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Impact of higher category infrastructure on public transport related to travel to work

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Abstract

Employee travel to work makes up a significant part of journeys in public and individual transport. Daily commuters often have a choice between several modes of transport. For the efficient use of public transport, the key task is its attractiveness and adequacy of the services provided with respect to the demand on a particular line. To do this, it is sometimes effective to bypass (large) cities located along the route of the line, in order to achieve the fastest possible travel time. It is in this context that the available higher-end infrastructure (bypasses) has a major impact, which is important not only for individual transport, but also, in some cases, for public transport. On the example of this article, it is shown that with a sufficiently strong transport session, it is expedient to bypass even the second largest city in the country. Public transport is monitored using transport modelling, which is an effective tool for forecasting future intensities in individual and public transport. By simulating various traffic scenarios, future traffic behaviour of passengers can be predicted with high accuracy. This modeling method is also used in this paper.

Keywords: Transport modelling; public transport; higher category infrastructure; surrounding municipalities

1. Introduction

The construction of new higher category infrastructure (e.g. road creating city bypass) poses a certain challenge for the public transport system. On the one hand, possible rerouting of lines to new infrastructure can shorten the transport time, on the other hand, the service of settlements located on the original route may be limited in this case. Decision about using of new and old road infrastructure for public transport is influenced by several factors.

For the purposes of this paper, the term original road network means infrastructure of a lower category, while new infrastructure means a higher category road network, especially city bypasses. The scientific activity of the author focuses on factors influencing the use of lower category infrastructure after its replacement by higher category infrastructure. This article uses a transport model that provides several tools to analyze traffic flows in the context of new infrastructure.

The aim of this article is to evaluate the effect of new infrastructure in relation to routing of public transport lines.

Presented research is based on the case study of commuting of employees to work in the newly prepared industrial park of Valaliky located 11 km far from the city of Košice (Slovakia) to the South. It is invidted that this industrial park will be connected to motorway network creating bypass of the city of Košice.

Modal split and traffic assignment between public transport modes (rail and bus) applicable for commuting to this industrial park will be monitored.

Lines of public transport from the northern part of the are historically routed to the second largest Slovak city of Košice. Opening of the Valaliky industrial park should create a new problem in this filed. Routing of public transport lines over the area of this city will make individual car transport more attractive due to extension of travel time. So, it will be needed to introduce new direct lines from the north of area to the Valaliky industrial park.

Finally, it is necessary to consider this situation in advance. Transport models play a key role in this process. Next effect needed to be taken into consideration is that the traffic will be concentrated to the time periods around changing of work shifts. So the common process of transport demand modelling should be changed. Presentation of this research is an aim of this paper.

For the complex view, it is needed to integrate this research also into general scope of roles of new transport infrastructure.

2. State of the art

In this chapter, the first part presents an overview of current scientific knowledge in relation to the use of bypasses. The second part of the chapter is devoted to traffic modeling, which is an important working tool of the author.

2.1. Situation regarding the replacement of transport infrastructure

Higher category infrastructure is (in the conditions of Slovakia) built mainly where the existing infrastructure has insufficient parameters (low speed, exhausted capacity, inadequate directional and height solution). The newly built infrastructure mainly includes bypasses designed to divert traffic away from city centres. It is also due to environmental reasons (pollution and safety). The use of higher category roads, in this case bypasses, depends on local circumstances. In general, their use is influenced by several factors, such as the intensity of traffic flows, the attractiveness of the city, etc. Some of these factors have already been the subject of research by the author (Mondek & Bulíček, 2018; Mondek & Bulíček 2019; Mondek, 2022). These include:

- Location of attractive objects in the city
- Attractiveness of the bypass for roads within the city
- Driving comfort on the bypass and bypassed route
- Extension of the road if a bypass is used

In this article, the author pay attention to the impact of the bypass on modal split in public transport, when there is a significant acceleration of one of the modes of public transport (caused by an object located out of city). Within the framework of the issue under examination, it is therefore essential to distinguish between the types of bypasses that can be encountered in practice. These bypasses are closely related to the road category (CUTR, 2014). In the first case, therefore, there are motorway bypasses whose social benefits are not negligible, particularly for transit traffic flows. A specific category in the area of motorway bypasses are those that are currently built in half profile (with a possible future extension to a full-fledged motorway). These types of bypasses arise either as a certain temporary state during construction or, in certain cases, for a longer period, which can be explained by the acute need to divert transit traffic from the city to the road that will be part of the motorway connection in the future. In addition to motorway bypasses, bypasses or relocations are also created on roads of lower category.

In researching the issue of bypasses, one can be inspired by an article (Dzebo, 2018) that presents a simplified model of traffic intensity on a planned bypass. When creating this model, one of the input requirements was that the data entering the calculation could be easily obtained. By entering the model, average daily intensities on lower and higher category roads are calculated using statistical methods, while in addition to daily intensities, the characteristics of the original road and bypass (length, number of connections, time spent driving on the original and new infrastructure) enter into the calculation. After collecting all the necessary input data, a simulation of traffic operation follows using user equilibrium according to the Wardrop theorem, which is performed repeatedly. The resulting model can be interpreted as the ratio of traffic density on a planned and existing road, whereby deviations of predicted future traffic intensities from simulated values are detected using regression analysis. Tools for traffic simulation are also used in terms of determining the optimal number of lanes on road bypasses or delays. For example, the publication (Shi et al., 2015) uses a so-called cellular automatic, which simulates the movement of vehicles in lanes on multi-lane roads. In this case, however, that simulation is essentially a microsimulation tool which, in the context of the issue being addressed and the level of resolution established, represents too much detail.

The publication (Coloma et al., 2018) stresses that planning new road infrastructure in cities, whether individual or networked, requires testing with an efficient and high-quality transport model. Such a model should be able to provide an overview of mobility in its current state, as well as forecast the future behaviour of residents after the construction of new infrastructure replacing (supplementing) the old one. The use of a transport model provides information about the behavior of residents in the various considered alternatives (route management options) and thus facilitates decisions on the final choice of route. In the future, in order to optimise the flow of vehicles on urban roads, the use of Intelligent Transport Systems is envisaged, which use modern technologies to direct vehicles to less congested roads (Koukounaris, 2019). At present, however, the use of these technologies is limited and in practice they occur mainly in pilot operation. But the fact is that the ubiquity of data and internet of things technologies also enable new demand-responsive public transport services, and innovative modes of public-private shared mobility (Kuo et al., 2023) thus, there is an overlap between several modes of transport.

2.2. Options for using a transport model

The transport modelling process is currently very popular in the field of transport. It is a frequently used tool for estimating future intensities on roads, intersections or public transport connections (Cingel et al., 2019). The most commonly used is four-stage traffic model (includes four calculation steps – Trip Generation, Trip Distribution, Modal Split, Traffic Assignment). This article focuses in particular on the latter two stages, which distribute vehicles and/or passengers between different means of transport and on different parts of infrastructure.

In addition to traditional transport modelling tools, alternative methods exist for the actual specification of the Modal split. These are, for example, a two-step data mining framework, composed of K-Means and decision tree methods, to obtain an interpretable model for a city-level modal split (Lee et al., 2022). A more advanced numerical method is the customized two-stage parallel computing algorithm (Zhang et al., 2023), which, in addition to modal split, also solves the traffic assignment problem, because efficiently solving this problem for large-scale transport networks is a critical problem for transportation studies. A similar issue, but using a different algorithm, is solved by the article (Ryu et al., 2017). This paper presented a modified path-based gradient projection algorithm for solving the combined modal split and traffic assignment problem. In both cases, it was found that the logit parameter has a significant impact on the modal splits and link flow patterns as it indicates how sensitive is the users to the cost difference between the two potential transit modes. At the development stage is the Best-Worst Method, also based on the multi-criteria decision-making method. Based on the papers findings, the application of Best-Worst Method results in competitive accuracy compared to the mainstream methodologies, moreover Best-Worst Method needs significantly less cost and time effort during the survey procedure (Duleba et al., 2021). As a limitation, the non-flexibility of the alternatives has to be noted.

In addition to methods based on the LOGIT model, or on multi-criteria decision-making methods in general, there are also alternative methods that are demanding on input data. These are in most cases based on empirical studies. As an example, the use of multi-modal macroscopic fundamental diagrams (Loder et al., 2021), where the authors proposed the first methodology to account for additional (external) delays in the shape of the macroscopic fundamental diagrams, and derived a vector-based approach to estimate multi-modal macroscopic fundamental diagrams (tri-modal and bi-modal). The pitfall, however, is that unfortunately, no tri-modal data at the network level exist to derive appropriate delay functions and validate the proposed vector-based approach.

Very often, the modal split between individual and public transport is monitored. For example, comparing the journey to work by car on the motorway and by bus on lower category roads. Article (Tian & Huang, 2015) examined in the presence of exponentially distributed random delay on motorway the joint decision-making problem of modal split and trip scheduling in a traffic network consisting of a motorway and a transit line. With the increase of uncertainty expectation, more commuters shift to transit mode, the number of auto commuters decreases and the duration of peak period on motorway is shrunk. On the other hand, more transit runs are required and each run services more commuters. Research (Santos et al., 2013) investigated factors influencing modal split of commuting journeys in medium-size European cities. One of the authors' findings is that it is clear that policies in favour of public transport, such as reducing fares and increasing the number of buses, are likely to increase the share of public transport in trips to work. The author of an article on commuting came to a similar conclusion (Buehler, 2011). In this case, it was found that offering tangible incentives that improve trip attributes such as trip time and cost can result in sustainable travel behaviour change in terms of modal shift and emissions savings by disrupting long-standing car commute habits. The findings produced from this study determined that a reduction in the mode share of private cars of up to 1.76% as result of shift to public transport modes, which experienced an increase of up to 2.87%, could be attained as a result of employing the policy measures appraised. These values do not look particularly relevant and would need deeper analysis to ascertain their relevance. This finding is supported by an article (Simons et al., 2017) which states that future interventions promoting sustainable travel behavior in emerging adults should be adapted to specific subgroups such as secondary school students, studying young adults and working young adults. Because of the need to travel longer distances, it is important to promote a multimodal lifestyle in order to encourage the combined use of active and public transport.

The combined modal-split/traffic assignment model is often also solved in logistics, specifically in freight transport. In these cases, however, other indicators are monitored, but similar to those for passenger transport. Unlike passenger transport, the transport of goods can be directed in advance, therefore there is no need to predict the behavior of passengers. A frequently solved problem is how to optimally split freight volume between road and rail transport (Dong & Transchel, 2020), which is further extended, for example, by detailed modeling of the various railway traffic flows (Rosell et al., 2022).

The next step in using the traffic model is the Traffic assignment level. Here, too, there is a whole range of algorithms that are constantly being modified in scientific research around the world. The quite used All-or-Nothing (AON) method often works with this stage, which forms the basic and simplest method in this field. It assumes that all users of the transport system will choose the shortest possible route for their journey by the mode of transport in question, while not allowing any alternative routes. There is already a certain deficiency from this argument, since in practice not all users use the shortest routes, either because they do not have complete information about the route in question or, for example, because of personal preferences and possibilities. By extending this method, Timetable-based, Headway-based and Transport system-based assignment methods were created in the PTV VISUM software for the needs of public transport.

The situation in the filed of daily commuting should be illustrated by the paper (Kleprlík & Bulíček, 2019). The research based on data from public census 2011 was conducted in the Eastern Bohemia. This part of the Czech Republic has similar conditions (agglomeration with ca. 200,000 inhabitants in core cities). There commute out of municipality between 20 – 25% inhabitants (municipalities under 1000 inhabitants); 12 – 20 % (up to 2000 inhabitants); and about 7 – 12 % (others). This illustrate why it is necessary to consider commuter flows carefully.

3. Materials and Methods

The area in question for research within the scope of this article is the area between the industrial park of Valaliky and the city of Prešov. Approximately 15,000 people should work in this industrial park in the horizon of 5 years (it will be the largest industrial park in Eastern Slovakia), which will of course create high demands on transporting employees to work from the large perimeter, the expected size of which is up to 100 km or 90 minutes of driving with a daily commute. Attendance will be directed from the nearby city of Košice, which is directly adjacent to the industrial park. It is the second largest city in Slovakia with a population of almost 230 thousand (the whole agglomeration has more than 350 thousand inhabitants). However, from the point of view of the author's scientific focus on road bypasses, commuting from more distant places is important. A good example is the city of Prešov, which is about 50 km away from the industrial park. It is the third largest city in Slovakia, the population is almost 85 thousand, together with the wider surroundings it is up to 200 thousand inhabitants. Based on the above data, it is therefore highly probable that a large part of employees will commute to the industrial park from the surroundings of Prešov.

The existing infrastructure between Prešov and Košice, usable for public transport fashions, consists partly of double-track (50% of length) railway line and motorway. Travel time of vehicles (trains and buses) is 30 minutes. The railway and bus stations in both cities are located close to each other, so both modes of public transport are equally accessible in terms of accessibility (Figure 1). Therefore, the issue of the first mile is not closely monitored in this, although in general (especially in relation to individual transport) its effect is significant. What matters is the last mile effect, i.e. how people get from Košice to the industrial park. The main expected last-mile system is the train, which should run between Košice station and Valaliky Terminal at shift times. For this type of transport, it is sufficient that transport services are provided only during shift changes, in this case three times a day (around 6, 14 and 22 hours). From the Valaliky Terminal, a shuttle bus will run directly to the plant area, which will provide transport of employees to the nearest possible place (closer than the parking lot for passenger cars). So, it must be noted that passengers from Košice will face to 2 interchanges (from Košice city urban public transport to train; from train to shuttle bus). Other commuters to 3 interchange (from local transport system to train or backbone bus line towards Košice; from train to train; to shuttle bus). Local transport system means one of these possibilities: city urban public transport in Prešov / regional bus line from home municipality to railway line / individual car (or bike or walk) used to approach train station) from home municipality. Based on information from the Ministry of Transport, the train line Košice – Valaliky will be a separate segment for which a public tender will be announced (this obligation arises from European legislation). For this reason, it is not expected that the transfer at the Košice station will be removed, or that this line will overlap deeper into the region.

In connection with the currently ongoing construction of the Košice motorway bypass, the question arises whether it is not possible to use it also for direct transport of employees to the industrial park, without stopping in Košice. In this case, it is possible to observe the following effects of the bypass being built:

- How significantly the modal split and traffic assignment in public transport will change after the introduction of direct bus connections.
- How passengers' time spent in the transportation process will change.

For research of the presented issue, the use of a transport model is suitable. The field of transport modelling and forecasting is an important part of transport planning, as it makes it possible to examine different planned scenarios in the field of transport infrastructure, without the need for their physical existence. This field of science is based on the very definition of a model, which is defined as an idealized imitation of the real world allowing to obtain relevant information about the studied system in order to propose and verify solutions at the same time. The author has a transport model of the Košice self-governing region (created within the framework of the Sustainable Mobility Plan of the region) and PTV VISUM modeling software. In the existing transport model, the network was modified and public transport lines were added. Similarly, the attractiveness of individual transport districts was modeled so that the transport model provided relevant results in relation to the studied issue.

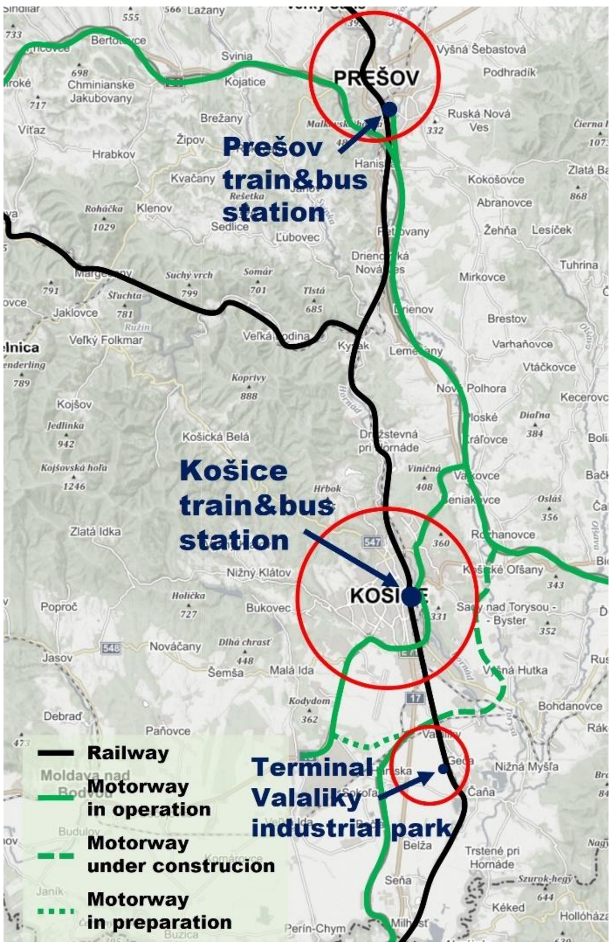

Figure 1. Scheme of railways and motorways in the designed area.
Map source is from: https://www.mapy.cz.

The use of a transport model is fit for purpose, as evidenced by the available literature. In the article (Carroll et al., 2019), the subject of research was to find out the impact of the potential emission reductions from a shift towards public transport, using a transport model. This question was appraised by means of four-stage transport modelling to estimate the impact of introducing measures that could lead to time and cost savings for commuting trip purposes. The transport model is a relatively frequently used tool in Slovakia, especially in connection with insufficient road infrastructure parameters. Traffic problems are undoubtedly a reflection of several variables, such as the quality of the infrastructure, the demand for transport, and the strong transport habits of the population. Using the example of the Kysuce region, it was proved in the article (Drliciak et al., 2020) that the enormous increase in regional traffic and the high ratio of the transit traffic, is the cause of regular traffic congestion. One way to improve this is to change the traffic mode and move users to public transport.

For complex, technical and operational condition of given railway lines should be also simulated to assess if these lines are able to serve all needed trains at time periods of time to change shifts at work. The paper (Bulíček & Bažant, 2020) show application of simulation with an effort to select line segments to improved interlocking system with the aim to improve the capacity for trains running subsequently in the same direction. Application of such assessment in this case of lines towards the Valaliky industrial park possibly should take a part of future research.

4. Results and Discussion

The solution to the defined problem consists in comparing two model scenarios for servicing an industrial park (Figure 2). For passengers from/to the direction of Prešov, the first scenario includes the railway line Terminal Valaliky – Stanica Košice with the possibility of changing to a connecting train connection from the Košice station to the Valaliky Terminal (red line). The second scenario consists in supplementing these connections with a direct express bus line Prešov – Terminal Valaliky (green line), running along the bypass of Košice (without serving this city). In both scenarios, a shuttle bus is operated between the terminal and the plant area (blue line). Travel time Prešov – Valaliky Terminal is 50 minutes by train. The express bus line in the second scenario has a travel time of 40 minutes.

Table 1. Travel times in both scenarios.

Transport mode	1st scenario	2nd scenario
Railway Prešov – Košice	30 min	30 min
Interchange Košice	8 min	8 min
Railway Košice – Valaliky	12 min	12 min
Bus Prešov – Valaliky	–	40 min
Interchange Valaliky	5 min	5 min
Shuttle bus	5 min	5 min

The transport model of the Košice region is processed in specialized software PTV VISUM. The individual modelled scenarios cover all three eight-hour shifts, which are considered as core shifts in the factory.

The parameters of the transport model and the functions used are based on the calibration process. The data were obtained in the form of a questionnaire investigation. For the modal split (mode choice) stage, the Logit function (1) was used with the parameter c = -1, which was determined by comparing model and observed data. The accuracy of the traffic model is high, which is shown in the attached graph (Figure 3) showing model and actual data.

$$f(U) = e^{cU} \tag{1}$$

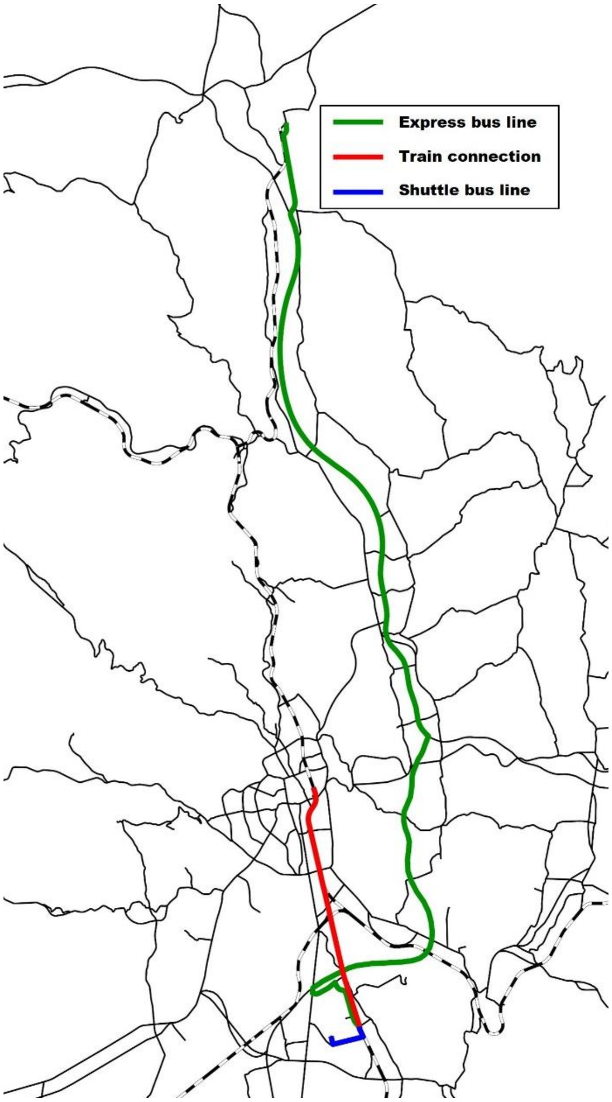

Figure 2. Scheme of designed lines.

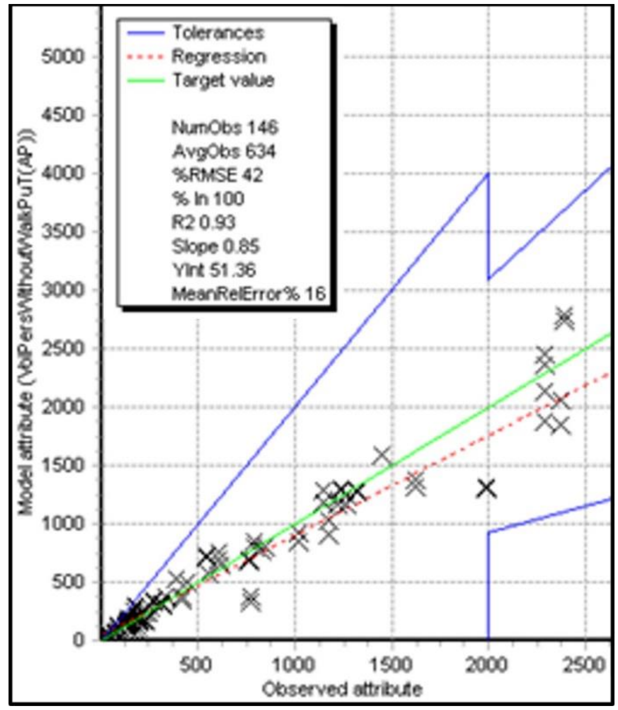

Figure 3. Comparison of model and observed data.

Data source is from Transport model of Košice self-governing region.

4.1. Results

The transport model used shows that the transport potential of public transport (after deduction of individual transport) between Prešov and the Valaliky industrial park is 400 passengers per day (this number does not include passengers from the agglomeration and the wider surroundings of the city) in both directions. This value was therefore used as a model value for the purposes of researching the problem in question. Thus, in the first scenario, the entire volume of passengers is transported by rail, since the equivalent of an express bus service is not in place. An interesting situation arises in the second scenario, when more than half of the passengers are transferred to the bus subsystem. The modal split on this session changes to a ratio of 52.5:47.5 in favor of bus service (Figure 4).

However, bus transport has its limits and cannot be developed unhindered. The limits are determined by the capacity of the bus itself, taking into account (with respect to travel time) only seats, the number of which is approximately 80 in large-capacity buses. The limitation is also represented by the frequency of buses itself, which is not unlimited and from an economic point of view it is not efficient to run several buses in close succession, in this case the train is a more advantageous alternative. In the case under study, three connections are made for each shift in a 5-minute sequence. Such a connection is more attractive than a train run only at one time. This may also be the reason why the attractiveness of the bus line is so high on the studied show.

The transport model also allows for a broader view of the issue under study. It is thus possible to observe the effect of the introduction of an express bus line on the total commute to the industrial park from the whole region. According to forecast data based on the transport model, the total number of people travelling to and from the industrial park by the rail transport system will be 8,270 persons per day (Figure 5). In this model, rail transport is envisaged, which will be the main public transport system in connection with the Valaliky industrial park. After the introduction of the new bus line, according to the model, 210 journeys will be redirected to bus transport, which represents 2.5% of the share of public transport related to the provision of public transport services to the industrial park.

The above research on the scenario shows that the impact of new infrastructure has an impact on the extent and use of public transport. However, the actual usability of public transport for commuting may change over time. With an attractive offer of public transport, its usability will increase over time also for users of individual transport, while increasing the time spent in the transport process compared to individual transport.

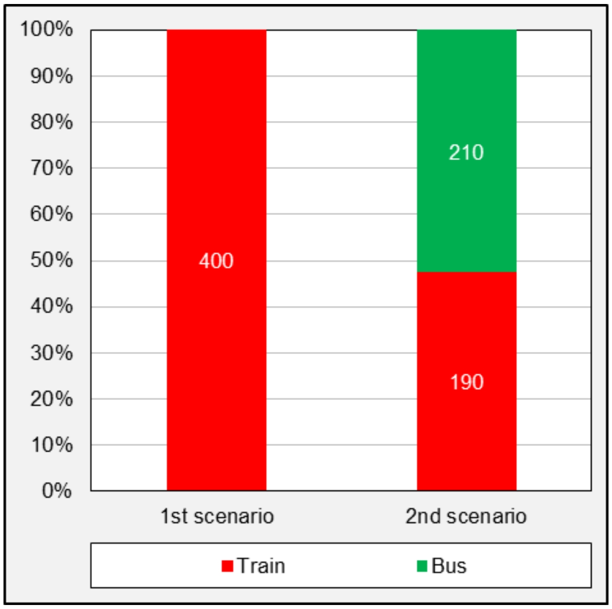

Figure 4. Modal split in public transport in 1st and 2nd scenarios.

These findings add to a growing body of evidence to support the assumption that changing the built environment can bring about changes in travel behaviour (Heinen et al., 2015).

4.2. Discussion

The results of the case study are largely dependent on the quality and execution of the transport model. In this case, it is a calibrated and validated transport model of the Košice self-governing region, which, however, covers a large area. The research in this article focuses on transporting employees to shifts that shift three times a day, but this situation is averaged over one full day (24 hours). Nevertheless, the macroscopic model provides relevant results because it mainly captures trends and emerging opportunities, absolute values being less important in this case. It turned out that the direct express bus connection has its potential, but its actual operation and use is highly dependent on the time positions of the connections, capacity, comfort and speed of these connections. Reducing travel times alone is less beneficial than using of rail transport. However, the fact is that the transport model does not address the stability of rail transport, which is limited by the technological possibilities of a single-track line, as a result of which there could from time to time be a situation where it might not be possible to change trains at the Košice station. Therefore, after the negative experience of some passengers, the potential of a direct express bus connection could be even higher.

An important factor that could affect the modal split is the price. A prerequisite, which is also implemented in the transport model used, is the use of an ITS zone tariff, i.e. the fare itself is the same in both scenarios considered. In other cases, it may be the case that bus transport will be cheaper because employers will contribute to it. This can then have a significant impact on the modal split, as it is assumed that most passengers will use cheaper bus services supported by companies. The limiting factor in this case will be the capacity of the bus, when in rare cases it will be necessary to implement a reservation seat system. Another issue affecting commuting propensity in general is the length of working hours. In the case of longer shifts (12 hours), where there are fewer shifts per week, there may be a greater willingness of employees to travel longer distances. Conversely, with daily commuting (8-hour shift), the willingness to travel for a long time may be low. But the fact is that when working in the manufacturing sphere, there is a willingness to use public transport, since it is difficult for employees to work for 8 or 12 hours, and another 2-3 hours to spend like driver in a personal car. In this situation, the existence of public transport is important, the attractiveness of which (especially travel time) must be close to individual transport.

In future research, it is possible to focus on a multimodal solution to the problem, i.e. to include individual transport in the transport model. According to current assumptions, individual transport will account for approximately 60-70% of the modal split when commuting to work in the industrial park. It turns out that the willingness of passengers to change the mode of public transport is not so high, and given the scale of individual transport, it is necessary to motivate users in particular. In this case, attention should also be paid to other factors, such as the location of stops and parking lots in relation to the destination achieved, the existence of an integrated transport system (transport and tariff integration) and the overall attractiveness of the public transport system (quality of vehicles, intensity of connections).

5. Conclusions

In the near future, passenger transport to industrial parks in Eastern Slovakia will be both a challenge and an opportunity for public transport. According to current estimates, approximately 30,000 new jobs should be created in Eastern Slovakia within 7 years. To fill these jobs, passengers will also need to be transported over longer distances, which creates demands for speeding up public transport connections. One of the possibilities of speeding up bus connections is skipping some stops and guiding them along city bypasses, which brings their considerable acceleration. In this regard, however, it is also necessary to monitor the transport needs of bypassed places, which constitutes one of the research topics of the author.

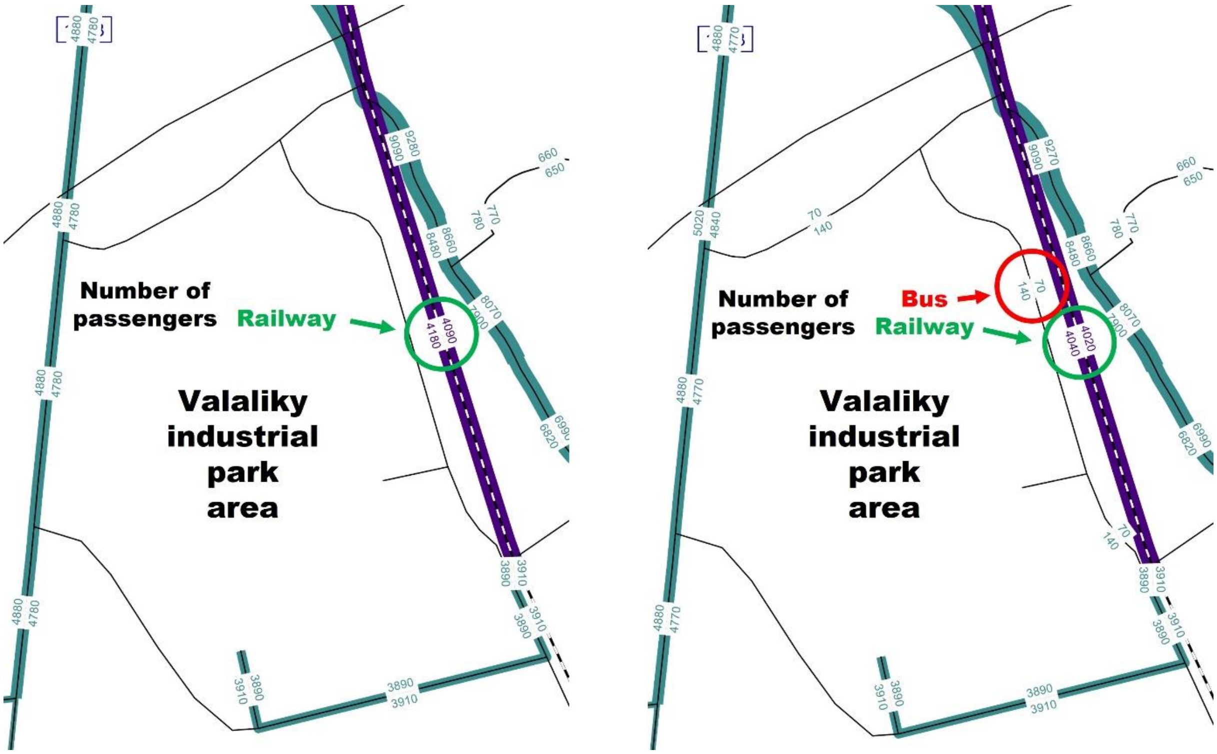

Figure 5. Change of transport load of lines between 1st (left) and 2nd (right) scenarios displayed on the cartogram.

On the model example of travel between Prešov and the Valaliky industrial park, it was shown that there is a potential for bus connections bypassing a large city. However, their management must be on a sufficiently strong transport session so that such a connection is sufficiently utilized and profitable (e.g. to transport employees to/from work). The modal split in public transport has changed from the dominance of trains to about the same proportion of trains and buses, while it is clear that such a large city as Prešov has the potential for direct connections with a strong passenger flow. Although the time of passengers in the transport process is shorter when using an express bus line, the usability of this line depends mainly on the speed and reliability of other modes of transport. The manufacturing sector itself is sensitive to the timeliness of staff attendance, and therefore the stability of the transport system is an important factor that may favour direct connections over transfers.

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