population flows in Poznan metropolitan area
Rys. 1. Główne korytarze transportowe przepływów ludności w obszarze metropolitalnym Poznania

The three selected corridors give a very good spatial, environmental, social and economical background to conduct the research of such types of possibilities. The main reasons are: high

population's density of areas, which are under the influence of these corridors (i.e. a lot of potential passengers), the localisation along main roads and railway routes (the easier substitution in the relation car-train) as well as the existence of relatively good infrastructure of train stations in towns situated along the analyzed routes.

The observations made during the conducted analysis of the spatial dynamics of population flows (associated with commuting to work and schools) were, that these flows are the biggest in the morning (between 6 and 10 o'clock) in the south corridor and the smallest in north one. In addition, the flows are cumulated close to the administrative borders of the city, which makes these parts of the corridors more vulnerable to the congestion. It was found, that the most important targets of these flows are the centre of the city (due to the high concentration of workplaces and schools) and the areas located along the corridors already within the borders of the city. It means that besides the commuting to the centre, people also travel at shorter distances – closer to their places of the residence. The probability of such distributions was confirmed by the high value of the Pearson's correlation coefficient (0,958), which confirms the travels made by the use of cars are the main method of the movement of people (60%) among the locations of suburban areas and Poznan. However, in case of the section of the road between Lubon and Poznan (southern corridor), the commuting realised by cars has a smaller share, probably due to the greater availability of good connections provided by public transport (buses and trains). There is also a big share of commuting rides, realised after 10 o'clock, which excludes this group from the test group of commuting to the work or schools. The part of eastern corridor between Swarzedz and Poznan has a fairly big share of commuting rides realised by cars, which can be caused by the good infrastructure (highway), which encourages (raises demand) to use individual rather than public means of the transport.

The importance of such events for transport system of the whole areas is very significant. 75% of total flows of population in all corridors occurs between 6 and 10 o'clock; however, it is even more concentrated in northern corridor, i.e. between 6 and 8 o'clock. The peak hours in the afternoon for this corridor occurs earlier (already before 16 o'clock), while it is more extended in two other corridors and takes place between 15 and 20 o'clock. However, the morning travels between 6 and 10 o'clock and returns (from Poznan) in the afternoon can be regarded as the typical ones for the whole metropolitan area. It also confirms pattern of periodic and regular character of commuting to work and schools in the metropolis, well known from other urban areas [Rodrigue et al. 2006].

The main traffic roads within the corridors (having the bigger throughput than by-streets connected with them) are more preferred than byways and so called short cuts. The highest but still small tendency (app. 25%) to such short cuts is among the users of the southern corridor and the smallest one among those, who use the northern corridor. This discrepancy can be explained by the bigger density of the transport network in the south, and therefore giving the greater possibility to use different routes. Regarding the volume of the road traffic, there are significant differences among corridors, resulting probably from the population density as well as the structure of the transport network of the suburban areas. The similarity of daily cycle of dynamics of the movement of the people to the fluctuation of flows, realized as the commuting to work and schools, seems to be very interesting, with strongly recognized peaks: in the morning (till 10 o'clock) and in the afternoon (between 15 and 18 o'clock). The additional occurrence was observed within the eastern corridor: significantly smaller share of people from the municipalities adjacent to this corridor (24,3%), in comparison to 50,5% in the southern corridor and 55,2% in the northern one. These smaller values result from a greater role of the eastern corridor as a transit route of clearly over regional importance.

Considering the conditions of the road congestion, the average measured speed of the movement was significantly smaller than the speed in conditions of the free movement, which corresponds to so called Relative Delay Rate (RDR), being greater than zero. The worst situation was identified during the morning peak, along the northern and eastern corridors and in the afternoon along the southern corridor – the average speed were half of this under free movement conditions (respectively 31,1 km/h, 42 km/h and 34,4 km/h). It is equal to RDR indicators, having in these cases respectively 100%, 64% and 94%. It means that people spend in their cars while commuting to work and schools twice as much time as in the conditions of free movement for the same distance. It seems also interesting, that in case of the southern corridor, the number of cars in the morning peak hours is higher than in the

afternoon, while delays show the reverse tendency. The reason of such situation is probably the influence of other factors, e.g. changes in the traffic not related to the population displacement. The significant delays were also observed in the morning in the southern corridor and even during the day in the eastern and southern one. In such cases, the average speed fell significantly below 50km/h and thus causing the increase of the RDR indicator over 30%. It means, the throughput of these routes is definitely too small comparing to the roads' load. The average speed of the movement in remaining cases was significantly more than 50 km/h (RDR indicator below 20%), i.e. within the conditions of the free movement (restricted only by traffic regulations). The peak in the afternoon in the eastern corridor was a surprise in this study. It was characterized by lower level of the congestion, which means that (on the contrary to common opinions) the increased level of the traffic does not necessary lead to the delays in the movement of the people. In addition to temporary fluctuations, the RDR indicator showed the spatial diversification, mainly in the area of the northern corridor, where the parts of roads located close to the administrative borders of the city generated bigger delays due to the traffic jams. The explanations of such events should be found in the high accumulation of the flows of vehicles and the control processes of these flows at the crossroads with traffic lights. There were practically no such situations in other corridors, probably connected with the higher throughput of routs, which managed more smoothly the accumulations of the flows of vehicles.

The overview of the present road conditions and the ways of the realisation of the commuting to work and schools in metropolitan area of Poznan showed that the congestion causes the delays of the flows of the population in analyzed transport corridors. The interesting reference to conducted studies is how these commuters perceived this situation. The opinions of the inhabitants of locations within the analyzed area are various, as it could be expected. The inhabitants of the northern corridor are most dissatisfied with the current situation, mainly due to big delays in the morning peak hours. The situation is much better in other corridors, but nevertheless, only the small part of these respondents of surveyed population is actually content about the conditions of their commuting. Many of those people are already used to such situation and do not perceive the current situation negatively.

Based on the conducted researches, some characteristics connected with the intensity and the distribution of commuting to work and the road congestion seem to be convergent. Despite the fact, that the research was done on the bigger amount of data, the strongest relationship was found between the volume of passenger flows and total flows, since up to 98,2% of the variability of first feature was explained by the second one. The gradient of this function describes the value, by which the traffic level increases by every additional individual car, i.e. there is a relation: one individual car to 0,14 vehicle of other type.

The constant coefficient is not reliable in this case, due to its low statistical value ($p>0,05$). On the other side, the relationship between the volume of commuting cars and the traffic level is weaker, but nevertheless the observation can be made, that the correlation between individual cars and total passenger flows is higher. It confirms the assumption, that the change of the amount of people commuting to work can more likely affect the intensity of passenger flows than the total transport flow (which includes also the transport of the goods). Despite the fact, that only the half of the variability is explained by the changes in volumes of commuters using individual cars, it seems important to emphasize, that there are also other factors, like daily fluctuations in transit flow, which can play a significant role.

In addition to relationships between volumes of passenger and total flows, the regression analysis showed also significant connections between commuting and transport flows connected with these rides and the road congestion. The regression analysis, including so-called relative delay ratio (RDR) did not provided promising results, which was shown by high values p and small determination coefficients. On the contrary, the analysis of the average speed gave better results. The constant coefficient for the line of the best adjustment can be interpreted as the speed in the situation of no congestion, although this value (obtained during the regression analysis for 86 km/h) seems to be even too high. It is due to the traffic regulations and some restrictions of the modelling process. In addition, the coefficient of the line gradient describes the value by which the speed of the vehicle will be changed in case an additional vehicle or a person will join the flow. It turned out, that this relationship is rather of logarithmic nature, while the higher determination coefficient (R^2) and the smaller standard

error (S) were obtained for logarithmized date. It means these date fit better than the date without the logarithmic transformation. In other words, the average speed of the vehicle is changed rather as a natural logarithm of the flow volume (the convex dependence) – e.g. the speed of the travel decreases rapidly at the lower unit volume of the rides, which could be interpreted as follows: when the transport flows are bigger, each individual person in the vehicle can affect more the speed of the flow by the reduction of the actual amount of vehicles being in the motion. This is although less important with the increasing of the congestion level, when the network is overloaded up to critical values. The difference between standing in a traffic jam involving 1000 or 1100 vehicles is less noticeable than the difference between standing in a traffic jam involving 10 or 100 vehicles.

The analysis of regression residuals of the lines of the best adjustments for variable defined as a number of places in vehicles of the commuters is needed for proper stochastic modelling of the volume and the road congestion. This modelling was performed for various scenarios of the population flows in transport corridors of Poznan agglomeration.

The research of the influence of the introduction of proposed project of suburban trains and additional incentive instruments (or disincentive ones) for the individual commuting by cars was made by the help of the survey. The volume of these flows was modelled for six various scenarios:

- basic – introduction only the suburban trains, without additional instruments for the regulation of the flows,
- MBS – combination optimizing the most effective instruments for the regulation of the flows, without the system of charges connected with congestion and the increase of parking charges in the city area,
- MBS* - combination optimizing the most effective instruments for the regulation of the flows, including the system of charges connected with the congestion and the increase of parking charges in the city area,
- introduction of the congestion charges – option of the introduction of the congestion charges for city area of Poznan during weekdays,
- increase of the parking charges – the option of the increase of the parking charges in city area of Poznan,
- simultaneous introduction of congestion charges and the increase of parking charges - simultaneous introduction of congestion charges in weekdays and the increase of parking charges in city area of Poznan.

The hourly distributions of the flows obtained from the researches were compared to the current situation, e.g. without a more efficient use of the existing railway infrastructure. The results confirmed the assumptions, that only the introduction of the new project of suburban trains (basis scenario) has a great influence on the reduction of the morning peak by approximately 1100 (32%), 1600 (38%) and 2600 (59%) rides per hour along respectively: northern, eastern and southern transport corridor. The greatest scepticism to the introduction of such a solution was recorded among the inhabitants, using the northern corridor. The users of the eastern corridor showed more enthusiasm about it, but the greatest interest was observed along the southern corridor. In this case, the people, having the modern and fast railway transport, were more likely to use the alternative solution instead of using their own cars. The commuting by the use of railway is already at present realised along the southern corridor more often than in eastern and northern corridor, and probably it is the reason of the obtained results.

The analysis of the scenarios including additional instruments regulating the flows (as accelerators or inhibitors) showed that the best results were obtained by the use of the scenarios MBS and MBS* - the combinations reducing the modelled level of the use of individual cars as the mean of commuting to the level below 20 or even 10% of the initial volume. The smallest volume of commuting travels in these scenarios was recorded in the northern corridor, where the additional instruments regulating the commuting flows would probably find the best adjustment to the preferences among commuters, using their cars. On the other side, the biggest flows would remain in the eastern corridor, confirming the big preferences of those inhabitants to use their own cars. The confidence interval in these researches is between 10-12% and therefore the differences between the results of MBS and MBS* scenarios are

not significant. It means, the solutions such as congestion charges and changes in parking charges could be replaced by local instruments regulating the flows, e.g. buffer parking around the railway stations (so called park-and-ride ones).

On the other hand, the influence of congestion charges and the increase of parking charges within the city area as the instruments of commuting policy were identified as a significant one. However, this effect is various in the various examined corridors, the smallest impact was observed in the southern corridor, when the introduction only of the additional trains was a sufficient incentive to resign from own cars. The obtained results are less promising in other corridors, where the bigger preferences to use own cars were recorded. Summary – the congestion charges have the stronger influence on the reduction of usage of the own car than the parking charges. Therefore, it is not surprising, that the combination of these two solutions is of the synergistic nature and so-called final result of their introduction is biggest than the simple sum of them. It should be noted however, that this increases in not significant, due to the fact, that it concerns the same group of the population. The obtained results show that the inhabitants prefer to use their own cars despite the congestion charges and the parking charges within the city zone and therefore other instruments should be applied.

The introduction of the suburban trains, especially associated with the introduction of the other instruments regulating the flow (based on the system encouraging the desirable behaviours and discouraging the undesirable behaviours), shows the high potential for the possible reduction of the commuting rides performed by cars. However, the influence of this solution on the traffic level and the congestion is of the highest importance in the estimation of its usefulness.

Two lines of the best adjustments from the regression analysis (table 1) were obtained during this research. The formula, obtained as its result and describing the relative delay rate as well as total road flow as a function of the volume of commuters using their cars, were considered statistically poorly explained for forecasting purposes (in first case – high values p, in second case – low value of the coefficient R^2). Therefore, the evaluation of the effectiveness of this project to reduce the road congestion is based on the changes of the average speed of the vehicle.

The obtained results (comparing to initial conditions along the northern corridors and after the introduction of expected scenarios) show, that the midday and all-day traffic will be significantly reduced (even after the introduction of the basic scenario only). It would lead to the higher speed of the vehicle, practically similar to the speed in the congestion-free conditions (small differences ±10km/h are negligible, due to the size of the confidence interval and the value of the standard deviation S).

The greater variability of the traffic volume is observed during the morning peak, which indicates its greater dependence in relation to the proposed introduction of suburban trains. The congestion charges and the increase of the parking charges in the city area of Poznan, would reduce the level of the road traffic – but not as efficiently as MBS and MBS* scenarios. The interesting results can be observed during the analysis of the basic scenario – the level of the road traffic is higher after the introduction of the project of suburban trains in comparison to situation before this introduction. The limited accuracy of the model function obtained from the regression analysis is the reason of this and therefore it should not be taken for the forecasting. The situation in the eastern corridor is similar to the situation in the northern corridor. The mere introduction of suburban trains reduces the volume of individual cars to the level of 400 per hour during the day and in the afternoon peaks, which enable to obtain the speed of the car close to the values characteristic for the traffic in free conditions – limited only by the valid traffic regulations (with the confidence interval 10,03% and at the confidence level 95%). The reduction of the amount of individual cars would be associated with the increase of the average speed of the car also during the morning peaks. The scenarios MBS and MBS* turn out to be once again the most effective ones. The differences between their influence and the introduction of the congestion charges and the increase of the parking charges are not so significant as in the case of the northern corridor. The habits of people to use their own cars as well as some facilities related to this, e.g. possibility to use the highway – can be the reason of this. The final effect of the introduction of suburban trains along the eastern corridor manifested in higher speed of all passengers and the reduction of the road congestion. The reduction of the flows along the southern corridor was not so high during the day and in the afternoon peaks (with the confidence interval 10,87% and at the

confidence level 95%). However the expected increase of the average speed of the car in these periods of the time is more significant, which could suggest, that the road congestion in this corridor is not caused by the individual cars, but rather by other vehicles involved in the traffic of this corridor.

Table 1. Formulas obtained and used to model the passenger traffic and the average speed of the car
Tabela 1. Formuły uzyskane i używane do modelowania ruchu pasażerskiego oraz średniej prędkości przejazdu

Variable (x)	**Variable (y)**	**Line of the best adjustment**	**S**	**R^2**	***p***	***p* const**
CCV	PTV	$y = 421 + 0.193x$	348	51.0%	0.009	0.007
Ln(CCV)	AS	$y = 86.1 – 5\ .60x$	9.18	44.6%	0.018	0.001

Remarks: Amount of surveys: 3200
- *CCV – amount of places in vehicles of commuters*
- *PTV – volume of the passenger road traffic*
- *AS – average speed of the car*

Source: own calculations base on date obtained from Municipal Roads Management in Poznan and own surveys

In the case of the morning peaks, the mere introduction of suburban trains reduces the number of individual cars up to the situation, where the additional instruments regulating the flows are not necessary. It is the result of the more positive attitude of inhabitants using the southern corridor to the train transport and therefore there is no need to use the additional instruments, based on the system, which encourages the desirable behaviours and discourages the undesirable behaviours in this regard.

Following this study, the commuting passenger transport was stated to play the key role within the whole area of the agglomeration of Poznan. The most of the inhabitants would not be able to reach their workplaces, schools and services without the proper functioning of this transport, and it could disturb the integration and the competiveness of the whole metropolitan area [Broll 2004]. The examined dynamics of population flows indicates that the commuting rides based on individual cars are the basis of all passengers' flows occurring between suburban areas and Poznan. The central part of the city is the most intensively used one for this purpose. It means, that thousands of cars enter every day this area, limited spatially, and additionally reduce its throughput. It means that these shuttle flows seriously influence the functioning of the transport system of the city as a whole. It is also the confirmation of a well-known rule of internal relationships of the metropolis, which manifests not only in the influence of the city on the surroundings but also vice-versa, at least at an equivalent level. Therefore, the efficient and effectively functioning system of the public transport seems to be indispensable to achieve the long-term competitiveness and the viability of the whole agglomeration area.

Although, the cyclic fluctuations of the flows were observed along all transport corridors, there are big differences in their volumes, directions, scheduling and the types of used means of the transport. The morning and afternoon peaks of passenger flows are characteristic for all corridors and are equal to the maximal value of the volume of the road traffic. It is also the confirmation of a well-know theoretical relationship between the suburbanization and the increase of the road traffic [Rodrigue 2006].

However, the results obtained from the researches not always confirm this statement. It turn out, that the biggest delays were recorded along the northern corridor, being the least urbanized one and of the lowest density of the population. The underdevelopment of the communication infrastructure and practically no alternative connections (detours, shortcuts) seems to be the critical factors in this case. This situation is consistent with other situations observed in 80's of the last century in many cities of the West. Consequently, it was the significant impulse to create modern and efficient transport systems. However, the researches of schedules of the flows, in the connection with the average speed of the car and the relative delay ratio revealed an additional factor, causing the congestion in the northern corridor – the limitation of time of the peaks of the cars' concentration only to two hours – in comparison to four hours in other corridors. Unfortunately, the reason of such situation cannot be fully explained using the conducted researches and can be a good reason for further investigations.

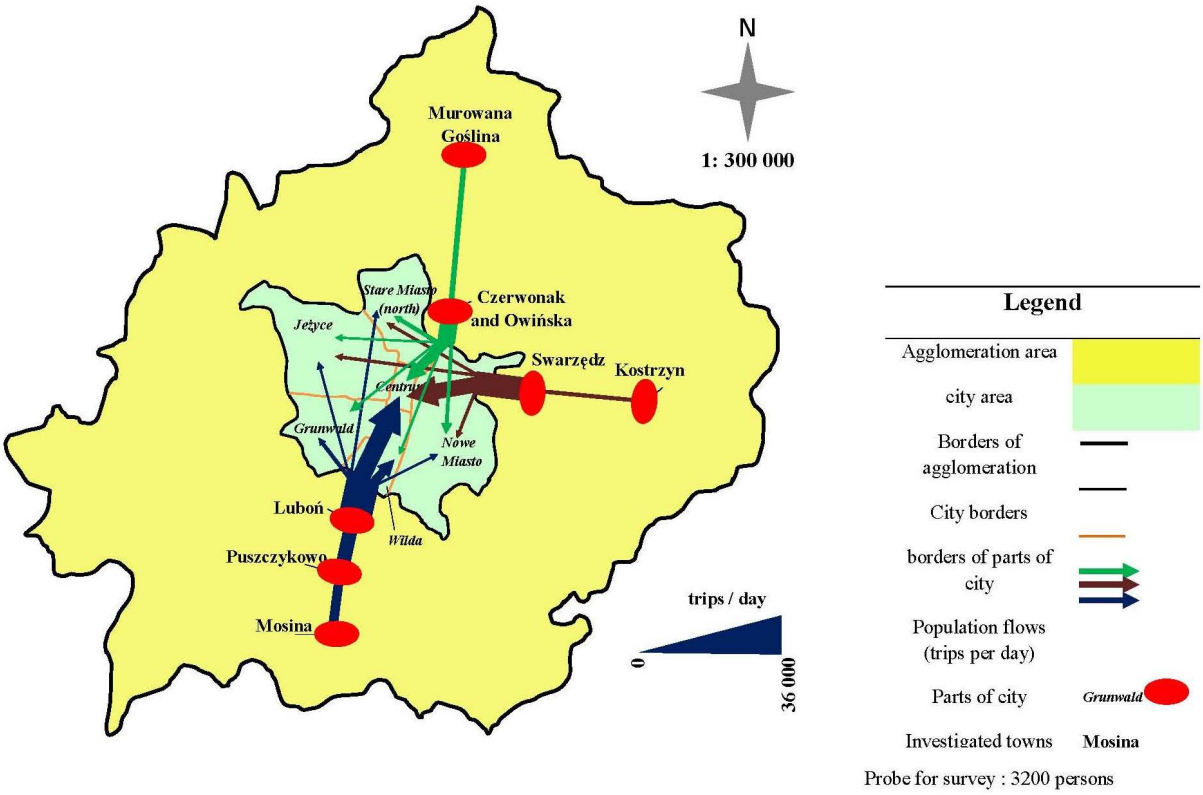
The similar researches conducted in other countries proved that the continuous communication problems express themselves very often in the lack of residential satisfaction of the inhabitants [Broll 2004]. It was also officially confirmed in surveys, conducted by the author among the inhabitants of the areas along the northern corridor (Czerwonak, Murowana Goślina). They experience the biggest delays, which cause the biggest dissatisfaction of the conditions of the road traffic among them comparing to the inhabitants surveyed along the other transport corridors. On the other hand, the most satisfied with the current situation is not the group which has an access to the highway (along the eastern corridor), but this one, which has an access to many alternative possibilities of the public transport (buses and to some extend trains). It confirms the rule, that the diversity of the communication routes and the convenient public transport can effectively replaces the highways to reduce the delays due to the congestion.

As it was already stated, the investigated events concern very complicated and dynamic urban area. However, thanks to conducted investigating procedure, a quite important insight and the identification of the way of the functioning of this urban organism were allowed. The strong connections between the total traffic level and the level of passenger flows show, that the increased congestion in peak hours is caused mainly by individual cars and not by the lorries and buses. Additionally it was found, that the daily flows of the population are strongly positively correlated with the changes of the volume of the commuters. The form of the relation between the speed of passenger flows (the average speed of a car) and the volume of road traffic seems to be very interesting from the point of view of the road traffic engineering. The logarithmic nature of these relationships was found, i.e. the speed of the travel drops more rapidly for the smaller volume of the road traffic and commuters than for the bigger values of this volume. It means that the traffic congestion causes some kind of the blockade of the further rapid decreasing of the flow speed. These relationships taken jointly indicate, the commuting of the population in the metropolitan area of Poznan contributes greatly to the formation of the road congestion, like in other large urban areas, such as Barcelona [Asensio 2002] or Tallinn [Tammaru 2004]. Therefore, the purposefulness of activities should be recognised in the promotion of local job markets, which reduces directly the necessity of the commuting [Domański 2006] as well as to shift the greater part of the individual commuting to the public transport system. It can lead to the reduction of the flows and therefore to the reduction of the road congestion.

A significant role of the public transport in the process of the improving of the effectiveness of population flows was already taken as an axiom, both by scientists and by politicians and business. It is also confirmed by the results of conducted researches, that the better usage of the existing infrastructure of suburban railways could undoubtedly reduce the flows realised by the use of the individual cars and therefore reduce the congestion level. However, the range of this reduction depends on the area, where it would be introduced and additional instruments regulating the flows (based on the system encouraging desirable behaviours and discouraging undesirable behaviours). It is interesting to point out; that the biggest enthusiasm to introduce the suburban trains was recorded among the inhabitants of the area, where the system of suburban trains already functions, providing the alternative to the commuting transport. It suggests that the test variant should be introduced before the full-scale implementation of new solutions. In this way, both inhabitants and the authorities could estimate the advantages and disadvantages of a new solution. Furthermore, the effectiveness of the instruments regulating the flows and introduced as a part of the transport policy (congestion fees, the increase of parking fees in the city area) will be probably confirmed in the practise, especially in the eastern corridor of the metropolitan area of Poznan, where the inhabitants show the strong habits to use their own cars in transport flows. It should be pointed out, that the introduction of such instruments on the city scale could be quite expensive and therefore it would undoubtedly cause the discussion on the purposefulness of these actions as well as some kind of inequality of the inhabitants. The solutions of these types could be certainly successful on the local scale – to encourage the inhabitants for combined travels – the connection of the railway public transport together with free buses to the railway station or a buffer parking of a park-and-ride type. It should be noticed, that the adaptation of the existing railway infrastructure could significantly reduce the costs of this project and help to create truly integrated transport system, not only the passengers' one but also the goods' one.

The means of the public transport are regarded as more economical and social effective ones. However, the disadvantages of these types of solutions are noticed as well. For example, the people

living close to the railroads are exposed to the increased doses of the noise and vibrations. Furthermore, at least a part of the population by the resigning of the use of their own cars could suffer some kind of a discomfort to use the public transport. The instruments regulating the flows and based on the system to encourage the desirable behaviour and discourage the undesirable behaviour are also sometimes critized. The open questions are still: Why should the authorities provide the free buses? Why should they provide the land for the buffer parking and thereby promoting the commuting to Poznan instead of concentrating on the local business, which could create workplaces near the residence of the population? There is also the problem of the correct forecasting of future scenarios of the spatial development of the whole agglomeration area. Will such a solution be needed and what kind of the technical support for it will be necessary? It seems that only the technical and financial aspects of such project require further separate studies. However, it is out of the aim of this study, which was concentrated on the task to investigate, whether the project of suburban trains using the existing railway infrastructure in the agglomeration of Poznan, can influence the reduction of the congestion level. The results seem to provide the promising prospects to improve the transport conditions in the whole agglomeration of Poznan. In a broader context, the study showed, that Polish cities can also develop their transport systems in more sustainable way by the better use of the existing railway infrastructure, despite of the marginalizing its utilitarian value in the last years, especially at the end of the twentieth century. At present, these aspects should be regarded as the opportunity to create the modern public transport system for inhabitants of agglomerations, which are exposed to the growing problem of the congestion.



Source: own work based on the surveys

Fig. 2. The spacial distribution of the population flows from selected locations to Poznan metropolitan area
Rys. 2. Rozkład przestrzenny przepływów ludności z wybranych miejscowości obszaru metropolitalnego do Poznania

CONCLUSIONS

The procedures and research methods applied to conduct this study are also used in various disciplines – from the geography of the transport, through the city logistics up to traffic engineering and economic sciences. Such a combination of research instruments were necessary to determine, whether the optimization of the dynamics of the population flows in transport corridors of the metropolitan area of Poznan can lead to the reduction of the road congestion by the better use of the existing railway infrastructure. The results obtained in multi-methods analysis showed, that such solution is likely to be a successful one as an alternative to the road transport. At present, the dominant form of the commuting travels is the individual transport by cars, which daily shuttle trips are connected with flows between suburban municipalities and Poznan. The centre of the city is the main target for these people. The reduction of commuting trips performed by cars could have a positive impact on the improving of the traffic conditions in the central part of the city. At present, the high level of the road congestion is observed both in the centre of the city as well as in transport corridors, especially during the morning and afternoon peak hours. It is probably the reason, why most of the inhabitants are not satisfied with the commuting conditions, characterized by significant delays and the slow speed of the movement. It seems to be ironic, that the same people are the main reason of the increasing road congestion along the transport corridors by their habits and behaviours. The reduced speed of the travel and big traffic jams during morning and afternoon peak hours are the main evidences of these occurrences. In other words, the congestion problem caused by the commuting is present in investigated area and is the main reason of the reducing of transport efficiency realized in the whole agglomeration. Can the introduction of suburban railway transport improve the situation?

The modelling conducted in the research process of this study and based on the regression analysis and survey data clearly showed that, the introduction of such a solution could reduce the road congestion, especially when the system encouraging the desirable behaviours and discouraging the undesirable behaviours will be included in this project. The solutions covering the whole area of the city, such as the introduction of congestion charges and increasing the parking charges would certainly increase the economical effectiveness of such solutions (the majority of the commuters would choose the trains), but taking into the consideration the social aspects in the wider range, the combinations of the local solutions, such as free parking places and the increased frequency of trains seem to be able to be even a greater success. The combinations of such solutions were derived in the studies based on the survey data and optimization algorithm (MBS). It means, the strategies and solutions designed in accordance with articulated preferences of the population, may be more effective than large-scale initiatives issued by a superior. This aspect seems to be often not taken into the consideration by the politicians and decision-makers and often plays a significant role in the process of designing of efficient transport systems.

The conclusion raised on the basis on this study is, that railway transport system can significantly reduce the level of the road congestion and thus improve the efficiency of the entire system of the urban transport. Furthermore it was demonstrated, that the "difficult" heritage of the poorly used or unused railway infrastructure, occurring in many urban areas, could be often successfully adapted to be a modern solution for the transportation needs of the inhabitants. It is particularly important in the context of the political past of Polish cities, which experience the big increase of the congestion in the last years. The financial resources of these cities to solve these problems are restricted, while often they have infrastructures weakly used and being the remnants of old conditions and relationships of social and economic development.

There is still a question to be considered, whether a similar solution could improves the effectiveness of the management of population flows also in other European and world metropolitan areas. The dynamics and complicated character of transport systems and the possible significant influence of other factors, such as changing preferences and behaviors of inhabitants, the type of the infrastructure or even a cultural environment, mean that the usability of the similar project in other geographical areas is uncertain. The true reactions and subsequent behaviors of the inhabitants are the most uncertain factor also in case of Poznan. It is not clear, that the inhabitants will act in the same way, as they declared in the survey and which is the background of the success of this project. The one

conclusion is certain, without the confrontation and the combating of the congestion; the transport system of the cities will be blocked and will have negative consequences of economical, environmental and mainly social nature.

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DYNAMIKA PRZEPŁYWÓW LUDNOŚCI OBSZARÓW METROPOLITALNYCH

STRESZCZENIE. W artykule przedstawiono analizę dynamiki przepływów ludności w korytarzach transportowych obszaru metropolitalnego, na przykładzie Poznania. Wykonane badania miały na celu określenie mobilnych preferencji ludności a także możliwości polepszenia efektywności działania transportu miejskiego, głównie w aspektach związanych i prowadzących do zmniejszenia kongestii drogowej - przy pomocy lepszego wykorzystania istniejącej infrastruktury kolejowej obszaru a także innych instrumentów polityki transportowej. Uzyskane poprzez analizę multimetodyczną rezultaty wykazały, że takie rozwiązanie ma szansę odnieść sukces jako alternatywa dla transportu drogowego a różne strategie i rozwiązania zaprojektowane zgodnie z wyartykułowanymi preferencjami ludności, mogą być bardziej efektywne, niż wielkoskalowe inicjatywy o charakterze odgórnym. Występujące często w wielu obszarach zurbanizowanych "trudne" dziedzictwo słabo lub wcale niewykorzystywanej infrastruktury transportu kolejowego, może zostać niejednokrotnie z pełnym powodzeniem zaadaptowane dla rozwiązania potrzeb transportowych ludności.

Słowa kluczowe: obszar metropolitalny, zarządzanie miastem, kongestia, transport pasażerski, logistyka miejska, dojazdy do pracy, przepływy ludności.

DYNAMIK DER BEVÖLKERUNGSSTRÖME IN METROPOLITANEN BALLUNGSGEBIETEN

ZUSAMMENFASSUNG. Der Artikel präsentiert eine Analyse der Dynamik der Bevölkerungsströme in den Transportkorridoren eines Stadtgebiets, am Beispiel der Stadt Poznan. Das Ziel dieser Studien war es, die mobilen Präferenzen der Bevölkerung sowie die Möglichkeiten zur Verbesserung der Effizienz des Stadtverkehrs zu bestimmen, vor allem in solchen Aspekten wie die Überlastung der Straßen und deren Reduzierung durch eine bessere Nutzung der vorhandenen Schieneninfrastruktur sowie andere Instrumente der Verkehrspolitik. Die Ergebnisse einer Multi-Methoden Analyse zeigten, dass eine solche Lösung eine erfolgreiche Alternative zum Straßenverkehr darstellen könnte und die verschiedenen, den artikulierten Präferenzen der Bevölkerung zufolge geplanten Strategien und Lösungen viel mehr als großgeskalte, höheren Orts aufgezwungene Initiativen wirksam werden können. Das oft in vielen städtischen Gebieten vorkommende, "schwierige" Erbgut von wenig oder gar ungenutzter Eisenbahn-Infrastruktur kann oft für die Lösung der Transportbedürfnisse der Bevölkerung erfolgreich adaptiert oder angewendet werden.

Codewörter: Metropolitanes Ballungsgebiet, Stadtverwaltung, Verkehrsüberlastung, Personenverkehr, Stadtlogistik, Transport, Pendeln, Bevölkerungsströme.

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