University of Pardubice
Faculty of Transport engineering

MODELLING OF PARKING SYSTEMS

DISSERTATION THESIS

2024 **Daniel Vymětal**

PhD student

Ing. Daniel Vymětal

Study program

Technology and management in Traffic

Study specialization

P1041D040001 Technology and management in Traffic

Trainer

doc. Ing. Josef Bulíček, Ph.D.

Trainer specialist

Ing. Martin Vojtek, PhD.

Training workplace

Department of Transport Technology and Control

Content

Introduction

It is evident that the current rate of increase in the traffic load on urban centres is unsustainable and needs to be actively addressed. Even though there is an increase in public transport capacity, the growth in individual car traffic is very evident, with an average increase in car traffic capacity of 10% between 2016 and 2021 [1]. It is therefore quite legitimate to assume that this load will continue to grow, thereby increasing the demands on the traffic in quiet inner-city areas. In addition, the issue of global climate change and the associated drive to reduce the emissions produced has also recently emerged, which will result in a change in transport behaviour - away from internal combustion engines in cars, either to electric cars or other types of alternative propulsion. However, it is evident that this transition will increase the organisational requirements for charging them when parking, which can be very well served by car parks.

Even though the system of car parks has become a common part of transport planning in German-speaking countries (Germany, Austria and Switzerland), there is still no coherent national or European concept of how to approach these systems, which may have a negative impact on their use and consequently on the traffic load of urban centres themselves.

1 Current status of the studied issue

In practice – In addition to the use of parking lots at VD on the outskirts of cities, it is advisable to pursue the possibility of building catch basins at suitable VD stations. The paradox is that VD stations located outside of the urban area (which is often mentioned as a disadvantage for some railway stations) may have an advantage here (easier access to land, less environmental impact of the parking lot on the community, traffic recovery of a less demanded station, etc.). Naturally, the validity of this assumption depends on local conditions both in the area and in the VD system. Another conclusion is that charging for such parking may have a regulatory function (Munich). In general, however, the issue of charging must be approached very cautiously, lest the charge end up having exactly the opposite effect (after all, parking in company garages in the city centre, which the user perceives as free, creates a cheaper alternative in the end; similarly, the user may perceive a situation where he or she prepays for parking in the city centre for a longer period of time). Similarly, this is also true for P+R opening hours following shift changes. And, as the example of Moldava nad Bodvou has shown, it is absolutely essential to design the timetable of the connecting VD appropriately. In addition, the period of the VD at peak times must be taken into account, as a longer period of connections may result in the user rejecting the catchment car park. This may be all the more relevant in the context of cultural events that may end late in the evening. It is after the end of such an event that the user will not be offered the opportunity to transport the VD to the catchment car park at a reasonable time. Alternatively, there will be a situation where the catchment car park is already closed. A further complication may be early morning/late night connections to distant destinations, where the user wants to park his vehicle at the intercept car park and continue the VD to the train station (or airport) so that he can use the first connection to a more distant destination with sufficient reserve. Again, opening hours or insufficient VD period at marginal times may lead to user rejection.

Thus, from the above examples, it can be seen that the factors that critically influence the demand for the use of catchment car parks from the user's perspective can be summarised as follows: Period of VD connections in peak hours; period of VD connections in off-peak hours in relation to the purpose of the journey; price of parking at the intercept car park; price of parking in the city centre; correlation between the price of parking in the city centre and at the intercept car park; appropriate distribution of VD connections within the day; extent of opening hours of the intercept car park; maximum parking time at the intercept car park; sufficient number of free parking spaces; security.

In scientific knowledge – Shen [1] goes on to point out in his case study conducted in a part of Beijing called Shunyi that China has seen a 20% increase in urbanization in twenty years, but a 10-fold increase in the number of cars in the last ten years. These are clearly extreme figures, and this study provides an interesting insight into whether the car park system can cope with such an onslaught. The authors of this study address the issue of the P+R car park system in a similar way to their colleagues in the west, i.e. in an attempt to optimise the location of the P+R car park. However, in addition to the classical cost minimization effort, the authors decided to use vector optimization, where they set the objective to find a suitable location for the P+R parking system and choose an appropriate tariff policy based on minimizing the cost of building the P+R interceptor parking, but also minimizing the emission burden.

The Beijing study further concluded that a **P+R system is most effective when linked to rapid public transport** (usually metro or rail) **at 10-minute intervals**.

Transport Scotland commissioned The Effects of Park and Ride supply and pricing on public transport demand [2] from the University of Leeds in 2012, in collaboration with Arup and Accent, in various cities in Scotland. The methodology used in the project combined a review of secondary data sources and a literature review with targeted primary data collection, which was then used to develop forecasting models. The project investigated parking in catchment car parks at train stations, bus stops and at locations where it is possible to cross the Firth of Forth through a number of case studies. The project reached different conclusions for catchment car parks, train stations and bus stops. For interceptor car parks and train stations it was found that every 100 parking spaces added only generates between 4 and 10 new passengers per day. The authors attribute this conclusion to two factors: **low elasticity of demand and substitution effect** (i.e. passengers who previously used to cycle, walk or bus to the railway station start using IAD for this purpose). An **increase in the price of parking by £1** (31 CZK, at the average CNB exchange rate for 2012) would **reduce demand for rail transport by 3.0-4.9%.** The results of this project suggest that the **potential to encourage modal shift to public transport depends** on a number of factors, including parking policy, the availability and quality of public transport and urban development planning. For both types of car parks studied, i.e. at railway stations and bus stops, it is important to take into account local circumstances and characteristics in order to design effective and sustainable strategies for improving the traffic situation.

Macioszek [3] in a case study from the Polish city of Kraków focused on the use of the P+R system. In their work, they analyzed the use of Kraków's catchment car parks in the time period from March to December 2018. In their study, they concluded that the **highest number of entries to the P+R system** occurred on weekdays between **6-9 a.m.** and the highest number of **exits between 3-7 p.m.** This clearly corresponds to the temporal location of activities in the city. The authors also tried to find out what could lead to higher usage of the P+R system and after a questionnaire survey, it was concluded that higher frequency of public transport connections would contribute to higher usage of the P+R system. However, more detailed analysis would be needed here. It was also found that the age of the driver, the length of time they have held a driving licence and financial income have an impact on the use of the P+R system. On the other hand, the length of the car journey was found to have little effect on the use of the catchment car park, which is in a way a logical result.

Dr. Chena and his team [4] state that there are **two key factors** that influence the attractiveness of the offer to users: **Time to find a parking space in the city centre** (The authors of this study concluded that users have a high aversion to the risk of not finding a parking space close to their destination and subsequently having to search for an available parking space. The study further states that users are very willing to accept a higher parking price to eliminate or at least reduce this risk); **P+R parking charges** (The authors highlight an interesting finding here, namely that users are very willing to accept a higher parking price close to their destination. However, this is not the case for parking a vehicle in a metered car park.)

An interesting study, which does not deal directly with the P+R system as such, but with the determination of the number of parking spaces as such, is the study by Yaron Hollander and colleagues [5], which was produced in collaboration between the University of Leeds and the Israel Transport Institute. In the study, the authors used Game Theory, specifically the Stackelberg game between passengers and the government (the choice of moves is not simultaneous but sequential) to determine the optimal number of parking spaces. It is a competitive game, but at the same time it is not a zero-sum game. In the case of the MDA, it is a proxy term for a catchment car park promoter, a transport company operating a public transport service, an organiser of an integrated transport system, etc., since in each city this may be the responsibility of a different entity or even several such entities at the same time. The MDAs, through their transport policy, then seek to apply strategies that will help them to achieve, or at least come as close as possible to, the system optimum. On the other hand, there are then the ordinary users of the transport infrastructure who try to achieve their subjective optimum. Logically, these two optima cannot be equal, but some sub-objectives may be identical. At the same time, it can be seen that the solution to the problem cannot exist in terms of pure strategies, but rather in terms of mixed strategies, where the individual resulting percentages may represent the choice of a certain population. It is worth mentioning that a characteristic feature of the Stackelberg game is that the choices of the moves of the individual players are not simultaneous but sequential. Thus, in the game there is a Stackelberg leader (MDA) who initiates his move, which is then responded to by the Stackelberg followers (drivers). In general, then, the MDA's moves are still strategic and the drivers' moves are operational, i.e. significantly more flexible. As part of this study, the authors asked the question "What is the maximum possible reduction of parking spaces in the downtown so as not to weaken the competitiveness of the downtown." They further state that the term "downtown competitiveness" is a rather abstract concept and more or less represents specific policy goals of the MDA that need to be appropriately specified. In this case, the authors decided to create several different scenarios on the basis of which the MDA could then make a decision.

It is the mathematical model of the Stackelberg game that could very well be applied to the issue of catchment car parks, due to the fact that MDAs create the rules of the game (whether by deciding where the catchment car park system will be built, but also by controlling pricing, opening hours and to some extent the type and period of follow-up traffic) to which drivers respond with some delay. The modelling itself offers the possibility to find out how many drivers could be diverted from the traffic stream (both in absolute value and relative value) to a given car park for a given pricing and period of follow-up traffic. It is evident that the traffic model itself would need to include the travel time of the follow-on traffic compared to the travel time of the car, the stability of the timetable, opening hours, or charging for traffic at rest at the final destination.

2 Dissertation goal

From the sources analyzed, it is evident that the situation around catch basins was most often addressed at the interface between the impact of pricing on catch basin use, the length of the PT follow-up period on catch basin use, and the location of catch basins. The fact that the situation with ICT and the associated traffic congestion in urban centres will not decrease and a higher outflow of users to the PT system cannot be expected, nor can a solution in the context of autonomous vehicles be expected. And it is therefore quite legitimate to assume that a solution cannot be found only at the city level due to the limited areas for parking and the unsustainability in terms of taking new areas. Nor within the region due to resource constraints, where it is not possible to create a supply of connections to cover the entire demand in space and time. For these reasons, it is clear that the solution must lie at the interface between these two levels, with the MDA having the ability to regulate parking use in the town centre through the level of parking charges.

An interesting inspiration for establishing the key hypothesis and subsequently the objective of this dissertation is a study by Yaron Hollander [5], which focused specifically on the dependency of city centre parking charges and their subsequent usage, using game theory. With some modification of their procedure, a maximum price for parking in the downtown could be determined so that the maximum number of drivers are diverted to the catchment parking lot and the attractiveness of the downtown is not compromised.

Hypothesis H_0: There is an optimal price setting for parking in the town centre that maximises the use of the catchment car parks while maintaining the attractiveness of the town centre.

Objective of the dissertation – The aim of the dissertation is to test the validity of hypothesis H_0 using a mathematical model of the Stackelberg game.

It aims to achieve this goal by identifying the system, then decomposing it and performing a force field analysis to analyse the decision-making processes of the driver and the MDA and, based on the Stackelberg game, to delineate how the MDA should proceed to get as close as possible to the system optimum of diverting the maximum number of vehicles from the city centre to the interceptor car parks.

Stackelberg's game seems to be an ideal solution because, for example, the vector optimization method is more suited for solving the location of the parking lot itself than for complex decision-making tasks. This makes it different from most models used in game theory because it is a sequential game. In other words, decision making and player reactions do not occur instantaneously, but gradually.

The four-stage model, on the other hand, is not entirely appropriate for the reason that, while it can appropriately model the diversion of traffic to interceptor parking lots, it cannot well describe the decision-making processes that lead MDAs to take certain actions to which users subsequently respond. The genetic algorithm is more suited to the design of a follow-up traffic network. Stackelberg's game seems to be the best for describing the decision-making process of the MDA and subsequently the users for this case, mainly because the reaction of the users to the MDA's actions does not occur immediately, but gradually and the subsequent reaction of the MDA is again gradual.

3 Processing methods and method of solution

It is clear that the user decision-making and MDA systems are not isolated from each other, but instead influence each other. The relationship between these two systems is complex and can take many forms.

The MDA decision-making system creates the conditions for user decision-making by setting the rules, tariffs and availability of parking facilities. These factors constrain the user's decision-making options in the following ways:

1.The price of parking at the interceptor parking lot – MDA sets the prices for parking at the interceptor parking lots, which directly affects user decision making. If prices in the catchment car parks are lower than in the city centre, users may be more motivated to use the catchment car parks.

2.Downtown Parking Regulation – MDAs may limit the availability or increase the price of parking in the downtown area, which may induce users to seek alternatives such as catch basins.

3.Time and financial availability of the town centre – the MDA decides whether to charge for access to the town centre by introducing tolls or by regulating environmental requirements for vehicles. At another level, the MDA can also to some extent (based on legal conditions) reduce the maximum speed on some roads (and subsequently enforce this by stretch speed metering), creating traffic chicanes, which can achieve a deterioration in the travel time of IADs heading into the city centre in favour of VD.

4.Quality and capacity of catch basin parking – MDA decides on the location, capacity and quality of catch basins, which influences user's decision making. If the

MDA provides easily accessible, safe and convenient catch basins, users will be more motivated to use them.

5.Frequency and quality of public transport – MDAs, often in cooperation with the organisers of integrated transport systems or transport companies, influence the frequency and quality of public transport between the interceptor car park and the city centre. If public transport is fast, convenient and frequent, users may be more motivated to use the catchment car parks.

6.Promotion of catchment car parks – MDAs can actively promote the benefits of catchment car parks, which can influence users' perceptions and decisions. Information on availability, pricing and links to the city centre can motivate users to use the catchment car parks.

On the other hand, users influence the goals of the MDA system through their decisions. The demand for metered parking, which is the result of user decision-making, may lead to the need for changes in transport tariff policy and infrastructure. For example, if it is determined that users prefer downtown parking over metered parking, the city may respond by changing rates or changing the capacity of metered parking (increase) or downtown parking (decrease).

This interaction between systems is dynamic and changes over time. Changes in one system can have an immediate or delayed impact on the other system. For example, the introduction of a new tariff in a catchment car park may have an immediate impact on the user's decision-making, while changes to public transport may have a delayed effect. This interaction of systems can then be described using Game Theory.

Game theory is defined as the analysis of conflicts by mathematical models between intelligent and rational agents (where at least one of the agents must be rational - games versus nature). Thus, Game Theory offers general mathematical techniques useful for analyzing situations where two or more individuals make decisions that affect the welfare of other individuals. [6]

In the general context of game theory, a user's decision process of where to park his vehicle can be viewed as a game with an infinite number of strategies. The user has the option to park their vehicle at various locations within the city centre, including locations where, although parking is illegal, they are also considering various locations within the wider city or region. Amongst these strategies is the option to park the vehicle in a catchment car park. However, for the purposes of this thesis, the author narrows the list of these strategies to four - parking the vehicle in the city centre (as close as possible to the destination), parking the vehicle at the nearest catchment car park, parking the vehicle at a 'live' catchment car park (i.e. one near a railway station (stop, terminal) where it is possible to change to VD services to the city centre), the whole journey made by VD.

In trying to manage user decision-making, the MDA (player 1) again chooses from an infinite number of strategies in which it tries to maximize the number of users who divert from IAD use in favor of VD at the lowest possible cost.

The user (player 2) tries to minimize his cost and maximize his utility when choosing one of these strategies. His decision may be influenced by a number of factors (criteria).

As a first solution option, the game of chicken is offered. This is a game where, in general form, players choose between two strategies - retreat and non-retreat. Although it is a game that can be described as a conflict between the MDA and the user, where the MDA is considering whether to intervene in the parking policy (preferred option - do not intervene - cost saving) and the user in turn is considering whether to park the vehicle in a catchment car park or in the city centre (preferred option is to park as close as possible to the destination). However, the latter is not suitable for dealing with the case of the user's decision-making process, because the MDA sets individual parameters that have an impact on the user's decision-making, and at the same time it is not a pure antagonistic conflict. The Stackelberg game is offered as a better solution.

If the interceptor (player 1) can influence the factors (price of parking at the interceptor, regulation of parking in the city centre, time and financial availability of the centre, quality and capacity of the interceptor, frequency and quality of public transport and promotion of the interceptor), the game becomes interactive. In this case, both players choose their strategies in order to maximize their utility, taking into account the expected decision of the other player.

The Stackelberg game is a hierarchical duopoly model where one player (the leader) chooses his strategy first and the other player (the follower) responds to this strategy. In this case, player 1 (MDA) is the leader and player 2 (user) is the follower [7].

4 Achieved results

The **proposed methodology** was applied to the three largest cities in the Czech Republic **- Prague, Brno and Ostrava**. In this application, a starting point was randomly selected, which is located in one of the surrounding municipalities. However, one of the points is an ordinary municipality with no higher specifics, but with a connection to the chosen destination (and also to be able to use the catchment parking for the trip). The second point is a municipality located in the catchment area to the selected destination primarily by road. The third point is another county town. Within Prague, there are four municipalities - Chvaletice, Mladá Boleslav and Hradec Králové. When considering journeys to Brno, the municipalities are Višňové, Znojmo and Olomouc. For Ostrava, the municipalities are Bílovec, Hlučín and Prague. For each assessment, 4 different scenarios are taken into account - The whole journey is made by ICT; the journey is made by ICT to a catchment car park and then by PT; the journey is made to a lively (but unofficial) catchment car park near a transport point (railway station, bus stop, metro station, ...) from where there is a direct connection to the city centre; the whole journey is made by PT. The journey is always directed to an administrative building in the form of a regional office, a city office or a municipality in each city.

Prague – In all three cases considered, the dominant strategy for users is to ride the ICT to the city centre. The primary factors influencing this dominant strategy are the travel time between the start and destination points. Livable interceptors suffer from a lack of parking and their alternatives are too far away. The Černý Most interceptor car park then suffers from a combination of high costs from the journey made and a lower degree of safety than parking in the city centre. In other words, driving to the city centre is not that much more costly for the user than parking in the catchment car park, but it reduces the convenience of the journey for the user by having to change to a subsequent PT and is therefore affected by subsequent service periods.

It should also be noted that parking in the city centre has been selected at a relatively high cost of 370 CZK/12 h. However, it offers the user a higher degree of security and the possibility of security of a parking space in the form of a reserved space. The obtained benefits of each strategy for the assessed municipalities are then shown in a summary graph in the figure for better clarity. It should be added, however, that this is an individual decision not a recurrent one. As it is unlikely that a user would be willing to pay such an amount on a daily basis on a monthly basis. At the same time, it should be noted that these facilities offer monthly or yearly parking reservation at lower prices.

Brno – For the Znojmo-Brno session, the dominant strategy was to park the vehicle at the emergency car park in Miroslav. A very similar situation (although in this case it was not the dominant strategy) was the Višňové - Brno journey, where it was advisable to park the vehicle at the railway station in Moravský Krumlov. This points to the fact that line 244 Brno - Hrušovany nad Jevišovkou-Šanov is suitable for the synergy of ICT and PT. The other lines are clearly dominated by ICT.

Ostrava – When comparing all the routes leading to Ostrava, it can be said that the interchange car park on the Hlučín route does not create sufficient attractiveness for users to attract users, even in the main direction for which it was intended - the Hlučín area. It should also be said that in all situations the best strategy for users was to use the ICT to move to the destination of the intended journey.

Increase in parking fees in the city centre car park

Unsupervised parking – The increasing cost of parking in an unattended car park has a large impact on the utility of the user making the entire ICT journey. Interestingly, when the price of parking in the downtown secure parking lot increases, the attractiveness of the PT and the livable interceptor parking lot increases. However, the attractiveness of the catch basin parking does not grow much.

Secure parking – If the city centre car park is secure, then the effect of price on the user's normalized utility is very limited. That is, the user is able to accept a higher price for parking if he is sure that his vehicle will not be damaged or stolen.

Increase in expected expenditure in a car park

There is a higher degree of sensitivity of the user to the increase in the cost of the journey made with parking the vehicle in the car park. If the cost of parking a vehicle in a car park increases, this effect will be reflected positively not only in the user's utility from the realised ICT-only trip, but also in the PT.

Thus, the results presented above show that the user perceives differently the cost of parking in the catchment car park and in the city centre. Thus, it can be seen that the user is willing to pay a significantly higher price in the city centre than in the catchment car park and thus tolerate higher parking fee increases in the city centre. For this reason, **hypothesis H_0 must be rejected**. This is precisely because parking price increases in the city centre do not lead to significant use of catchment car parks, but rather to the use of PT. However, the results show that increasing the price of parking in the catchment leads to a decrease in the use of catchment parking. At the same time, the results show that the user is willing to pay significantly more for safety.

5 Benefits of a dissertation

Within the literature analysis of current scientific knowledge, the author concluded that almost no papers deal with the actual decision-making process of the user. That is, the decision-making system that the user goes through when choosing how to get to the city centre or where to park their vehicle.

The author of this dissertation decided to create such a system and describe it in detail in order to show what factors have a major influence on the user's decision-making process. At the same time, he also decided to describe the MDA's decision making system in creating a system of catchment parking and subsequently creating the conditions within this system. This dual description was chosen in order to make it more apparent what factors that influence the MDA have a direct impact on the user and their decision making.

A further contribution of this work is the methodology developed to rank the attractiveness of each catchment car park in relation to the other options and the chosen starting point. The author used modified Stackelberg games from game theory to develop this methodology.

Literature

[1] Shen X, Chen F, Su B, Chen Q, Yao J. Optimization of park-and-ride system: A case study of Shunyi in Beijing. Advances in Mechanical Engineering. August 2017. doi:10.1177/1687814017714987

[2] THE EFFECTS OF PARK AND RIDE SUPPLY AND PRICING ON PUBLIC TRANSPORT DEMAND . Leeds: Transport Scotland, 2012. Dostupné také z: https://www.transport.gov.scot/media/30102/ j253322.pdf

[3] Macioszek, E.; Kurek, A. The Use of a Park and Ride System—A Case Study Based on the City of Cracow (Poland). Energies 2020, 13, 3473. https://doi.org/10.3390/ en13133473

[4] Influence of Parking on Train Station Choice under Uncertainty for park-and-ride Users. Online. Procedia Manufacturing. 2015, roč. 3, s. 5126-5133. ISSN 23519789. Dostupné z: https://doi.org/10.1016/j.promfg.2015.07.537. [cit. 2024-06-12].

[5] HOLLANDER, Yaron, Joseph N. PRASHKER a David MAHALEL. Determining the Desired Amount of Parking Using Game Theory. Journal of Urban Planning and Development. 2006, 132(1), 53-61. ISSN 0733-9488. Dostupné z: doi:10.1061/(ASCE)0733-9488(2006)132:1(53)

[6] AUMANN, Robert J. a HART, Sergiu. Handbook of Game Theory With Economic Applications. 2. Elsevier North Holland, 2007. ISBN 978-0-444-89427-4.

[7] ČÁSTEK, Ondřej. Využití stakeholderského přístupu při strategické analýze podniku. 1. vyd. Brno: Masarykova univerzita, 2010. 242 s. ISBN 978-80-210-5411-0.

Own publication

Publication activity related to the topic of the dissertation

[I] CHLUMECKÝ, Jaroslav, Jan FRONĚK a Daniel VYMĚTAL. Regional Railway Transport Between Regions in the Czech Republic. Transportation Research Procedia [online]. 2020, 2021, (27), 132-137 Dostupné z: doi:10.1016 /j.trpro.2021.02.01

[II] FRONĚK, Jan, Jaroslav CHLUMECKÝ, Tomas HORNÍK a Daniel VYMĚTAL. Development of modal split in the Czech Republic according to national census. Transport Means [online]. LT, 2020, 30 September 2020, (234), 1000-1005. ISSN 2351-7034.

[III] FRONĚK Jan, Jaroslav CHLUMECKÝ a Daniel VYMĚTAL. Covid-19 pandemic vs. public transport attractiveness - literature research and selected solutions and recommendations. Perner's Contacts [online]. Pardubice, 30-06-2021. ISSN 1801-674X.

[IV] CHLUMECKÝ, Jaroslav, Jan FRONĚK a Daniel VYMĚTAL. Proposals for Improving Mobility in the City of Pardubice and its Surroundings Through Selected Measures. Transport Means 2021: PROCEEDINGS OF THE 25th INTERNATIONAL SCIENTIFIC CONFERENCE [online]. ISSN 2351-7034.

[V] VYMĚTAL, Daniel, Jan FRONĚK a Jaroslav CHLUMECKÝ. Navržení umístění parkovacích systémů Park and Ride v Moravskoslezském kraji. VEREJNÁ OSOBNÁ DOPRAVA 2021 [online]. Bratislava, 2021, 117-121. ISBN 978-80-89565-49-8.

[VI] FRONĚK, Jan, Jaroslav CHLUMECKÝ a Daniel VYMĚTAL. Příklady opatření pro zatraktivnění veřejné dopravy ve městě i v regionu. VEREJNÁ OSOBNÁ DOPRAVA 2020 [online]. Bratislava, 2020. ISBN 978-80-89565-43-6.

[VII] VYMĚTAL, Daniel, Jan FRONĚK a Jaroslav CHLUMECKÝ. Hierarchizace záchytných parkovišť v rámi regionu. VEREJNÁ OSOBNÁ DOPRAVA 2020 [online]. Bratislava, 2020. ISBN 978-80-89565-43-6.

[VIII] CHLUMECKÝ, Jaroslav, Jan FRONĚK, Daniel VYMĚTAL a Petr VANĚK. Selected Methods for Improving Public Transport. Transport Means 2022: *Proceedings of the International Conference* [online]. ISSN 1822-296X.

[IX] FRONĚK, Jan, Jaroslav CHLUMECKÝ a Daniel VYMĚTAL. Length of transfer time between connecting trains – is there an ideal value? IRICON. 2023.

[X] FRONĚK, Jan, Jaroslav CHLUMECKÝ a Daniel VYMĚTAL. Travel speed of 100 km·h-1 as the limit of competitiveness of railway transport. Horizons of Railway Transport 2023.

[XI] FRONĚK, Jan, Daniel VYMĚTAL a Jaroslav CHLUMECKÝ. The effect of the shortcomings of selected transfer terminals on the time lost by passengers. Transport Means 2023: proceedings of the international scientific conference. 2023.

Publication activity other

[XII] FRONĚK, Jan, Vojtěch KUDLÁČ, Vojtěch PORWISZ a Daniel VYMĚTAL. Nabídka přepravních služeb na lince dálkové železniční dopravy – poptávka, kapacita souprav, oběhy souprav a služby. Nová železniční technika: nové železniční trendy. 2019. no. 5, s. 26-29. ISSN: 1210-3942.

[XIII] FRONĚK, Jan, Vojtěch KUDLÁČ, Vojtěch PORWISZ a Daniel VYMĚTAL. Nabídka přepravních služeb na lince dálkové železniční dopravy – náklady tržby, kompenzace. Nová železniční technika: nové železniční trendy. 2019. no. 6, s. 24-27. ISSN: 1210-3942.

[XIV] FRONĚK, Jan, Jaroslav CHLUMECKÝ a Daniel VYMĚTAL. Veřejná doprava v regionu po modernizaci tratě Praha - Kladno. VEREJNÁ OSOBNÁ DOPRAVA 2021 [online]. Bratislava, 2021, 136-140. ISBN 978-80-89565-49-8.

[XV] CHLUMECKÝ, Jaroslav, Jan FRONĚK a Daniel VYMĚTAL. Porovnání výhodnosti aplikace preferenčních opatření na vybrané autobusové lince v Praze. VEREJNÁ OSOBNÁ DOPRAVA 2021 [online]. Bratislava, 2021, 141-146. ISBN 978-80-89565-49-8.

[XVI] CHLUMECKÝ, Jaroslav, Daniel VYMĚTAL a Jan FRONĚK. Příklady vhodného i nevhodného použití vyhrazeného jízdního pruhu pro vozidla MHD. *Verejná osobná doprava 2022: zborník* [online]. Bratislava, 2022 ISSN: 978-80-89565-54-2

[XVII] FRONĚK, Jan, Daniel VYMĚTAL a Jaroslav CHLUMECKÝ. Analýza tarifních struktur IDS. VEREJNÁ OSOBNÁ DOPRAVA 2020 [online]. Bratislava, 2020. ISBN 978-80-89565-43-6.

Souhrn/Abstract

V disertační práce autor provedl vyhodnocení vývoje současné situace z pohledu stupně motorizace vozidel a vývoje autonomních vozidel. Dále se v rámci práce zaměřil na současný stav v praxi a to především u dvou měst – Prahu a Brno. Následně autor v práci provedl analýzu současného stavu vědeckého poznání a na základě získaných dat vypracoval SWOT analýzu a analýzu silového pole. V další části autor stanovil nulovou hypotézu a cíl této disertační práce. Poté je proveden popis systému rozhodovacího procesu uživatele, zdali odstaví své vozidlo v centru města nebo na záchytném parkovišti, dále je provedena identifikace prvků a vazeb mezi nimi. Následně je proveden popis rozhodovacího systému městské dopravní autority a jsou identifikovány body interakce. V samotné návrhové fázi je sestavena metodika pro určení atraktivity jednotlivých záchytných parkovišť, a to za pomocí modifikované Stackelbergovy hry. Ta je následně aplikována na 9 různých scénářů ve třech městech – Praze, Brně a Ostravě.

In the dissertation, the author evaluated the current situation in terms of the degree of motorization of vehicles and the development of autonomous vehicles. Furthermore, the thesis focused on the current state of the art in practice, especially for two cities - Prague and Brno. Subsequently, in the thesis, the author analysed the current state of scientific knowledge and based on the data obtained, developed a SWOT analysis and a force field analysis. In the next section, the author established the null hypothesis and the aim of this dissertation. Then, a description of the user's decision-making system of whether to park his/her vehicle in the city centre or in a catchment car park is made, and the identification of the elements and the links between them is made. Subsequently, a description of the decision-making system of the urban traffic authority is made and the interaction points are identified. In the design phase itself, a methodology is constructed to determine the attractiveness of each interceptor car park using a modified Stackelberg game. This is then applied to 9 different scenarios in three cities - Prague, Brno and Ostrava.