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MOŽNOSTI ODSTRANĚNÍ BARIÉR V RÁMCI ŽELEZNIČNÍ NÁKLADNÍ PŘEPRAVY PROSTŘEDNICTVÍM SDÍLENÍ DAT

POSSIBILITIES TO REMOVE BARRIERS IN RAIL FREIGHT TRANSPORT THROUGH DATA SHARING

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1 Current knowledge of topic

The basis for a control of transport processes, regardless of transport mode, is availability of reliable data about status of elements (objects) used in the processes. For example, in case of control at transport nodes, it is desirable to have information about both vehicles and current traffic situation at the node sufficiently before the arrival of the vehicles at the particular node. Information on the traffic situation on main lines is usually available, but other information are still unavailable or unreliable.

State-of-the-art of research in the field of RFID on railways and approaches used

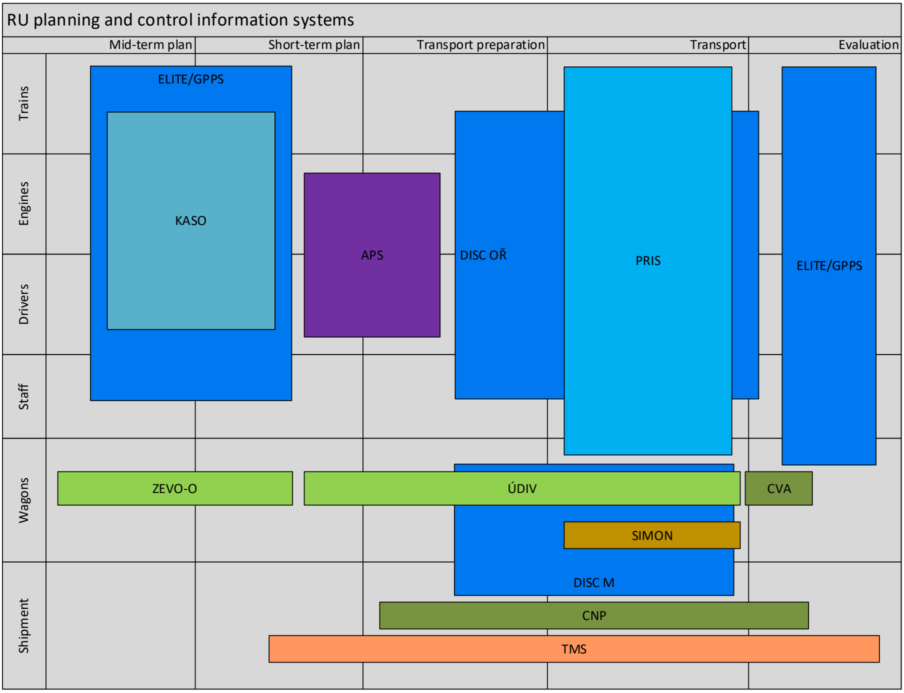
Hell and Varga (2018) are engaged in research on vehicle identification in accidents. Another direction dedicated to a communication between elements on wagons is presented by Ußler, Michler and Löffler (2019), who carried out radio technical analyses concerning the mobile radio connection of elements on wagons in a railway environment in which large metal masses have a significant influence, in which the positions of the sensor and RFID tag were evaluated, while also not forgetting the communication between the vehicle and the information system. The topic is also addressed by Balog, Semanco and Simeková (2015). The field of selection of suitable tags was dealt with, for example, by Hricová (2016), who lists the conditions and methodology of selecting suitable tags in several steps. In their paper, Fernández et al. (2009) present a prototype of RFID technology on railways called Transf-ID, which was created on the basis of their own research and which describes RFID usage on rolling stock, bogies, axles and swap bodies.

System features and requirements for placing RFID technology on the vehicle

According to Hranický, Šperka and Čamaj (2021), the basic property of the RFID system in rail freight transport is the ability to identify elements, train, wagon or shipment at each point of the transport chain. According to Mašek, Kolarovszki and Čamaj (2016), RFID tags must be resistant to environmental influences in the railway sector (here they coincide with Fernándéz et al., 2009 and Balog and Mindas, 2016), cheap and scalable, but also energy-efficient and self-sufficient.

1.1 Freight railway undertaking information systems

Current IT support in the field of local control is insufficient and reduces the efficiency of resources used in a traffic node. The figure below shows the information systems used by the railway undertaking for traffic planning and control.



Information systems for planning and control (author using OLTIS Group, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g and ČD IS, 2021)

1.2 Traffic control and decision-making at a node and its surroundings

At the same time, each activity has defined the required resources (staff) and thus the need for these resources is subsequently defined (Mazač, 2021). According to Šperka (2020), most of the processes in train-formation stations except large marshalling yards are carried out at the limit of feasibility (of course, depending on peaks). However, rationalization without the deployment of effective tools would rise demands on staff in traffic offices, who already usually hold more functions and their workload is high (Šperka, 2020). The processes of control and decision-making in the traffic of a node and its surroundings have been solved in the past using methods of operational analysis, which includes analytical and statistical methods and approaches. Some approaches were heuristic, as is stated e.g. in the textbooks entitled Operational Analysis in Railway Transport by František Brandalík and Pavol Kluvánek from 1984. In case of trains approaching the node or, more precisely, the marshalling yard, Brandalík and Kluvánek (1984) deal with statistical investigation of the input flow of trains. However, Houda (2020) mentions that the absence of a realistic plan (what will actually happen in a particular shift in the next hours or minutes) arising from several planning stages, moreover with the help of information systems, does not give dispatchers any really usable instructions according to which they should control the traffic, because all scheduled activities are no longer valid at the moment. Because there are several exceptions that have changed the plan and it is therefore almost useless. According to Houda (2020), in case of high delays of freight trains, train-formation stations serve as buffer against further transmission of the delays over the network. He mentions that in case of infrastructure closures or other circumstances and the resulting high delays of trains, conflict situations arise when deciding which of the arriving trains should be preferred. He points out that the operational information system (PRIS), which provides the dispatchers with information on the shipments and the composition of the train, has no process-optimization mechanisms. The same case is the line control system DISC OŘ.

Kopecký (2021) argues that all decisions on the order of receiving of trains with regard to wagons transported to certain directions and with regard to scheduled departure times of trains is very difficult, moreover with regard to cases in which an arriving train transports priority wagons or wagons with a fixed transfer between trains. Houda (2020) adds that in situations where arriving trains have high delays, it is almost impossible for a dispatcher to predict the times necessary to carry out activities with trains and make optimal or at least good decisions based on previous experience. Although the dispatcher has information about the current location of the train in the DISC OŘ system, in many cases he is not able to estimate the time of arrival (ETA) at the station, because there are, e.g. one or more bottlenecks on the train route. Outcomes from the systems reflecting the traffic and related information on load handling that would be available throughout the transport network are insufficient (Houda, 2020). Mazač (2021) claims that this functionality is achievable despite its considerable complexity. It also states that the impact of the decision to give priority to the one train over another is not even approximately automatically compared, or that the system does not provide with feedback resulting from the tasks carried out.

1.3 Radio block control system

The radio block system is based on similar principles as the European Train Control System (ETCS), but with many simplifications. According to Veselý, Kačmařík and Pavel (2019), the radio block signalling system is based on wireless communication between vehicles and control centres via public data networks and on train indication using GPS position messages and entering position codes by the driver. This simple system does not achieve the same level of safety, but practical operation has proven to be a viable and effective solution for traffic security on less used regional lines. The basic components of RBS are the radio block centre (RBC) and the vehicle unit (RBV). Based on the analysis of experience (on-site investigations, empirical results, statistical data), the following are examples of some of the shortcomings which have been identified.

- The system is not 100% reliable in terms of determining the exact position of the train.
- The reliability of the data communication between the RBC and RBV is only about 80%, failure occur, for example, in hilly terrain.
- The system is not able to detect and actually check the track occupancy at a station.
- Many operations are dependent on their faultless execution by the staff.

1.4 Summary

Based on a literature review and analysis of the current state of railway operation, two basic barriers to seamless flow within the supply chain can be defined. The first barrier is the lack of relevant information about vehicles and trains available at nodes, which can be solved by technology of automatic object identification and tracking. The second barrier is deficiencies in the traffic control systems themselves, especially in the sections of infrastructure and the times before the arrival of the train at the node, where the dispatcher does not have the relevant information – see the first barrier – but even if he did, he has no tool supporting decision-making in demanding situations, either on the network of regional and main lines adjacent to the node or in the node itself.

2 Objective

The thesis deals with the proposal of a way of obtaining and sharing reliable traffic data as well as the proposal of dynamic traffic control.

The aim of the dissertation is to propose the possibility of removing barriers to ensure uninterrupted digital flows of information through automatic identification system and usage of information in the processes in railway freight transport nodes and on sections adjacent to transport nodes through the system of dynamic control including decision-supporting features.

3 Methods and solution approaches

Methods and approaches applied in the thesis are described in the following sub-sections.

3.1 Fuzzy logic and multi-criteria decision-making method

Multi-criteria evaluation methods make it possible to assess the different importance of criteria by using different weights, as stated, for example, by Fotr (2006). Next, submits that, as a general rule, the procedure for evaluating variants lays weights for the various criteria, which reflect the importance of each criterion, applying the rule that the more important criteria are assigned higher weights. The method of fuzzy logic and standard methods of multi-criteria decision-making are used to design the decision support system of dispatchers. According to Klapka, Dvořák and Popela (2001), the problem of multi-criteria decision-making can be characterized as "a set of *possible variants (decisions, solutions) is given and we have to choose the variant that is as best as possible with respect to the given set of criteria (viewpoints, characteristics)".* And it further describes that both quantitative and qualitative criteria may occur among the criteria considered. It adds that '*quantitative criteria make it possible to establish criteria values for each variant'.* Various methods are used to determine the weights – in the case of this work, point scales and the determination of the order of applied criteria are used, because in the operation of railway transport the decision depends on the ranking. The method used for the evaluation of criteria and achievement of goals is fuzzy logic, as it largely corresponds to the way traffic dispatchers make decisions. Its application will largely preserve the existing non-automated processes (those that are desirable and effective), which precede the decision-making process of dispatchers in nodes and follow up on specific decisions. Fuzzy logic, according to Fuzzytech (2009), is a mathematical branch that denies the traditional assumption that everything in the overall area of reasoning belongs to a given area of reasoning or does not belong – this theory determines "how much" an element belongs to a set or not.

3.2 Heuristic approach

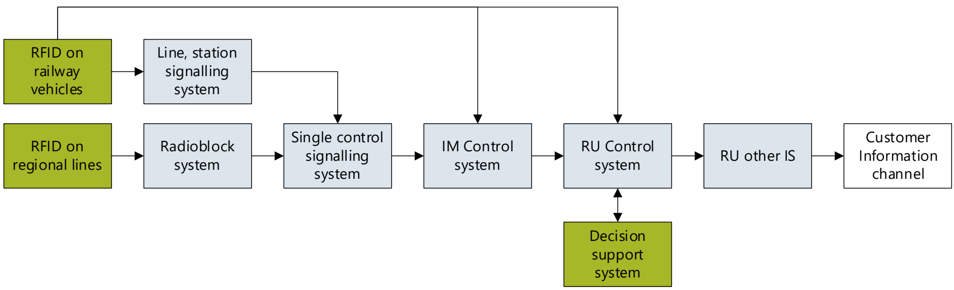
According to Tomek and Vávrová (2000), it is possible to encounter the fact that the existing mathematical methods cannot be successfully used or their use is even impossible due to the specific nature of the problem being solved. In these cases, a heuristic approach can be chosen, which consists in finding a solution using an algorithm that the researcher thinks leads to a solution, but is unable to prove this idea by an exact method and formulation. Klapka, Dvořák and Popela (2001) mention that "*In operations research, the heuristic method is characterized as a method for finding "good" solutions (i.e. solutions close to optimal) using an intuitive approach and at reasonable computational costs."* In conclusion, Tuzar, Maxa and Svoboda (1997) state that *"The quality criterion of a heuristic method is mainly practical experience gained through their use".*

3.3 Query method with expert estimation elements

Personal interviewing of experts, employees of the operation is used in the dissertation. According to Kozel et al. (2006), this is the most traditional type of questioning, which consists of direct communication between the interviewer and the respondent. According to him, the primary data are obtained on the basis of interviews. The results of the interviewing were then used as a basis for the use of the expert estimation method, which is based on anonymous cooperation with experts and experts among themselves anonymously. According to Štědroň et al. (2012), the expert estimation method itself can be used to obtain new original ideas.

4 Results

The dissertation deals with a proposal to remove some barriers in rail freight transport. The areas covered by the proposals and the results achieved are in the green scheme.



Proposals and other parts of the transport system (Author)

4.1 Proposal of a system for decision-making of dispatchers in nodes

The proposal consists in modifying the interface of information systems and modifying traffic control process, respectively introducing decision-making support, which consists in evaluating individual trains approaching a node using multi-criteria method and fuzzy logic method, prioritizing these trains and issuing recommendations to the dispatcher. With train prioritisation, which in practice means the establishment of the train processing order in the marshalling yard and has an impact on the actual approach of particular train to the node, it will make it easier for railway operator dispatchers and infrastructure manager dispatchers to make operational decisions based on the outputs of the automated train evaluation system. It should be noted that the trains that enter the comparison have a planned or estimated arrival from the marshalling yard within a floating time period of the day. For entering input data, semi-automated calculations and evaluation of trains, it is possible to use MS Excel tool or software developed by the author within the Student Grant Competitions project.

Design of interfaces for communication between operational systems

The proposal is based on the extension of the TAF TSI regulations with regard to node or marshalling yard, where the following parts of the transmitted data should be modified:

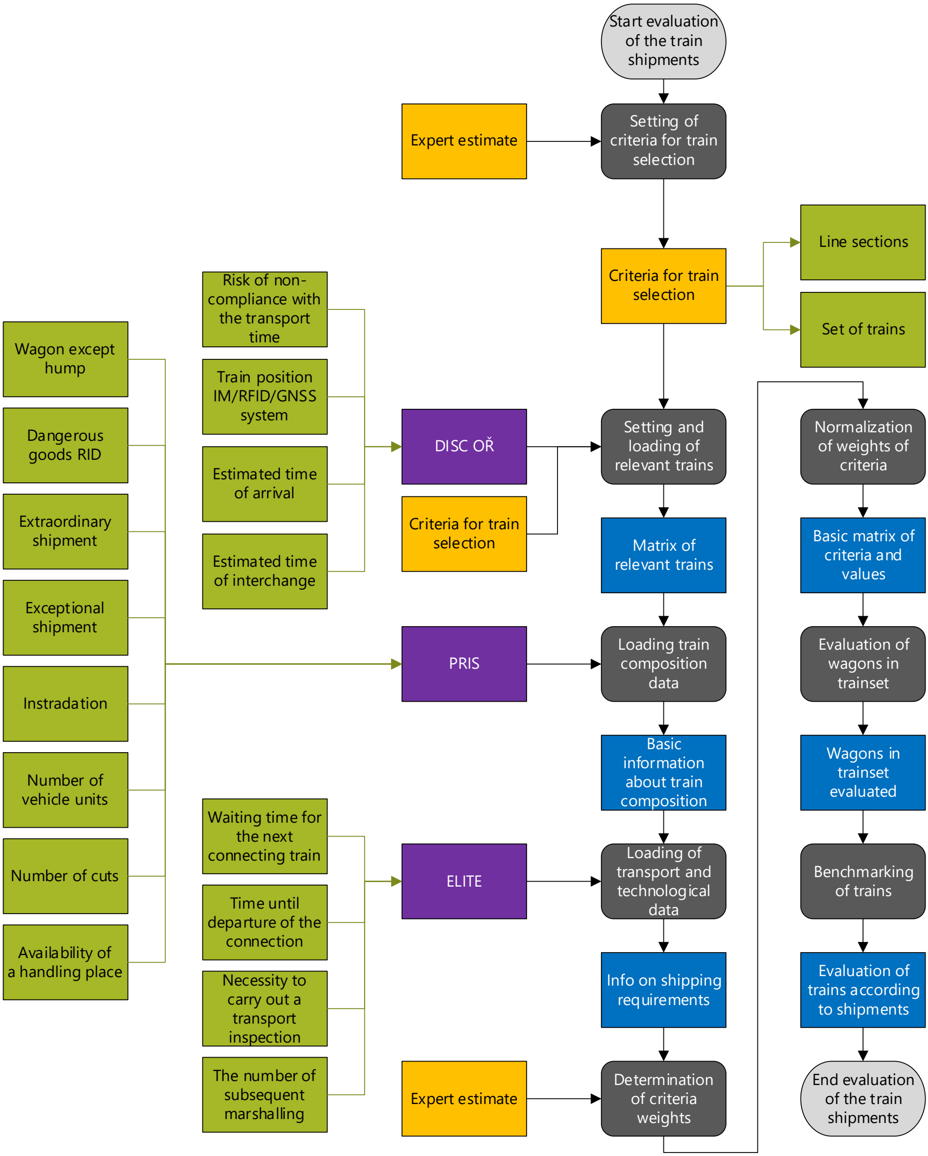
- Path request,
- train preparation,
- train running forecast,
- information in case of traffic disruption,
- estimating the time of handover and arrival of the wagon (ETI/ETA of the wagon),
- wagon running,
- interchange reporting.

Train prioritisation

Train evaluation and prioritization is proposed as a two-phase. The first phase entitled “Evaluation of train composition” evaluates the wagons and determines the “priority” of the train from the perspective of transport of consignment and marshalling yard technology. Standard methods of multi-criteria decision-making are used in this phase. The second phase called "Traffic situation evaluation" is based on evaluation of individual trains from the traffic point of view – positions of trains in the network and estimated time of arrival. ´Fuzzy logic method is used in this phase.

Evaluation of train composition

To determine or evaluate the priority of trains when deciding on the priority admission of trains to perform technological tasks in the marshalling yard, the method of multi-criteria decision-making based on assigning the number of points to each criterion is used.



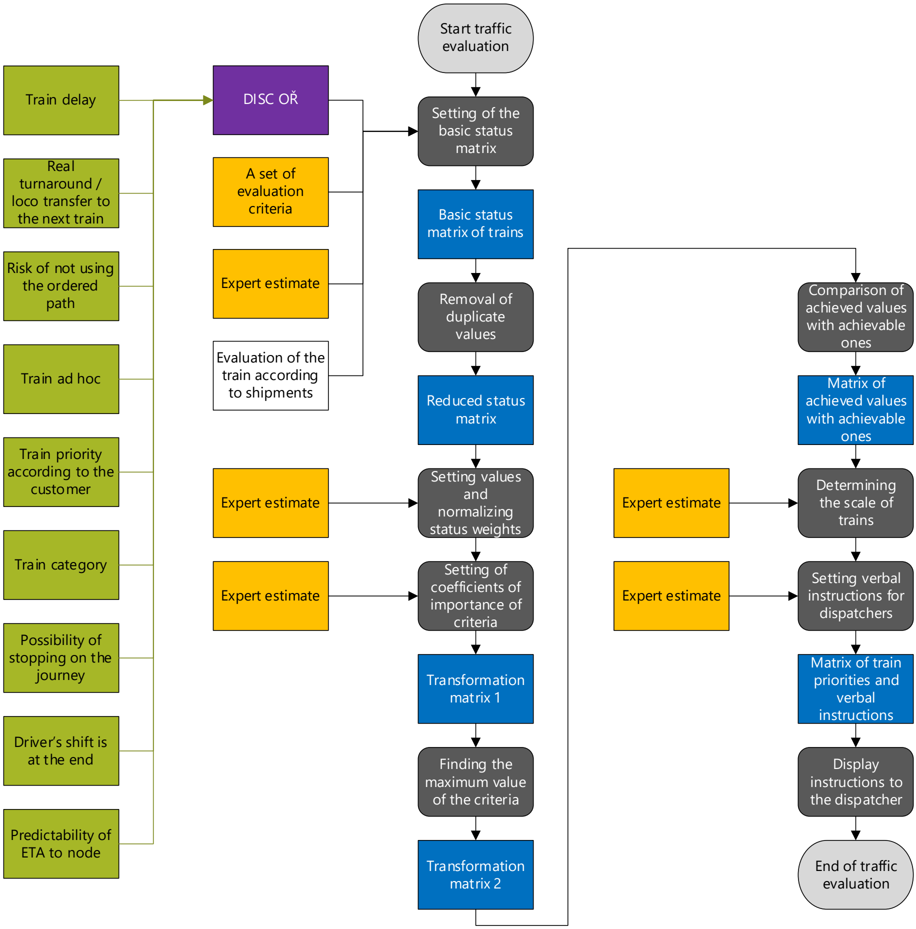
Evaluation of train composition – algorithm (Author)

Selected criteria describing the train composition and thus the impact on duration of the technology in marshalling yard. A point scale based on assigning nine points to the most important criterion and one point to the least important criterion is used to determine the priority of a train. The principle of positive and negative criteria is applied to each criterion, which aims to give priority to trains that require less resources or shorter processing time at the marshalling yard. The principle is to multiply the resulting value of the train for a given criterion (e.g. the number of wagons not going over the hump) by (-1). The value of the criterion is therefore subtracted from the overall rating of the train, which results in the train travelling more such wagons has a worse rating than another train with otherwise the same parameters. The weight of the criteria is determined by expert estimation in cooperation with the railway undertaking's dispatchers. In order to ensure the comparability of individual criteria values for specific trains, weights were standardized (relating the weights of individual criteria to a single whole). Evaluation of each wagon in the train set is performed according to the wagon point scale, which evaluates the "weight" of a particular wagon. Subsequently, the trains are compared with each other and a sequence according to the resulting values, which are the sum of the values for each criterion is issued. The highest priority is given to the train that has the highest value of the sum of the criteria. The value of the train priority according to train composition is also one of the criteria that is used in determining the priority of the train based on the traffic situation – the values of the criterion are added to the overall result. To ensure the significance of the evaluation of trains the values are multiplied by 100. In the scheme of the algorithm, the criteria are indicated in green. The agents entering the process are marked in yellow and placed to the left of the dark gray rectangles showing the activities of the algorithm. The blue color shows the current state within the algorithm.

Traffic situation assessment

Based on the evaluation of the traffic situation, the algorithm suggests the order of train processing and suggests to the dispatcher the procedure for working with the train using a verbal instruction.

The algorithm uses the result of the evaluation of train composition as an input criterion –a white cell in the diagram. Furthermore, the algorithm uses the criteria values (green color) obtained from the railway undertaking's information system. In case of ČD Cargo, it is the DISC OŘ dispatching system (purple color). Process inputs are marked in yellow and placed to the left of the dark gray rectangles showing activities. Current state step within the algorithm is in blue.



Traffic Situation Assessment – algorithm (Author)

The fields with expert estimation are not part of the standard routine process but are needed only for the initial setting of the algorithm for a particular railway node. To assess the traffic situation, criteria were set for the evaluation of individual trains moving on their routes in the direction of the marshalling yard. For simplicity, differences between individual lines are not taken into account – it means that the route is the same and the expected time of arrival of the train is similar. The assessment of the traffic situation is carried out on the basis of the method of fuzzy logic. To obtain an overall evaluation of the train priority, an evaluation is performed according to a point scale of 1 to 30. All criteria are positive.

Comparison and evaluation of train priority

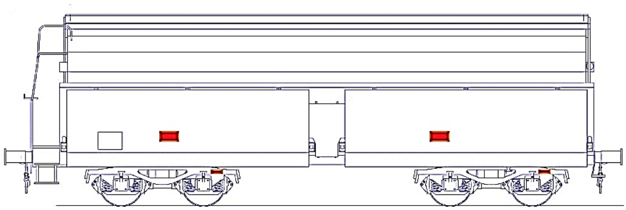
For a clear and quick evaluation of train priority and information to the dispatcher, a train priority scale is proposed. Trains are classified into individual grades on the basis of the percentage gain of points from the total number of possible points.

The priority levels are as follows:

- More than 70 points – the train has priority for running and processing immediately after arrival.
- 61 to 70 points – the train has a lower priority of running, but it runs on its route as standard, after arrival at the marshalling yard it is processed according to the currently available capacity.
- Less than 61 points – the train has no priority and runs on its route as standard. In case that there is no free capacity in the marshalling yard (e.g. there is no free track) or uninterrupted movement on the route is not allowed, the dispatcher may decide to stop the train on the way in a suitable station. If the train is not possible to stop due to train length, it must run directly to the marshalling yard and a track must be cleared before its arrival.

4.2 Proposal for the use of RFID in railway operation

This subchapter deals with the proposal to extend using of RFID technology on the railway, while applied research verifies the properties of the RFID technology decisive for routine operation in the railway environment, both from the perspective of reading tags placed on wagon frame and from the perspective of reading tags placed on components. The purpose of the research is to verify usability of the RFID technology in rail freight transport, both in the field of evidence of vehicle components or entire vehicles, and in the field of monitoring the passage of vehicles through points on the route. In practical use, many limitations and challenges related to the physical properties of RFID technology is encountered (there is a problem with signal interference between the reader and the tag). The results achieved determine the possibilities and limits of mounting RFID tags on freight wagons and their components. Proposed placement of tags on Talls series wagon is in the picture below.



Locations of tags on Talls series wagon (Author using ČDC, 2020)

The most important finding is that the average reading distance value for most tags in a railway environment is about 35% of the distance indicated by manufacturers. Based on practical experience, it has been determined that the reading distance is at least 1.3 m. This value meets the requirements of railway staff (Kopecký, 2021). Proposed appropriate and standardized placement of RFID tags on wagons, components and bogies, described below can help to remove the existing barrier to obtaining reliable and relevant information in information systems.

RFID tags on wagons

Wagon series	**Left position of the tag** (distance from the left bumper plate, in meters)	**Right position of the tag** (distance from right bumper plate, in meters)
Faccs	Frame (U-profile) under UIC number; (3 m)	Frame (U-profile); (3 m)
Falls	Left body side under UIC number; (2.5 m)	Right body side; (2.5 m)
Eas	Frame under UIC number in the first vertical field on the left, min. 0.15 m clearance from loops for fixation of load, towing hook and label rack; (2 m)	Frame under in the first vertical field on the right, min. 0.15 m clearance from loops for fixation of load and towing hook; (2 m)
Es	Frame under UIC number in the first vertical field on the left, min. 0.15 m clearance from loops for fixation of load, towing hook and label rack; (2.5 m)	Frame in the first vertical field on the right, min. 0.15 m clearance from loops for fixation of load, towing hook and label rack; (2.5 m)
Zans	Board with UIC number, min. 0.15 m clearance from towing hook and label rack; (2.5 m)	Frame, min. 0.15 m clearance from towing hook, handrail and beam for lifting jack; (2.5 m)
Zas	Frame, min. 15 cm clearance from towing hook, handrail, beam for lifting jack and label rack; (2.5 m)	Frame, min. 0.15 m clearance from towing hook, handrail and beam for lifting jack; (2.5 m)
Ua	The first field of the body side form the left, (2 m)	The first field of the body side form the right, (2 m)
Uacs	Frame (vertical part) under UIC number; (2 m)	Frame (vertical part); (2 m)
Sggmrss	Centre of frame; (7 m)	Centre of frame; (7 m)
Sgnss	Frame, min 0.15 m clearance from the left side of the UIC number and controllers; (3.5 m)	Frame, clearance min. 0.15 m from the controllers; (3.5 m)
Rils	Board with UIC number, min. 15 cm clearance from label rack; (2 m)	Signboard with parameters of wagon on the left from bogie; (2 m)

Source: author

Proposal based on the results of an experiment consisting in measuring the reading distances of tags placed on four types of bogies.

RFID tags on bogies

Type of boggie	Position of the tag
26-2.8	Next to the round-gap in the bodyside on the left or on the right
Y25	The right side of the longitudinal beam (U-profile), 0.20 m from the right end of beam or in the centre of the lower positioned longitudinal beam.
Talbot R	Bottom of the bodyside on the beam of the spring hinges
Diamond	Bottom of the bodyside under the beam of the springs

Source: author

Next part of the proposal deals with the removal of the information barrier on the movement of trains on regional lines, from which, as well as from track sections equipped with remote control of rail traffic, trains enter areas of nodes where a decision on the priority of train running must be made. The core of the proposal is the application of RFID technology into the radio block system with the aim of eliminating existing problems caused by inaccurate, erroneous or otherwise insufficient determination of the train position in the controlled area. Unlike the current situation, radioblock would only allow the vehicle to run if an RFID tag is read, which would be assigned to a specific geographic point and paired with a GPS location. The proposal envisages the integration of location data from RFID tags with the position obtained by GPS. Railway lines equipped with RBS with RFID technology would be equipped with RFID tags at least at the regular stopping points of trains. In the case of railway stations, all tracks shall be equipped with RFID tags, at least at both ends of each track and at the required stopping point of the train. For tracks with platforms, RFID tags can be placed at the ends of the platforms. To eliminate weather effects on reliability, the tag should be placed on the edge of the platforms or on the posts located at each track.

Selected impacts of RFID technology deployment:

- improvement of operational processes, e.g. operation at marshalling yards – automatic preparation of sorting lists, automatic train list, confirmation of departure,
- reliable automatic or manual inspection of vehicle components (bogies, wheelsets, buffers) when a train is interchanged between operators,
- ensuring of train movements on lines without a standard signalling system.

4.3 Evaluation and discussion of results

The proposals respond to problems in operation, such as the increasing complexity of operation, worse abilities of dispatchers who do not have enough information or experience, the quality of information in the correct form, the difference in the approach of dispatchers to traffic control, the absence of real rational priorities of trains based on their current or at least planned parameters, and finally the shortcomings of information systems that would actively support the decision-making of dispatchers. The analyzed problems represent barriers that were solved by the author with the aim of their removal or at least minimization.

The dissertation contains a set of proposals consisting of three parts, which are in some respects independent, but are means to achieve the overall goal:

- Proposal of an interface and system to support dispatchers' decision-making;
- Proposal of the of RFID technology on wagons;
- Proposal of the use of RFID technology with radioblock on regional lines.

The main part of the theses is the proposal of system that supports decision-making of dispatchers.

Strengths of the system for decision support of dispatchers:

- system clarity,
- ease of use,
- universal use,
- system connectivity.

Weaknesses of the system for decision support of dispatchers:

- with increasing time distance from the node, the quality of results decreases rapidly.
- the need to resolve ownership rights to the data of individual actors,
- availability of input data e.g. in case of international transport.

The other two proposals are supporting the main proposal and are based on the acquisition and sharing of data relating to train running. The decision support system for dispatchers uses input data obtained through RFID technology and from existing information systems of operators and infrastructure managers.

Usability of proposal of placing RFID tags on commonly operated series of freight wagons is proven by author and could be used for the standardization and development of RFID on railways in Europe. Despite the development of an automatic digital coupler, RFID technology may also be promising in the future, as the Europe's Rail project is currently developing automated checkpoints for checking the condition of vehicles (European Checkpoints), where RFID technology could also be applied. Another part of the proposal presents the possibilities of using RFID technology in the field of signalling system on lines with simplified control according to regulations D3 and D4. The difference is in the case of deployment on regional lines compared to deployment on main lines the placement of RFID tags and readers. In the case of regional lines, deployment does not necessarily require the installation of static gates. RFID tags are placed on the infrastructure and readers are placed on the traction vehicle. In the case of main lines, the location is reversed. The two proposals complement to each other. As a result, reliable data acquisition and sharing to dispatching and other information systems can be achieved.

Advantages of radio block with RFID:

- no need to install communication cables along the tracks,
- dispatcher has a precise overview of the train position on the track,
- hardware upgrade and installation are simple and cheap compared to the solution with ETCS,
- overall lower operation costs,
- possibility of remote traffic control from central control centres,
- higher level of traffic safety on many lines achievable in foreseeable future;
- increasing the durability and reliability, as the failure of RFID technology does not have a direct impact on operational safety.

The disadvantage of a radio block with RFID is the introduction of another element that requires maintenance and operation, but compared to the high costs of introducing a standard remote control system with ETCS are the costs of maintenance and operation much lower.

5 Benefits of the dissertation

The main benefits of the dissertation are as follows:

- analysis of the current status (data acquisition and sharing, traffic control, information systems used in rail freight transport, use of electronic identification technologies, regulations in the field of electronic identification technologies, traffic on lines equipped with the radio block system),
- conducting an experiment to obtain data on the properties of RFID technology in a real railway environment,
- use of the method of multi-criteria decision-making and fuzzy logic in the proposal of the decision support system of dispatchers,
- proposal of algorithms and implementation of RFID technology into the radio block system,
- proposal of standardized placement of RFID tags on freight wagons and implementation of RFID technology in rail freight transport.

References

BALOG, Michal, Pavol SEMANCO a Zofia SIMEKOVÁ, 2015. Informatization of Rail Freight Transport by Applying RF Identification Technology. In: *Internet of Things. IoT Infrastructures. IoT360 2014* [online]. Cham: Springer. DOI: https://doi.org/10.1007/978-3-319-19743-2_10. [cit. 2021-01-29]. Available at: https://link.springer.com/chapter/10.1007%2F978-3-319-19743-2_10

BALOG, Michal a Miroslav MINDAS, 2016. Informatization of Rail Freight Wagon by Implementation of the RFID Technology. In: *Smart City 360°. SmartCity 360 2016, SmartCity 360 2015* [online]. Cham: Springer. Volume 166. DOI: https://doi.org/10.1007/978-3-319-33681-7_50. [cit. 2021-01-29]. Available at: https://link.springer.com/content/pdf/10.1007%2F978-3-319-33681-7_50.pdf

BRANDALÍK, František a Pavol KLUVÁNEK. *Operační analýza v železniční dopravě*. Bratislava: Alfa, 1984.

ČD IS, 2021. *Informační systém PRIS* [software]. 2nd August 2021 [cit. 2021-08-02].
FERNÁNDEZ, J. González et al., 2009. Transf-ID: Automatic ID and Data Capture for Rail Freight Asset Management, In *IEEE Internet Computing* [online]. Volume 13, no. 1, s. 22-30. DOI: 10.1109/MIC.2009.24. [cit. 2021-01-26]. Available at: https://www.cp.eng.chula.ac.th/~natawut/Class/2110684/2553-1/Papers/mic2009010022.pdf
FOTR, Jiří. *Manažerské rozhodování: postupy, metody a nástroje.* Praha: Ekopress, 2006. ISBN 80-86929-15-9.
FUZZYTECH, 2009. *What is Fuzzy logic?* [online]. [cit. 2019-12-10]. Available at: http://www.fuzzytech.com/
HELL, Péter M. a Peter J. VARGA, 2018. Accurate Radiofrequency Identification Tracking in Smart City Railways by using Drones. In: *Interdisciplinary Description of Complex Systems* [online]. Volume 16, no. 3, s. 333-341. DOI:10.7906/indecs.16.3.5. [cit. 2021-01-28]. Available at: http://indecs.eu/2018/indecs2018-pp333-341.pdf
HOUDA, Pavel, 2020. Vedoucí skupiny technologie PJ Praha, Praha, 12th Fabruary 2020.
HRANICKÝ, Michal P., Adrián ŠPERKA a Juraj ČAMAJ, 2021. RFID technology and its effects on improving technological processes at the Čierna nad Tisou station. In: *Transportation Research Procedia* [online]. Volume 55, s. 466-474. ISSN 2352-1465. DOI: https://doi.org/10.1016/j.trpro.2021.07.010. [cit. 2021-08-20]. Available at: https://reader.elsevier.com/reader/sd/pii/S2352146521004051?token=37AA7CD8F753CC10EBB10A7807772E8EA0EF305B61D40423E0A96B933624C265CEC2B7C228767412E5F04D5569D23A10&originRegion=eu-west-1&originCreation=20210909104650
HRICOVÁ, Romana, 2016. RFID as a tool of competitiveness increase of rail freight. In: *Acta Tecnología* [online]. Volume 2, no. 1, s. 11-14. DOI: doi:10.22306/atec.v2i1.9. [cit. 2021-01-29]. Available at: http://actatecnologia.eu/issues/2016/I_2016_03_Hricova.pdf
KLAPKA, Jindřich, Pavel POPELA a Jiří DVOŘÁK. *Metody operačního výzkumu*. Vyd. 2. Brno: VUTIUM, 2001. ISBN 80-214-1839-7.
KOPECKÝ, Martin, 2021. Vedoucí oddělení procesního inženýringu, Praha, 26th August 2021.

KOZEL, Roman et al., 2006. *Moderní marketingový výzkum: nové trendy, kvantitativní a kvalitativní metody a techniky, průběh a organizace, aplikace v praxi, přínosy a možnosti*. Praha: Grada. ISBN 80-247-0966-X.

MAŠEK, Jaroslav, Peter KOLAROVSZKI a Juraj ČAMAJ, 2016. Application of RFID Technology in Railway Transport Services and Logistics Chains, In: *Procedia Engineering* [online]. Volume 134, s. 231-236. ISSN 1877-7058, DOI: https://doi.org/10.1016/j.proeng.2016.01.064. [cit. 2021-08-30]. Available at: https://reader.elsevier.com/reader/sd/pii/S1877705816000679?token=F65E75D56B74E5A0BE240FAF57A5C1AD35E372408861C42907014481D6CC168A7FE881E254F77E45DD87BBD62A8880EF&originRegion=eu-west-1&originCreation=20210909110043

MAZAČ, Pavel, 2021. Vedoucí realizačního týmu ELITE. Pardubice, 2nd August 2021.

OLTIS GROUP, 2021a. *Information system ELITE* [software]. 2nd March 2021 [cit. 2021-03-02].

OLTIS GROUP, 2021b. I*nformation system GPPS* [software]. 15th March 2021 [cit. 2021-03-15].

OLTIS GROUP, 2021c. *Information system ÚDIV* [software]. 4th April 2021 [cit. 2021-04-04].

OLTIS GROUP, 2021d. *Information system TMS* [software]. 3rd August 2021 [cit. 2021-08-03].

OLTIS GROUP, 2021e. *Information system SIMON* [software]. 18th August 2021 [cit. 2021-08-18].

OLTIS GROUP, 2021f. *Information system DISC OŘ* [software]. 2nd July 2021 [cit. 2021-07-02].

OLTIS GROUP, 2021g. *Information system DISC-M* [software]. 22nd July 2021 [cit. 2021-07-22].

ŠPERKA, Lubomír, 2020. Systémový analytik, Olomouc, 2. listopadu 2020.

ŠTĚDROŇ, B., M. POTŮČEK, J. KNÁPEK, P. MAZOUCH et al., 2012. *Prognostické metody a jejich aplikace*. Praha: C. H. Beck. ISBN 978-80-7179-174-4.

TOMEK, Gustav a Věra VÁVROVÁ. *Řízení výroby*. 2., rozš. a dopl. vyd. Praha: Grada, 2000. Expert. ISBN 80-7169-955-1.

TUZAR, Antonín, Petr MAXA a Vladimír SVOBODA. *Teorie dopravy*. Praha: Vydavatelství ČVUT, 1997. ISBN 80-01-01637-4.

UßLER, Hagen, Oliver MICHLER a Günter LÖFFLER, 2019. Validation of multiple sensor systems based on a telematics platform for intelligent freight wagons. In: *Transportation Research Procedia* [online]. Volume 37, s. 187-194. ISSN 2352-1465. DOI: https://doi.org/10.1016/j.trpro.2018.12.182. [cit. 2021-01-30]. Available at: https://reader.elsevier.com/reader/sd/pii/S2352146518305970?token=F28FD670431F0A0FC1678A76CFD2B270245D50C766479FC897560FD450A4394B1EB673E994F52571CAAD5D0AFA9CB4EB&originRegion=eu-west-1&originCreation=20210909105715

VESELÝ, Karel, Petr KAČMAŘÍK a Michal PAVEL, 2016. Critical Safety Aspects of a GNSS Based Virtual Balise for ETCS. In: *Railknowledge bank*. [online]. [cit. 2020-01-05]. Available at: http://www.railknowledgebank.com/Presto/pl/MTk4MTRjNDUtNWQ0My00OTBmLTllYWUtZWFjM2U2OTE0ZDY3LjU3NzM=

List of publications

ŠOHAJEK, Petr, Martin ŠUSTR, Michaela ŠTĚPÁNOVÁ, Jiří ČÁP, 2018. Planning of rail freight unit train operation in the liberalized environment – instrument for dynamic assignment of paths on railway network. In: Proceedings of International Conference ICTTE, 2018. Belgrade: Faculty of Transport and Traffic Engineering, University of Belgrade, Serbia.

ROZOVÁ Dana, Martin ŠUSTR, Radovan SOUŠEK, Petr ŠOHAJEK, 2018. Crisis management in the railway transport and their additions. In: Proceedings of 22nd International Scientific Conference. Transport Means 2018. Kaunas: Kaunas University of Technology, Lithuania.

FUCHS Pavel, Dana ROZOVÁ, Martin ŠUSTR, Radovan SOUŠEK, Petr ŠOHAJEK, 2018. Critical infrastructure in the railway transport system. In: Proceedings of WMSCI 2018 - 22nd World Multi-Conference on Systemics, Cybernetics and Informatics. s. 182-186. Orlando: International Institute of Informatics and Systemics, United States of America.

KROČA Petr, Jiří ČÁP, Petr ŠOHAJEK, 2019. The TREX project – research and development of a new information system to support the transport of extraordinary consignments by rail. In: Proceedings of 23rd International

Scientific Conference. Transport Means 2019. Kaunas: Kaunas University of Technology, Lithuania.

ROZOVÁ Dana, Martin ŠUSTR, Petr ŠOHAJEK, 2019. Continuity of activities for railway undertaking. In: Proceedings of 23rd International Scientific Conference. Transport Means 2019. s. 1508-1511. Palanga: Kaunas University of Technology, Lithuania.

ŠUSTR Martin, Petr ŠOHAJEK, Petra SETLÍKOVÁ, Radovan SOUŠEK, 2021. Impact of the pandemic disease on the Railway Central Traffic Control Centers. In: Proceedings of 25th International Scientific Conference. Transport Means 2021. Kaunas University of Technology, Lithuania.

ŠOHAJEK, Petr a Jiří ČÁP, 2018. Interface for operational management system in marshalling yards. In: VII. International Scientific Conference of the Faculty of Transport Engineering, 2018. Pardubice: Faculty od Transport Engineering, University of Pardubice, Czech Republic.

ŠOHAJEK, Petr, Pavlína CZERNYANSZKÁ a Roman HRUŠKA, 2020. RFID technology deployment in the production logistics of buses. In: The 14th International Days of Statistics and Economics. Prague: University of Economics, Czech Republic.

ČÁP, Jiří, Martin KOPECKÝ a Petr ŠOHAJEK, 2020. Optimalizace řízení seřaďovací stanice v rámci projektu OPTIYARD. In: Nová železniční technika, ročník 28, 2020. Brno: Nakladatelství a vydavatelství MiS, Czech Republic.

ŠOHAJEK, Petr, Martin ŠUSTR, Pavla ŠMÍDOVÁ, Radovan SOUŠEK, 2022. A Reliable Low-Cost Signaling System for Regional Railway Lines. In: Prentkovskis, O., Yatskiv (Jackiva), I., Skačkauskas, P., Maruschak, P., Karpenko, M. (eds) TRANSBALTICA XIII: Transportation Science and Technology. TRANSBALTICA 2022. Lecture Notes in Intelligent Transportation and Infrastructure. Springer, Cham.

Souhrn/Abstract

Disertační práce se zabývá tématem odstranění bariér v rámci železniční nákladní přepravy prostřednictví sdílení dat mezi jednotlivými aktéry přepravního procesu. Práce je založena na dosavadních poznatcích v oblasti informačních systémů, systémů automatické identifikace, dispečerského řízení a železničního přepravního systému. Náplní práce je představení sady návrhů sloužících k eliminaci bariér, které spočívají ve vytvoření systému pro podporu rozhodování dispečerů na bázi metod vícekriteriálního rozhodování a zajištění relevantních dat pomocí technologie RFID.

The dissertation deals with the topic of removing barriers in rail freight transport through data sharing between individual actors of the transport process. The theses is based on existing knowledge in the field of information systems, automatic identification systems, dispatching control and railway transport system. The content of the theses is the presentation of a set of proposals for elimination of barriers, which consist in the proposal of a system to support dispatcher decision-making based on multi-criteria decision-making methods and the provision of relevant data using RFID technology.