University of Pardubice
Faculty of Transport Engineering

FACTORS INFLUENCING FURTHER TRAFFIC ON SECTIONS OF TRANSPORT NETWORKS REPLACED BY HIGHER-CATEGORY SECTIONS

DOCTORAL THESIS STATEMENTS

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Doctoral Student

Ing. Norbert Mondek

Study program

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Branch of study

P1041D5001 Transport Technology and Management

Supervisor

doc. Ing. Josef Bulíček, Ph.D.

Supervisor specialist

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Department

Department of Transport Technology and Control

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1 Current State of the Studied Issue

The research in the dissertation is based on an analysis of previous approaches to modernizing transport networks and replacing or supplementing them with new transport sections. This analysis focuses on examining the potential effects of higher-category infrastructure from the perspective of the considered modes of transport (fig. 1). Primary attention is given to investigating the existence of the effects of traffic and construction-induced demand in relation to this infrastructure. Additionally, methodological approaches used to evaluate the effectiveness of bypasses and reduce traffic congestion in city centers are analyzed across various countries and transport modes. Various theoretical foundations from the field of transport engineering and planning are presented, which serve as the basis for the development of the methodology used in this work.

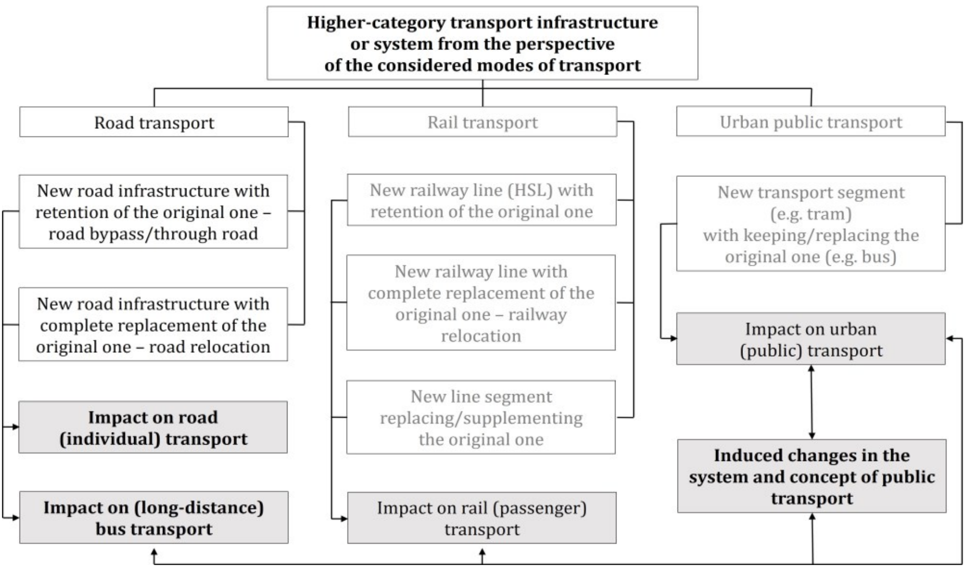


Fig. 1 Decomposition of the solved spectrum of research issues

Source: author

The closer relationships explaining the development of the studied issue are illustrated in fig. 1, where the elements highlighted in white represent causes, and those in grey represent effects. The bold font indicates the scope of the issue addressed in this dissertation, while the grey font marks the less investigated parts.

1.1 Summary of the Analysis of the Current State

The purpose of using literary sources is to analyze various approaches to solving transportation problems and their practical application, considering different aspects related to higher-category infrastructure, such as traffic-induced demand, changes in public transport systems, economic impacts, and environmental factors. This literature forms the theoretical framework for the dissertation and provides insights applicable to the research itself.

Source [1] is fundamental for understanding transport modeling methods, providing the theoretical basis for four-step transport modeling, which is one of the key elements in the dissertation. Among other things, it serves as the foundation for designing analytical tools and modeling transport flows. The use of transport modeling methods is appropriate for the issue examined in the dissertation, as confirmed by their application in other studies focused on the topic of bypasses [2; 3; 4] in various aspects of the solution.

From the perspective of individual and public transport, articles [5; 6] address case studies that examine the impact of bypasses on cities from various viewpoints. These case studies serve as examples of best practices in investigating the effects of new road sections on cities, urban transport, and the efficiency of public transport. The most frequently mentioned phenomenon is induced traffic, which refers to the generation of new traffic load after part of the flows is diverted to the bypass [7; 8]. In this context, there is also mention of building induction demand related to higher-category road, both in a positive light [9] and with negative impacts [10].

Among other things, the available literature [11; 12] also focuses on transport externalities such as noise, emissions, and congestion, as well as the environmental and climate impacts of transport infrastructure. These articles serve as a basis for assessing the environmental impacts of bypasses, which are closely related to the quality of life in urban areas.

In addition to transport modeling, the analyzed literature employs a variety of other methodologies, ranging from different alternative approaches [13; 14; 15] through simplified methods [16; 17; 18; 19], to statistical methods for evaluating public transport [6]. The diversity of approaches and their application have become the foundation for further dissertation research, where they are applied to address issues related to the replacement of transport networks and the evaluation of resulting effects.

Articles [7; 11] draw attention to monitoring traffic induction in connection with bypasses, partially confirming this effect. In terms of methods, overly complex and practically challenging approaches, as seen in articles [13; 14], are not followed. Instead, simplification combined with sufficient accuracy is preferred [16; 17], along with transport modeling [2; 4].

1.2 Starting Points for Research Activities

The basis for further development of the dissertation lies in highlighting gaps in current research, particularly in the area of interaction between different modes of transport. This also relates to the recognition of the need to create a methodology applicable to different geographical and infrastructural conditions, as a supporting tool for the replacement of transport networks.

The efficiency or societal benefit of road bypasses can be evaluated from two perspectives. The first concerns the actual use of the newly constructed bypass, which is mainly related to transit traffic passing through the city. This aspect can be assessed using directional traffic counts. The second aspect is the traffic situation within the city, specifically how the traffic load will change after the construction of a bypass. This issue is significantly more complex, as it involves not only the current traffic volume but also induced generated traffic that arises as a result of the new infrastructure (bypass) construction, both on the bypass itself and in the bypassed settlements.

A subset of road transport is represented by public scheduled bus transport, which, given its scope and nature, can be studied as a separate segment. This includes both regional bus transport conducted within a specific region and long-distance (interregional) bus transport. From the perspective of this type of transport and the corresponding distribution of transport flows, it is possible to quantify both the time loss for passengers caused by the use of the bypass (skipping a stop in the city) and the time savings for passengers for whom using the bypass is beneficial. The structure of transport flows itself can serve as a basis for decisions on diverting public transport routes away from cities, as well as for evaluating the effectiveness of this solution.

2 Objective of the Dissertation

From the thematic focus of the dissertation, the research activity addresses the issue of replacing sections of transport infrastructure, or parts of transport networks. The primary focus is on road and bus transport, particularly in terms of traffic and transport intensities on the original and new infrastructure. Based on this framework and the author's existing knowledge in the field of scientific research, supporting theses have been established, which form the foundation for defining the objective of the dissertation. These supporting theses are divided into two groups: the first group covers issues related to road transport, primarily individual transport, while the second group focuses on bus transport in relation to transit routes and the available and planned infrastructure.

The wording of the supporting theses is as follows:

1. After the construction of a bypass, the decrease in traffic load (intensity) in the city (town) will not be equivalent to the increase

in traffic load on the bypass, meaning that the overall traffic volume will increase.

2. Public transport services in towns with a bypass can be reduced to speed up travel on the main (monitored) route, while ensuring that the bypassed towns (villages) are still served to the required extent.

The objective of the dissertation is to evaluate the effects of bypasses and assess the identified factors in the context of the studied issue of replacing transport infrastructure, with the aim of developing a methodology to support decision-making in the replacement of transport networks or their parts. The subject of this methodology is the method of quantifying the impact of the new section of transport infrastructure on the replaced transport networks, presented in variants depending on the configuration of the new parts of the infrastructure. In relation to the defined objective of the dissertation, a hypothesis has been formulated, which is measurable and subject to verification:

- The effects being examined, on which this dissertation is focused, are interconnected.

For pairs of effects where dependence can be examined using regression analysis, the coefficient of determination R^2 is used, among other things, to verify this statement (see subsection 3.2 for more details).

3 Methods of Processing and Approach to the Splution

For the purpose of researching traffic intensities, analytical tools and transport modeling methods are used. In this case, elementary relationships from traffic theory are employed, such as the static description of traffic intensities and descriptive statistics, as well as system analysis methods applicable in decision-making for certain situations. The most advanced method is the use of a four-step transport model, where proper configuration for given conditions allows for the modeling of various scenarios under different input conditions. Given the need to verify the hypothesis and establish dependencies between individual effects, statistical analysis methods are also required. These methods are useful for predicting future traffic and transport intensities.

3.1 Four-step Transport Model

The field of transport modeling and forecasting is based on the definition of a model, which is described as an idealized replica of the real world that allows for the acquisition of relevant information about the studied system, with the aim of designing and verifying solutions [20]. The four-step model is one of the fundamental methods of transport modeling, depicting the movement of traffic flows within a transport network. The structure of this model [21], as indicated by its name, consists of four stages:

1. Trip generation – determining origin and destination flows.
2. Trip distribution – directing the flows.
3. Modal split – distribution of transport work.
4. Traffic assignment – assigning flows to parts of the transport network.

From the perspective of the issue addressed in the dissertation, the last two stages are the most important, as they allow for the observation of changes in traffic behavior after replacing lower-category sections with higher-category sections.

The four-step transport model is used in the dissertation as a tool to verify the effects associated with the existence of higher-category roads (system), while also monitoring the existence of individual factors influencing changes in traffic behavior. In the context of the topic addressed, this means the direction of traffic flows in road transport as well as transport flows in bus transport. To use transport modeling, available software support is employed – Aimsun Next and PTV Visum software. The advantage of this software is that it not only has the necessary algorithms implemented but also enhances research efficiency and the interpretation of its results.

3.2 Statistical Analysis

The statistical methods used in this dissertation can be divided into two groups. The first group consists of descriptive statistics, which do not require further explanation due to their widespread use and general familiarity. The second group includes correlation and regression analysis. These two are closely related, as correlation indicates the strength of the relationship or association between the examined variables, while regression examines the nature of the relationship between these variables [22].

When using correlation analysis, the Pearson correlation coefficient is calculated, which measures the correlation between variables. The coefficient ranges from -1 to 1, where a value of zero indicates no relationship between the examined variables [23]. The closer the coefficient is to one, the stronger the relationship, with a value of 1 or -1 indicating a direct dependence between the assessed variables. The second method in the described group is regression analysis. The difference lies in examining the dependence of the dependent variable on one (simple) or more independent variables (multiple), assuming a normal probability distribution. The quality of the identified regression model can be expressed by the coefficient of determination, which is commonly denoted as R^2 [24]. This coefficient takes values from 0 to 1 (0–100%), with higher values indicating that the model explains a greater proportion of the variability of the dependent variable.

The use of correlation and regression analysis is advantageous for the addressed issue because it allows the identification of statistical dependencies between the compared variables (factors, criteria) with relatively simple calculations (using MS Excel). The difference between these two methods is that, unlike regression, correlation does not express a cause-and-effect relationship, meaning that despite a high correlation, the examined variables may be independent of each other. The identified dependence can be verified using a regression curve, which also allows for the estimation of additional values of the dependent variable.

3.3 Multicriteria Decision-Making Methods and Criteria Weight Estimation

The use of these methods stems from the fact that the decision-making process involves multiple criteria (e.g., time, cost, quality), with the assumption of a finite set of such criteria [25]. Weight estimation methods are used to transform preference information, expressed in one form, into cardinal information about the weights of the criteria. This makes it possible to evaluate the priority of different routes or various modes of transport connecting two cities based on a combination of selected criteria.

A suitable and practical method for determining the weights of criteria in this case is Saaty's method, as the problem typically involves working with cardinal information, and the range of evaluators can be quite broad. The principle of this method is pairwise comparison of individual criteria, where the strength of preference of one factor over another is determined on a scale from 1 (equal importance) to 9 (absolute importance). Specific application is demonstrated in the example in subsection 4.6.

The next step is the evaluation of the compared alternatives, for which the TOPSIS method is suitable based on the available tools. This method works by calculating the distance of each alternative from the ideal and baseline alternatives. The best alternative is thus the one with the highest relative distance indicator, taking into account the distances from the baseline and ideal alternatives.

3.4 Comment on the Transport Modeling

The dissertation primarily utilizes four-step transport models, which were originally created for other purposes (e.g., as part of strategic documents). After certain modifications, their use is also suitable for the current issue being addressed. The second option involves creating a custom transport model, which simplifies or disregards some secondary variables. The purpose is not to create a universal model that comprehensively addresses a larger area but rather to develop an independent model. In future research, the same infrastructure can be used to study additional effects and factors. Transport models provide high variability in terms of outputs, allowing for the comparison of variables that are meaningful for the situation being studied.

4 Achieved Results

The content of this section is divided into two parts: the analysis from the perspective of road transport (vehicle intensity) and from the perspective of public transport (number of passengers). The subject of the analysis is to verify the impact of bypasses (higher-category infrastructure) on traffic in the replaced sections (lower-category roads) of transport networks, considering both perspectives. The solution to the presented issue takes place on two levels, utilizing analytical tools and transport modeling methods. These are not alternative approaches but rather a sequence of steps forming a comprehensive investigation (from general to specific), which is a prerequisite for an effective procedure.

4.1 Use of Analytical Tools in Road Transport

This section focuses on the research of the addressed issue using examples from eight Czech cities (Plzeň, Olomouc, Jihlava, Mladá Boleslav, Kolín, Chrudim, Nymburk, Vamberk) and six Slovak cities (Nitra, Martin, Poprad, Levoča, Svidník, Tornal'a). For the purpose of the dissertation, the selected cities were divided into three categories based on their regional significance. This division is based on the assumption that traffic behavior depends on the importance of the cities, the availability of services and other parameters of the settlements.

Each of the mentioned categories is represented by settlements from both of the studied countries. For the purposes of comparison and evaluation, the selected cities consist only of those where a bypass has been built within the last 15 years. The classification of a given city into a specific category may seem subjective, but it is based on the author's own knowledge, and it approximately corresponds to the population size and the location of key transport-related facilities within the city.

The observed variable is the traffic intensity on selected road sections, expressed as the annual average daily traffic (AADT) in the number of vehicles per 24 hours [veh·$(24\ h)^{-1}$]. The selection of specific sections in the cities corresponds to the original transit routes, which were highly frequented before the bypasses were constructed. Most commonly, these are parallel first-class roads, although in some cases they have since been reclassified to lower-class roads.

The length of the observed period varies in each city, depending on when the bypasses were constructed. For further analysis and to ensure comparability of the situations, it is necessary to standardize this calculation period, i.e., to approximate traffic intensities according to the required period. The following two formulas for estimating traffic intensities at the end of the required period, both in the city and on the bypass, were created by the author specifically for the research needs of this dissertation, taking into account the available data structure.

$$I_{Mk}^{poz} = I_{Mk}^{skut} + I_{C}^{vyp} n \cdot i_M \ [\text{veh} \cdot (24\ \text{h})^{-1}]$$
$$I_{Ok}^{poz} = I_{Ok}^{skut} + I_{C}^{vyp} n \cdot i_O \ [\text{veh} \cdot (24\ \text{h})^{-1}]$$

where: I_{Mk}^{poz} is traffic intensity in the city at the required end of the period [veh·(24 h)$^{-1}$],

I_{Ok}^{poz} is traffic intensity on the bypass at the required end of the period [veh·(24 h)$^{-1}$],

I_{Mk}^{skut} is traffic intensity in the city at the actual end of the period [veh·(24 h)$^{-1}$],

I_{Ok}^{skut} is traffic intensity on the bypass at the actual end of the period [veh·(24 h)$^{-1}$],

I_{C}^{vyp} is the calculated absolute year-on-year increase in total traffic [veh·(24 h)$^{-1}$],

n is the number of missing (approximated) periods,

i_M is the ratio of traffic flows on city roads [%],

i_O is the ratio of traffic flows on the bypass [%].

The result shows that, on average, 53.42% of traffic flows use bypasses, with the median (53.52%) being very similar. A basic overview is provided in fig. 2, which illustrates the relationship between the population size in the individual cities and the proportion of traffic flows in these cities.

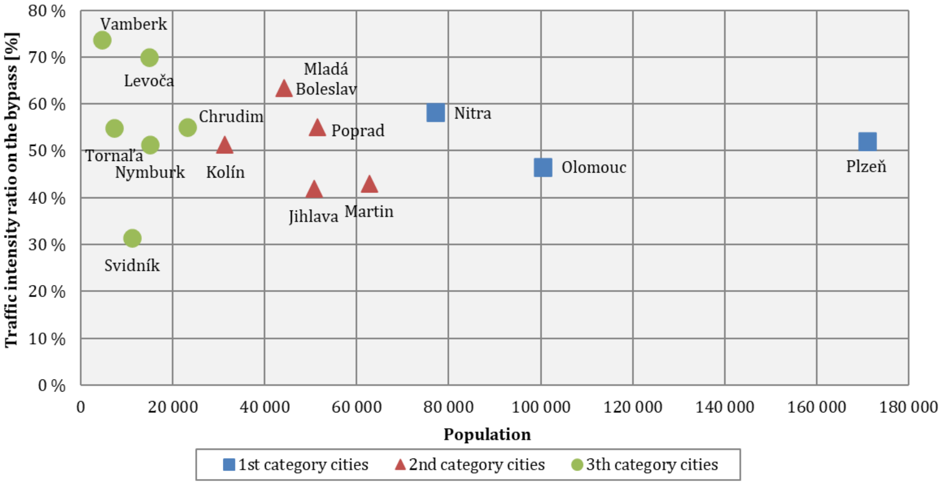


Fig. 2 Ratio of traffic intensities on bypasses in individual cities

Source: author

There is no significant relationship between the population size and the proportion of traffic using the bypass, as confirmed by the value of the Pearson correlation coefficient (-0.18). Interestingly, the most and least used bypasses are in third category cities. The maximum is reached in Vamberk, where 73.74% of vehicles use the bypass. The minimum proportion is recorded in Svidník (31.43%)

For a deeper understanding and more detailed scientific research into the studied issue, the subject of the research is to determine the difference between two measurements (at the beginning and at the end of the observed period), averaged over a one-year timeframe and expressed as a percentage (the ratio) of the current traffic volume (fig. 3). Similar to the previous problem, no significant relationship was found between the population size and the increase in traffic intensity (the Pearson correlation coefficient value is -0.15). On the other hand, it is important to note, as confirmed by the trend observed in the studied cities, that traffic intensity in the cities would certainly be higher and continue to increase in the absence of bypasses.

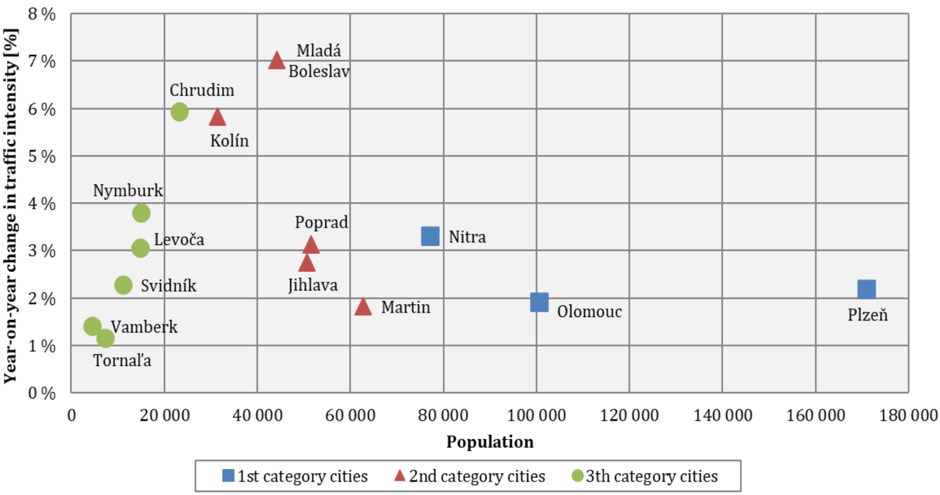


Fig. 3 Year-on-year change in traffic intensities in individual cities

Source: author

One of the main findings in relation to the studied issue is that in almost all of the cities analyzed (13 out of 14), the volume of traffic on city roads decreased after the construction of the bypass compared to the estimated values for the situation at the end of the period without the bypass. The median decrease in this case is approximately 37% (with an average of around 35%), but with a relatively wide variation range (68%).

When comparing the traffic situation on city roads at the beginning and end of the observed periods across the individual cities, a decrease in traffic intensity was recorded in 11 cities. An interesting finding is the demonstrated existence of the traffic induction effect, which is strongest in industrial and regionally significant cities. However, there are exceptions (Chrudim, Svidník), where traffic intensity in the city is likely increasing due to the absence of a bypass in all transit directions.

4.2 Use of Analytical Tools in Bus Transport

The dissertation also addresses bus transport, as its routing is significantly influenced by the configuration of road infrastructure. The research focuses on a selected set of eight Czech cities (Olomouc, Jihlava, Beroun, Vyškov, Jičín, Poděbrady, Mirotice, Čimelice) and seven Slovak cities (Nitra, Trenčín, Martin, Poprad, Levoča, Moldava nad Bodvou, Tornaľa), which encompass a wide range of possibilities related to bypasses. The study primarily focuses on long-distance bus routes, for which the use of a bypass (in the case of a decision not to serve the city) is the preferred option.

In general, the provision of bus services to cities depends on demand, the condition and parameters of the road infrastructure, the availability of other modes of transport, and technological possibilities. A significant factor is the quality of the road network and the existence of city bypasses, which can make a noticeable difference in travel times when deciding whether to serve a particular city or town. This factor is closely related to the road category—whether the bypass has motorway parameters or is a lower-category road. In this context, the key consideration is the achieved travel time on both compared routes, which depends on the speed of the vehicle. The average speed on the bypass should correspond to the following relationship, so that the potentially longer route via the bypass is shorter in terms of time than traveling through the city.

$$V_o > \frac{L_o \cdot V_m}{L_m}\ [\mathrm{km \cdot h^{-1}}]$$

where: V_o is the average speed achieved on the bypass [km·h^{-1}],

V_m is the average speed achieved in the city [km·h^{-1}],

L_o is the length of the bypass (new infrastructure) [km],

L_m is the length of city roads (replaced infrastructure) [km].

Even with a lower average speed (considering the dwell time at the stop), it is sometimes possible to accept slightly longer travel times, for example, due to higher driving comfort or in cases of high passenger turnover. For the comparability of the different alternatives in bus transport, the best option is to compare travel times on both routes (through the city and via the bypass).

The first finding is that the time savings for transit passengers when using the bypass can be relatively high, with the minimum recorded value being 5 minutes (Čimelice) and the maximum 20 minutes (Jihlava), with a median of 11 minutes. This saving is greater if the route bypasses multiple towns with potential stops. Another finding is that the relationship between the amount of time saved and the population of the given town is moderately strong (the Pearson correlation coefficient is 0.59). However, considering the defined dependent variable, a linear relationship is not entirely relevant, as the amount of time saved does not grow indefinitely with the population. A better regression model in this case is the use of a logarithmic function (fig. 4), which more accurately captures the situation (the coefficient of determination is 0.57).

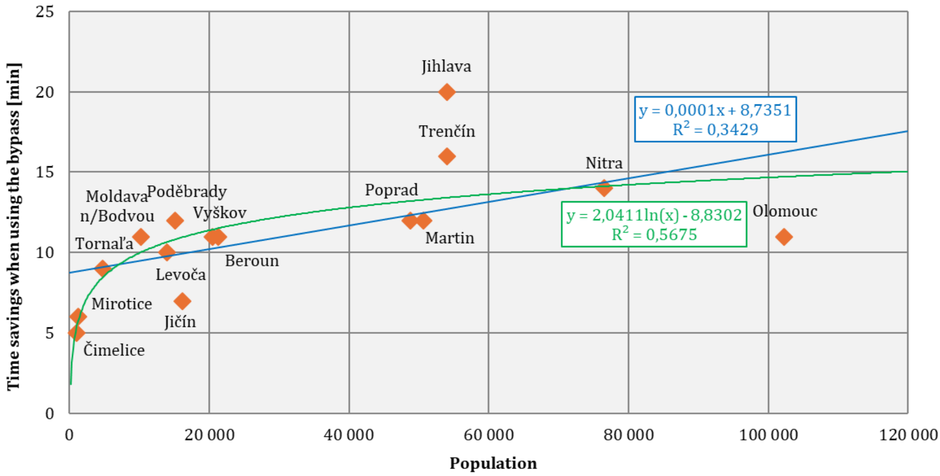


Fig. 4 Saving time for connections when driving on the bypass

Source: author

Another important finding is that, in the case of a similar study with the proportion of routes stopping in the city as the dependent variable, the relationship with the city's population is weaker (Pearson correlation coefficient is 0.41). In terms of applying regression analysis, the use of linear regression is possible (fig. 5), but with a low determination coefficient (0.16).

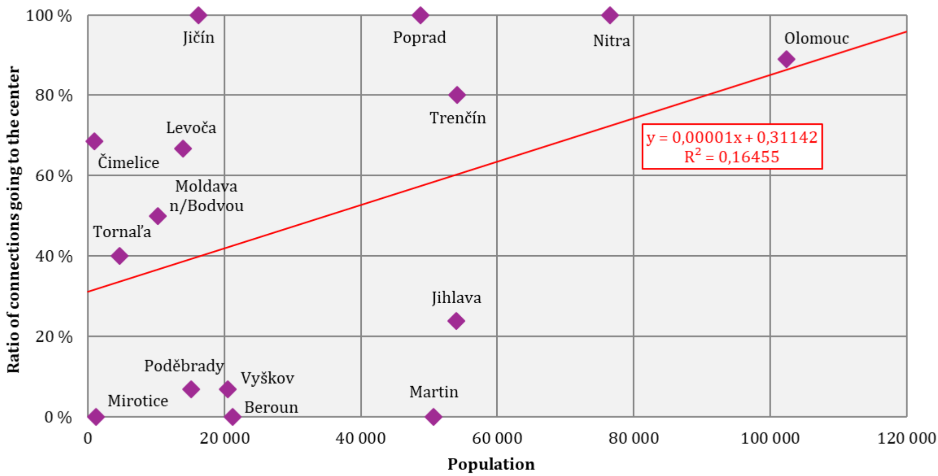


Fig. 5 Proportion of connections going to bus stands in individual settlements

Source: author

To allow for a more detailed assessment of practical situations, a simple mathematical model was developed in the dissertation. This model is based on the principle of so-called system equilibrium, and its functionality has been slightly modified to incorporate as many possible (typical) scenarios as possible, considering only the basic traffic relationships. This approach significantly reduces the computational complexity of the model.

From the perspective of improving the state of scientific knowledge, an important practical outcome of the model is determining the optimal operational concept for public transport routes to ensure the connection of a specific city to long-distance transport lines. The assessment can be conducted both from the perspective of passengers traveling to/from the city center or from the viewpoint of all passengers, including those in transit. The resulting transport operational concept can be compared with the current or planned situation and can assist in practice when deciding on bus route alignments.

As part of the research activity, this model is applied to two representative examples. The first focuses on the city of Jihlava, specifically on the issue of designing a new bus stop located on the D1 motorway. This stop is situated at the Pávov rest area, where regional and city buses traveling to/from Jihlava can also turn around. The model shows that a modified solution could either reduce the transfer time between long-distance and city transport by approximately 2 minutes (from 5 to 3 minutes), although this is not ideal in terms of passenger movement and system stability. The second option is to extend the city bus line to the city's peripheral areas, which would shorten the transfer time in the city center. This would reduce the total time loss for passengers traveling to Jihlava and its surroundings by 3 minutes.

The model is also applied to the example of the city of Mladá Boleslav, which is bypassed by the D10 motorway. The interpretation of the results is similar, but the time loss for passengers traveling to/from the city is higher (8 minutes) due to the use of a public urban transport line with a longer travel time. The presented solution is based on the use of analytical tools, meaning it is not resistant to various external factors that occur in road traffic. However, its significance lies in its simplicity, allowing the model to be applied to examine many situations without complex modifications.

4.3 Use of Four-Step Transport Modeling in Road Transport

To fulfill the research objective in relation to individual transport, the connection between two East Bohemian cities, Chrudim and Pardubice, was chosen as a representative example. These cities are located in the Pardubice region, with Pardubice having approximately 90,000 inhabitants and Chrudim about 23,000. The distance between these two cities is approximately 11 to 12 kilometers, depending on the chosen route (fig. 6).

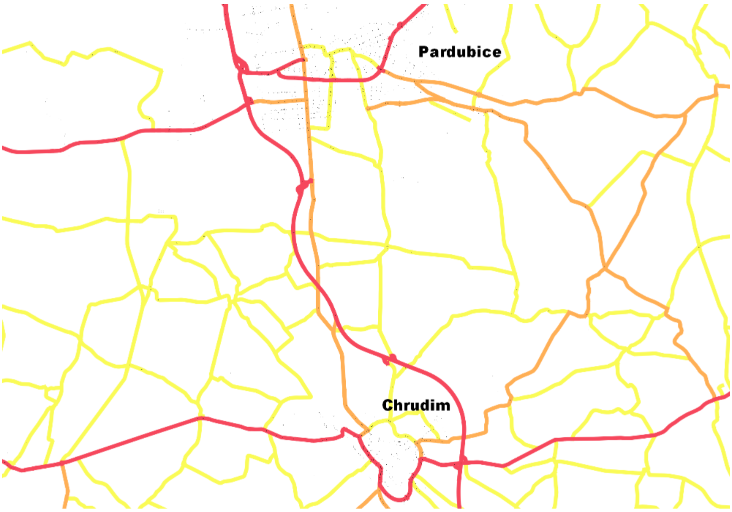


Fig. 6 Modeled transport network between the cities of Pardubice and Chrudim

Source: author

The cities are connected by first, second, and third-class roads, with the first-class road serving as a bypass for both cities. This is one of the reasons why this example was chosen, as it is interesting to observe whether the existence of a bypass changes the mode of transport between the cities, and if so, how significantly and on which routes. The modeling software Aimsun Next was selected for the research on the impact of bypasses.

In addition to the basic modelled number of trips (Assignment FW 100 – 100 trips between each zone in each direction), an increase of 50% and 100% is also considered. This means that the modeled traffic load between individual centroids in the OD matrix is 150 (Assignment FW 150) or 200 vehicles (Assignment FW 200) per hour. In relation to road capacity, this is a logical approach, as the given load simulates traffic intensities at different times of the day.

The results show that the traffic load on the different categories of roads does not increase evenly but primarily leads to the filling of available capacity. The differences in the observed traffic load must be considered separately for each direction. For roads heading towards Pardubice, there is a significant change in the share of vehicles using the different road categories (fig. 7).

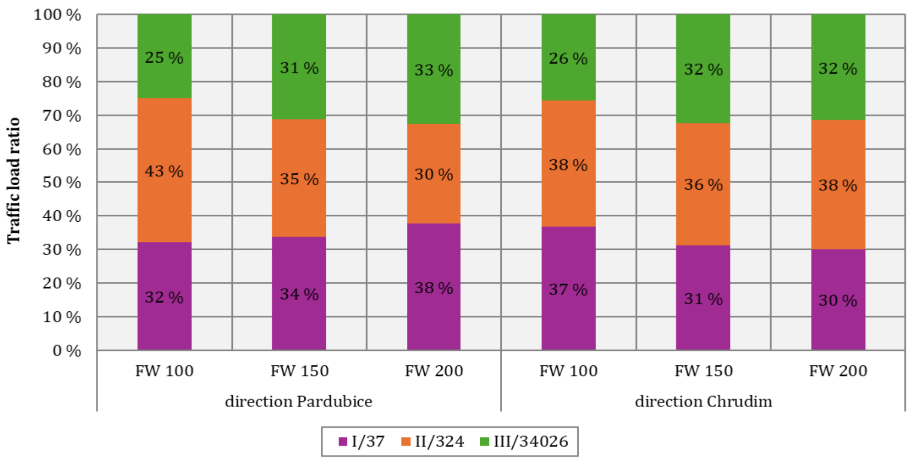


Fig. 7 Traffic load ratio broken down by road categories and directions

Source: author

With the model load FW 100, the second-class road is the most used (43% of trips), followed by the first-class road, and finally the third-class road. With the FW 150 load, the distribution among all categories is approximately one-third each. A turning point occurs with the FW 200 load, where the first-class road becomes dominant (38% of trips). This demonstrates the advantage of bypasses, as their directional alignment and technical parameters (fewer level crossings, higher average speed) make them suitable not only for transit but also for regional intercity traffic.

In the opposite direction (towards Chrudim), the situation is different. With the smallest model load (FW 100), the first and second-class roads dominate (37–38%), while the third-class road is the least used (fig. 7). As a result, in the following scenarios (FW 150 and 200), there is a sharp increase in traffic intensity on the third-class road. In all scenarios, the second-class road is the most used. This is due to the fact that this road serves as a feeder from the I/37 road, so the use of the first-class road is also reflected in the connected road network. A similar conclusion applies to the third-class road. The effect of the bypass is significant, particularly in the case of Pardubice, where the bypass (I/37 road) forms a high-capacity and relatively fast part of the transport infrastructure.

For the other considered routes between Pardubice and Chrudim, using the Traffic Assignment method, it was found that traffic is distributed across all available routes. The same assumptions apply to these routes as those identified in the model example connecting the city centers. Therefore, the placement of trip origins and destinations in relation to the bypass is crucial. As a result, the bypass is either unusable for certain parts of Pardubice (eastern part) or highly beneficial (western part).

The chosen example demonstrates that the way cities are connected to the bypass plays a significant role in its use for non-transit trips, with the parameters of other available routes and cities arrangement also being important. Therefore, it is essential to consider the issue comprehensively and take into account the available alternatives to the bypass, of which there are many in the studied area.

4.4 Use of Four-Step Transport Modeling in Bus Transport

Transport modeling allows for a similar approach to be applied in public transport as in individual transport. In this case, the research focuses on the Slovak territory, specifically the connection of the development area south of Košice to the nearby major hub city of Prešov (fig. 8).

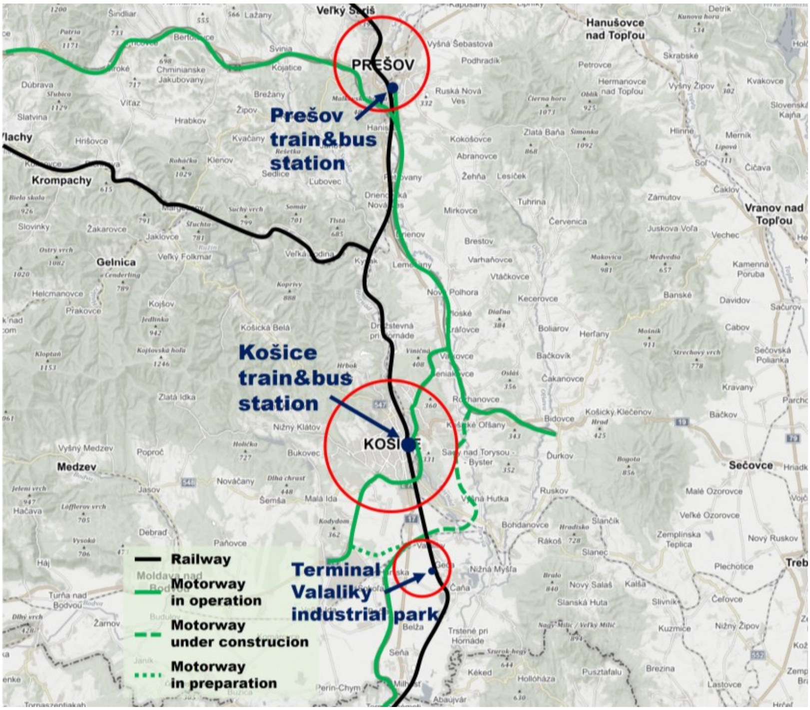


Fig. 8 Perimeter of the study area with marked road and railway infrastructure

Source: author using [26]

The area in question is the Valaliky industrial park. In the next five years, approximately 10,000 people are expected to work in this industrial park (it will be the largest industrial park in eastern Slovakia), which will naturally create high demands for employee transportation, even from more distant areas. For this research, the modeling software PTV Visum was selected.

In this case, all steps of the four-step transport model were used. The results of the first two steps (Trip Generation and Trip Distribution) indicate that the transport potential of public transport (after deducting individual transport) between Prešov and the Valaliky industrial park amounts to 400 passengers per day in both directions, excluding passengers from the agglomeration and the wider surrounding area. In the first variant, the entire volume of passengers traveling to/from the Valaliky Terminal is transported by rail, as there is no equivalent express bus service introduced.

An interesting situation arises in the second variant, where more than half of the passengers shift to the bus transport system. The modal split on the examined route changes from the original dominance of rail transport to a ratio of 52.5:47.5 in favor of bus transport (fig. 9). In the studied case, three bus services are operated for each shift at 5-minute intervals (and similarly in the opposite direction). This service is more attractive than a train running at only one time, which may explain why the bus service generates such high attractiveness on the examined route.

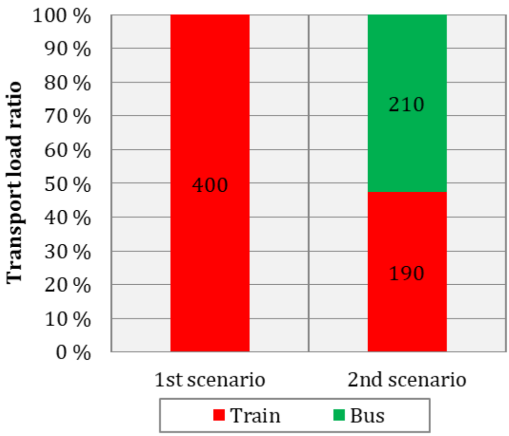


Fig. 9 Division of transport work on the solved relation in individual scenarios

Source: author

The modified and expanded transport model also provides a broader perspective on the issue being studied. Its results allow for the observation of the effects of introducing an express bus service in relation to the overall commuting to the industrial park within the wider region. According to forecast data from the transport model, the number of workers traveling to and from the industrial park by rail (Variant 1) is 8,270 people per day. After the introduction of the new bus line (Variant 2), the transport model shows that 210 trips are shifted from rail to bus transport, representing 2.5% of the share of public transport related to providing transport services to and from the industrial park.

One of the research findings is that higher-category infrastructure impacts the scope and use of public transport services. However, the actual usability of public transport for commuting may change over time. With an attractive public transport offer, its attractiveness for individual transport users will likely increase gradually, although this will also result in a longer time spent in the transportation process compared to individual transport. Other factors that may motivate the use of public transport include issues such as parking problems, traffic congestion, or potential future regulations.

4.5 Summary of Findings

In the area of road transport, it was found that the construction of city bypasses has a significant impact on improving traffic flow, reducing congestion on original roads, and generating positive environmental effects by diverting traffic away from city centers. The effectiveness of these solutions depends on the analysis of traffic impacts, with important factors being the availability of alternative routes, the attractiveness of new sections, and driver preferences. Transport modeling confirmed that bypasses reduce traffic load in city centers and improve connections between cities, with the quality and location of the infrastructure playing a key role.

In bus transport, it was demonstrated that the construction of bypasses leads to route optimization, shorter travel times, and increased operational efficiency, though it may negatively affect the service of bypassed settlements. An important factor is the possibility of a stop on the bypass, which, with proper planning, can improve the quality of life for residents without reducing the quality of public transport. An open question for further research is the issue of stops outside the bypass, for example, on the outskirts of cities. Key factors influencing public transport include the routing of the bypass, frequency of services, costs, and travel time, with political decisions and passenger preferences also playing a significant role.

The results of this scientific research are important for planning effective transport solutions that not only reduce traffic load but also optimize public transport and maintain the accessibility of city centers. Emphasis is placed on the generalization and transferability of the presented methods to address similar problems in other parts of the region and the country.

4.6 Proposal of the Methodology and its Application

The methodology for addressing the issue of replacing road sections with higher-category infrastructure consists of a clear and logical procedure developed based on the processes and results of the author's own investigation of the problem. This methodology progresses from problem identification, through its resolution, to monitoring the results and subsequent optimization. Each step is interconnected and designed to enable an efficient solution to the studied problem through the methods presented and explained in the previous sections of the dissertation.

In the case of road transport, in relation to a specific settlement, the solution involves multiple traffic flows, specifically transit traffic flows, flows starting and ending in this settlement with regional extensions, as well as routes that start and end within the same city. The methodological procedure for road transport is illustrated in the form of a simplified flowchart in fig. 10.

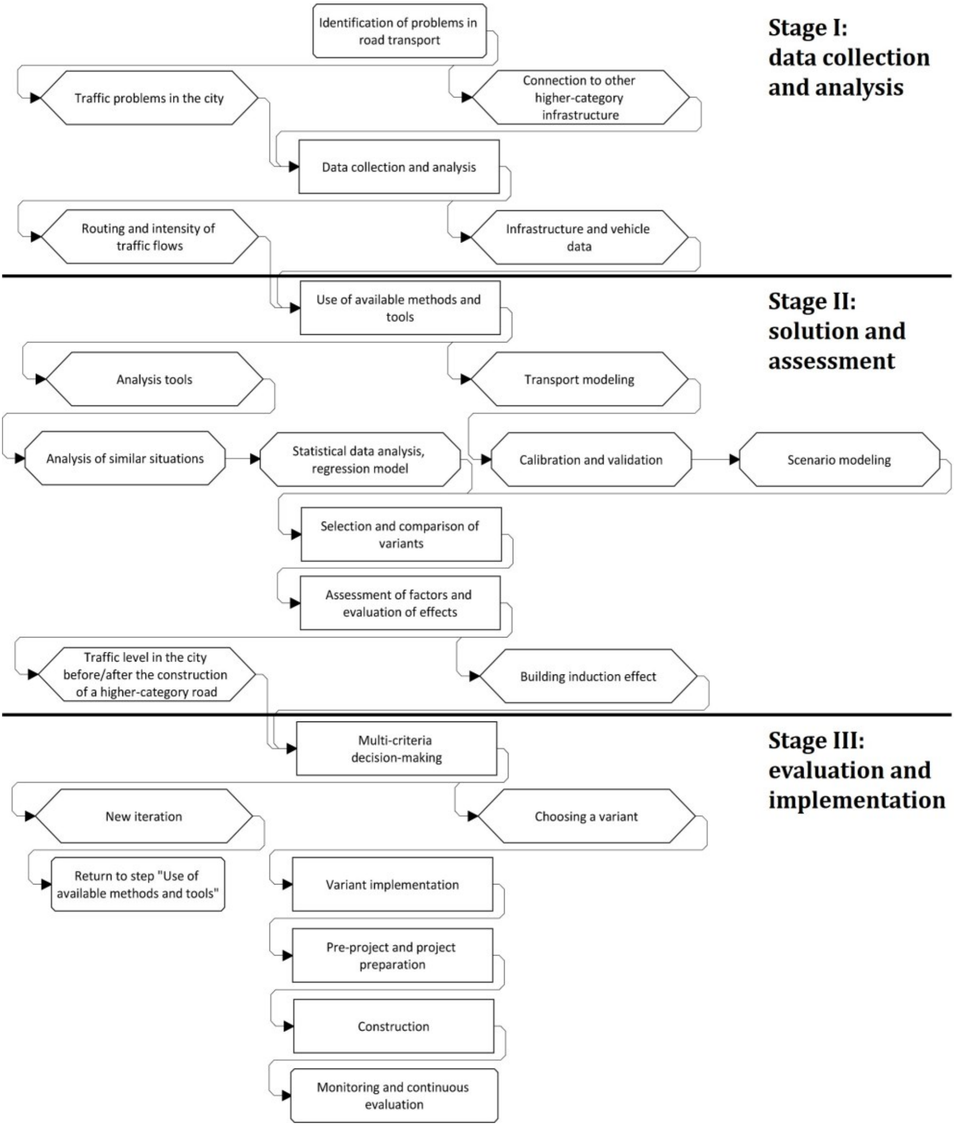


Fig. 10 Simplified flowchart of the proposed methodology for road transport

Source: author

A similar methodology is proposed for the public transport system (fig. 11). It focuses on the method of servicing cities with bus routes in the presence or planning of bypasses. Additionally, it examines the impact of bypasses in relation to optimizing the routing of these lines.

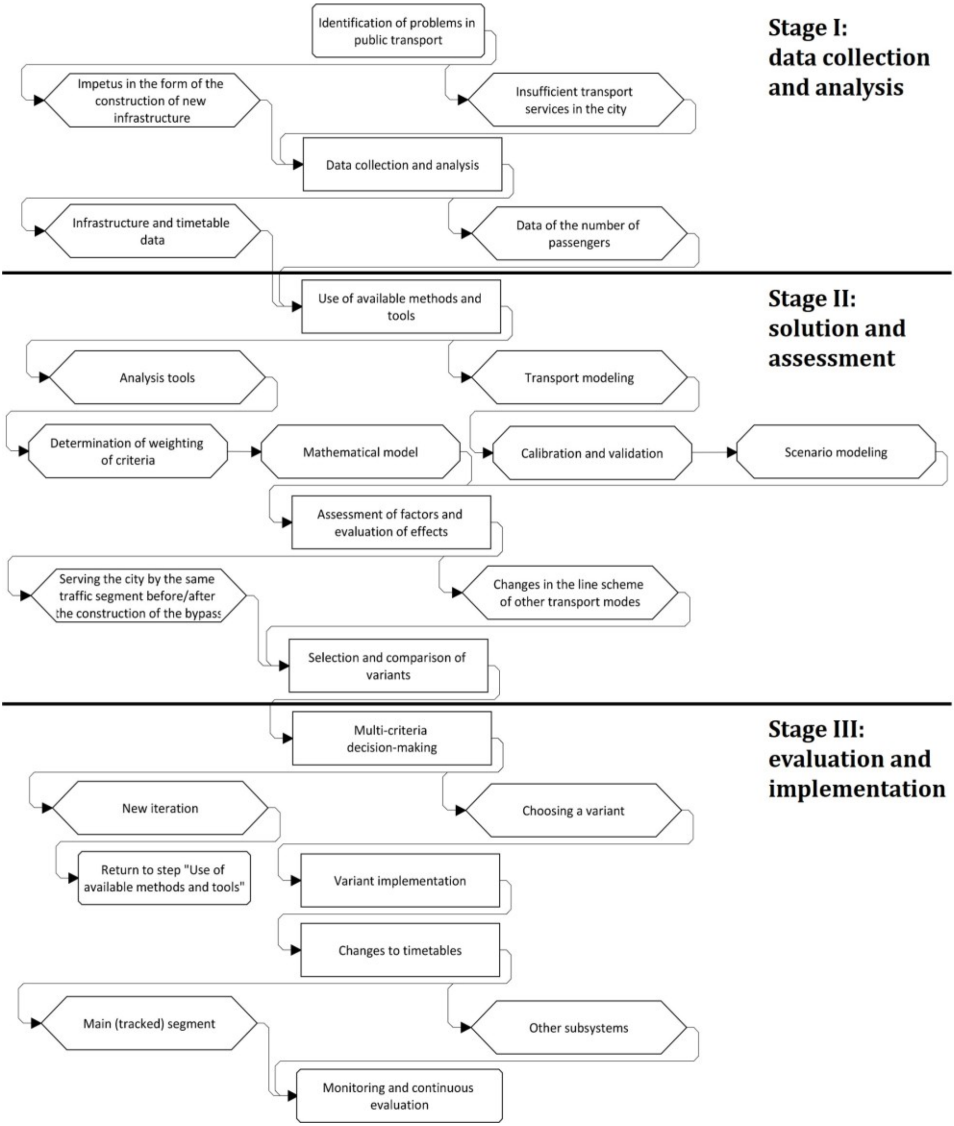


Fig. 11 Simplified flowchart of the proposed methodology for public transport

Source: author

The methodology is divided into two main parts, similarly to the rest of the dissertation, reflecting specific steps for road and public transport. Each step in the methodology is tailored to the needs and specifics of the respective transport systems. The proposed methodology also represents a systematic approach to addressing the issue of replacing transport networks, with a focus on general and transferable application in other regions or countries facing similar transport challenges. The individual steps of the methodology, along with their main objectives, tools used, and expected outputs, are presented in tab. 1.

Tab. 1 Summary of the proposed methodology for replacing transport networks

Step	**Objective**	**Tools**	**Output**
Data collection	Obtain data (accurate, model-based) on traffic and transport flows	Databases of infrastructure managers, transport operators, and other entities; surveys; statistical analysis	Data base (starting point for further analysis)
Analysis and modeling of traffic and transport flows	Analysis of the current state of traffic flows and transport infrastructure; modeling changes in traffic	Statistical evaluation; analytical tools; four-step transport modeling in specialized software	Analysis of traffic load and prediction of traffic conditions
Evaluation of alternatives	Compare alternative solutions	Multicriteria analysis; comparison with other strategic documents	The most suitable alternative (supported by data)
Implementation and monitoring	Project preparation and execution of the selected alternative; post-implementation evaluation	Specialized software; procedures in accordance with relevant legislation; post-implementation surveys	Improved infrastructure

Source: author

As a model example, serving to apply the widest possible range of tools and methods, the construction of new road infrastructure around the city of Prešov was selected. Prešov is a regional city located in eastern Slovakia, with a population of 82,286 (as of January 1, 2024), making it the third-largest city in Slovakia. The traffic situation in the city has long been problematic, as two main transit routes pass through it: west-south (Bratislava – Košice via the D1 motorway) and north-south (Poland – Hungary along the R4 route, known as Via Carpatia). While the first route already has a motorway bypass (opened in 2021), the so-called northern bypass in the north-south direction is currently under construction, with completion expected in 2027 (fig. 12).

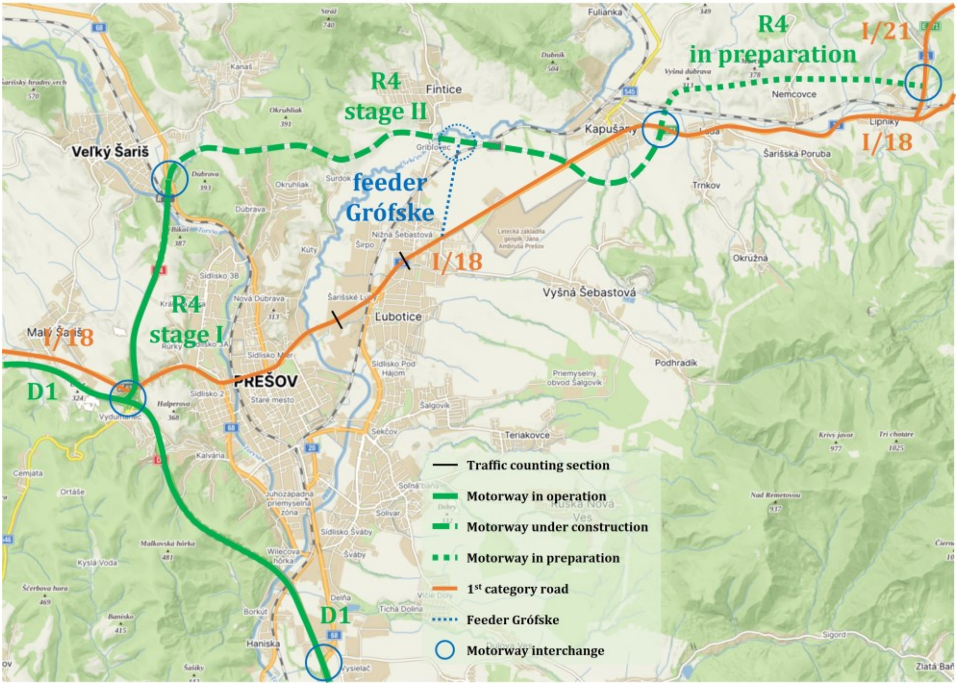


Fig. 12 Map of the studied transport network in the vicinity of the city of Prešov

Source: author using [26]

The construction of the northern bypass and its impact on traffic on city roads represents a suitable example for the application of the proposed methodology in road transport, with the focus area being the northeastern part of the city. In this part, there is currently a first-class road (lower category) designated I/18, which is the only entry (exit) point into the city in the observed direction (to/from Poland), while the under-construction R4 motorway (higher category) replaces or complements this road. In addition to the effect of the bypass itself, the example also addresses the connection between the bypass and the city, as the construction currently does not include the building of this connecting road, the so-called Grófske feeder (fig. 12). This issue provides a suitable impetus for applying the proposed methodology to support decision-making in replacing transport networks, as the resulting findings can be practically applied as arguments for or against the construction of this feeder road.

The use of analytical tools plays an important role in predicting the development of traffic conditions on city roads after the construction of the bypass. The essence of the regression model lies in determining and establishing the relationship between traffic intensity in the city before and after the bypass construction, where the independent variable is the situation before the bypass is built and the dependent variable is the situation after its completion. The result is a regression equation that can be used to predict traffic intensity in the city of Prešov following the construction of the bypass.

The created regression model is represented by a regression line, the formula for which is part of fig. 13. The model has relatively high accuracy, as indicated by the coefficient of determination R^2 (96.92%). This also suggests that the traffic situation in the selected cities follows a similar pattern, and there is a strong relationship between traffic intensity before and after the bypass construction. The Pearson correlation coefficient for this relationship is 0.98, which corresponds to a strong correlation between the two variables. Based on this fact, it can be assumed that applying the regression model to other cities with similar traffic and infrastructure conditions will provide relevant outputs.

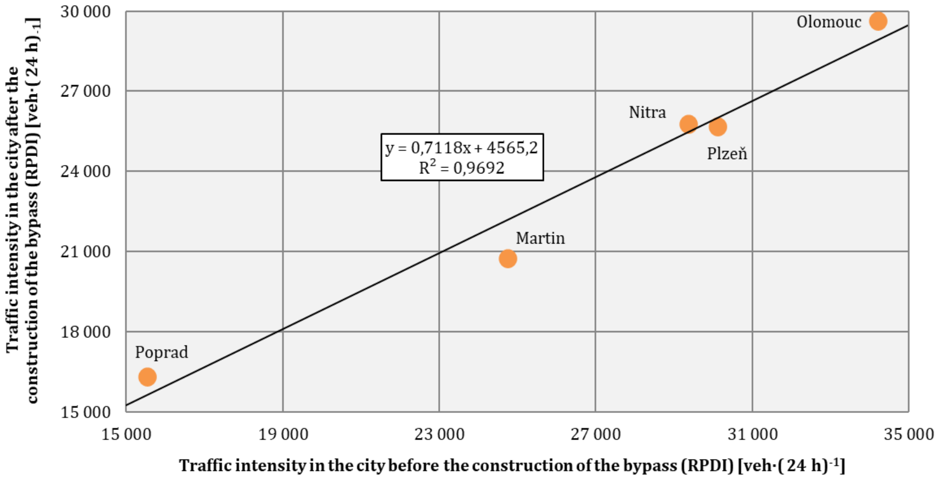
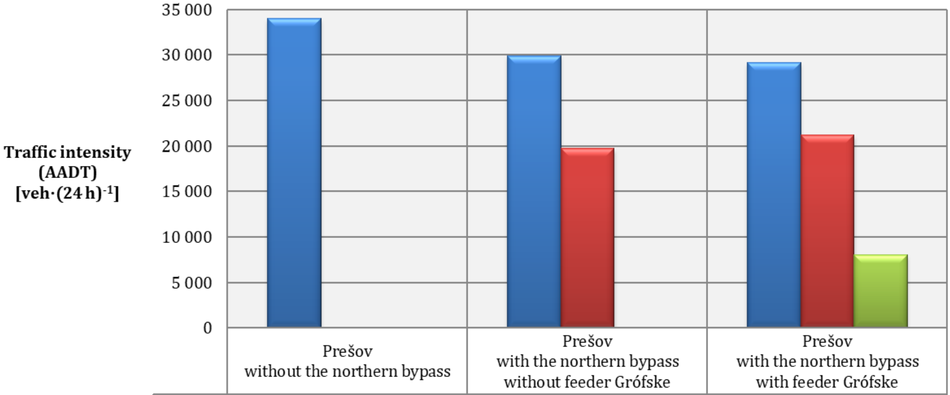


Fig. 13 Calculated regression model for predicting traffic in the city of Prešov

Source: author using [27; 28; 29; 30; 31]

A similar forecast can also be made using transport modeling methods. Moreover, in this case, multiple variants can be explored with a greater level of detail. In addition to the effect of the bypass itself, it is also possible to evaluate the impact and significance of the Grófske feeder on the traffic situation in the city. The calculation process must be repeated for each of the studied variants. In this specific case, the research focuses on the variant without the northern bypass, the variant with the northern bypass, and a third variant that includes the mentioned Grófske feeder. The results of the study are summarized in fig. 14.

The results of the performed computational procedures show the traffic intensities on the observed parts of the transport network depending on the modeled state of the infrastructure. An interesting finding is the forecasted traffic intensities in the city for the variant without the northern bypass, which are almost identical to the intensities observed in the 2022 traffic census. This situation is likely due to the current exhaustion of the road infrastructure's capacity, which corresponds to the traffic congestion occurring during peak hours on working days, reflected in the transport model using a resistance function.



	Prešov without the northern bypass	Prešov with the northern bypass without feeder Grófske	Prešov with the northern bypass with feeder Grófske
City	34 005	29 921	29 147
Bypass		19 732	21 181
Feeder			8 001

Fig. 14 Forecasted traffic flow intensities in the Prešov area

Source: author

Due to the current saturation of the road infrastructure, the transport model does not forecast further growth in traffic intensities over the next 20 years. Therefore, the capacity of the transport infrastructure and its current usage represent significant factors that influence future traffic on the roads.

In the studied peripheral area of Prešov, the use of the methodology can also be demonstrated in the case of public transport. Specifically, this involves the situation considered in the previous text in Variant 2 (including the Grófske feeder), supplemented by another section of the R4 road (Kapušany – Lipníky), which is currently in the planning stage. The use of the motorway, with its higher capacity compared to the standard two-lane bidirectional road I/18 running through the built-up areas of towns, creates the potential for reducing travel times for public transport routes. In this case, the addressed issue serves as a stimulus in the form of new infrastructure construction, which can be used to accelerate a selected set of public transport routes.

The Lipníky – Prešov section carries many regional bus routes, as this area sees the convergence of strong transport flows between the cities of Svidník, Stropkov, Michalovce, Humenné, and the regional capital Prešov. Additionally, other routes to different parts of the region are also operated here. The Prešov – Lipníky section is therefore quite dense with regional traffic, and a railway line runs parallel to it. In the assessed scenario, after diverting selected routes to the bypass, traffic in the villages decreases by approximately 50%. However, these are small villages, as Lipníky and Lada combined have a population of just under 1,500 people.

Given the above, transport modeling is a suitable method for assessing and evaluating the issue at hand. The situation illustrates a commonly addressed practical problem—the method of servicing intermediate settlements when bypasses are built around these towns and villages. The number of passengers in public transport vehicles in the examined variants is presented in fig. 15.

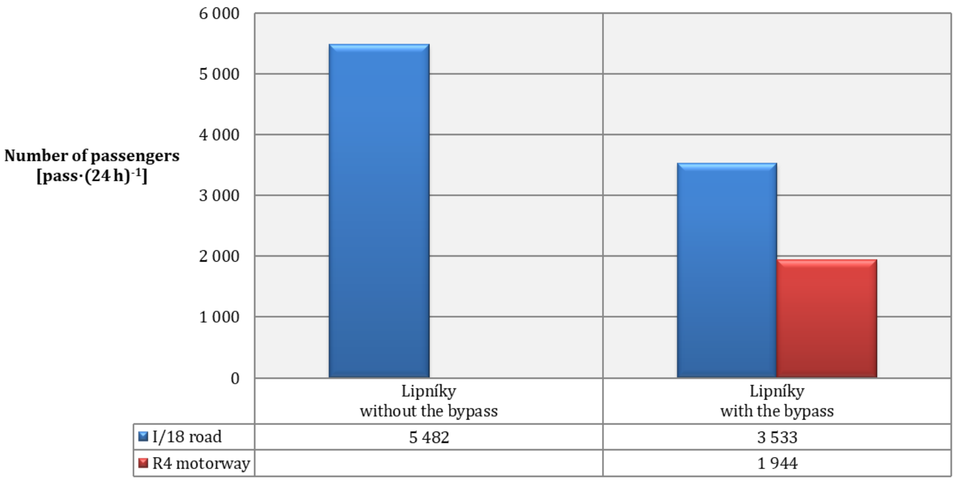


Fig. 15 Comparison of the number of passengers in buses in scenarios under consideration

Source: author

The data shows that in terms of passenger transport intensity, both assessed variants are essentially equal. The total number of passengers differs only by a few individuals, which corresponds to the level of statistical deviation. More interesting is the distribution of passengers among the different routes, where shorter regional routes on the original I/18 road show higher passenger volumes (64.5% of all passengers). Despite the fact that the majority of routes are operated on the bypass (53% of routes), the passenger intensity is higher on the original route. Based on this data, it can be assumed that time savings do not represent a decisive factor for the choice of a specific route in this case, due to its marginal impact compared to the total travel time.

The findings confirm that diverting certain regional bus routes to the bypass has a neutral effect on the number of passengers transported. However, the data shows that there will be no deterioration in the transport service for the bypassed settlements, as the observed passenger flow intensities will meet the transport needs of these settlements even with reduced service frequency. Based on the methodological procedure, the TOPSIS method is used to evaluate the examined variants. The result of this method shows that the proposed state has a higher relative distance indicator (0.65) than the current state (0.35), taking into account the weights and values of the individual criteria.

5 Contributions of the Dissertation

In relation to the established objective of the dissertation, the scope of work also included verifying the validity of the hypothesis and supporting theses. In this context, a connection was demonstrated between the construction of bypasses and the effect of traffic induction in cities, as well as with the quality of accessibility of bypassed cities in relation to their spatial arrangement. In public transport, it was shown that the existence of bypasses does not worsen transport serviceability, as any diverted segment of routes is replaced by an equivalent or alternative segment of available transport modes.

The contributions of the dissertation to science can be summarized into four key points:

1. **Expansion of theoretical knowledge on the issue of replacing transport networks**: The dissertation provides a solid foundation for contributing to the expansion of current scientific knowledge, particularly in the evaluation of the effects of bypasses using analytical tools and transport modeling methods.
2. **Development of a methodology to support decision-making in the replacement of transport networks**: A significant contribution of the dissertation is the proposal of a new and original methodology for evaluating the effects of bypasses and making decisions on how to replace transport networks with higher-category road sections.
3. **Application of analytical tools and transport modeling methods**: The dissertation enriches scientific understanding by applying specific tools to model various transport scenarios and their impacts on individual and public transport. For individual transport, unconventional use of transport models with model data is demonstrated, while for public transport, a specialized mathematical model was created.
4. **Universal applicability of the developed methodology**: The methodology proposed in the dissertation is sufficiently flexible to be applied to various types of transport systems in different geographic conditions, enhancing its value for further research and theoretical studies in transport engineering.

In terms of the practical contributions of the dissertation, the following points can be highlighted:

1. **Optimization of transport networks**: The dissertation provides practical procedures for the effective use of new sections of transport infrastructure. It also aims to assist in the strategic planning of bypasses, realignments, and similar roads to predict future traffic

loads in relation to factors influencing traffic on both new and replaced infrastructure.

2. **Support in the decision-making process**: The proposed methodology offers evaluators suitable methods and tools for assessing and evaluating the effects of new infrastructure sections. Through the use of multicriteria decision-making methods, various aspects and factors can be considered, leading to the selection of the optimal solution for a specific location.
3. **Improving public transport efficiency**: The application of the dissertation's findings leads to improved quality and efficiency of public transport, with the aim of finding attractive and sustainable solutions for servicing specific areas. This also creates a basis for future relief of individual transport in favor of public transport.
4. **Sustainability and benefits of new infrastructure**: The scenarios assessed and evaluated using the proposed methodological approach contribute to finding a solution that relieves urban roads, with a positive impact on the environment, thereby supporting the long-term sustainability of the infrastructure.

The stated contributions demonstrate that the dissertation has great potential to contribute not only to scientific knowledge but also to practical understanding and application in the fields of transport engineering, planning, and forecasting of transport infrastructure.

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Abstract

The subject of this dissertation is the design and application of a methodology to support decision-making in the replacement of transport networks. The work focuses on examining the effects and evaluating the factors influencing traffic and transport flows in road and public transport. For this purpose, analytical tools and methods of four-step traffic modeling are applied. The aim of the proposed methodological procedure is to evaluate the considered alternatives, with the goal of optimizing traffic flows, emphasizing the efficient use of infrastructure, particularly from the perspective of local governments and peripheral areas. The results of the work have practical implications for the strategic planning of bypasses and related public transport, and they are applicable in various geographical, transport, and infrastructural conditions. The work also brings scientific value by expanding knowledge on traffic induction and creating a universal methodology for addressing similar theoretical transport problems.