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REMOTE CONTROL OF RAILWAYS DURING THE CRISIS SITUATION

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1 Current situation in the remote control of railways

Transport Crisis management is an important element of the transport system.

1.1 Brief definition of crisis management problems in rail transport

The rail transport infrastructure must be judge as the critical infrastructure element. However, readiness for crisis should be an integral part of creating every new element, which can become a potential element of critical infrastructure, but in many cases it does not happen.

Risk management

Risk management should be an integral part of the all enterprises management. Risk management define risks level, identifying the causes and impacts of risks.

The risk identification should be placed before the negative effect of forces. Therefore, the Crisis readiness plans are created.

Crisis readiness plans

For individual crisis readiness plans, it is necessary to take into account the extent of the emergency in rail transport.

Other intensive and harmful powers may also impact CTC than the possible disease dispatchers, whether in the form of full shutdown of the or partial shutdown.

1.2 Current situation in the train movement control and train paths safety in the Czech Republic

The train traffic management, can be divide on the two types of traffic control. The first type of control is the local or normal train traffic control. The second method of train traffic control is remote control. Remote traffic control is characterized by the control of several line sections and stations from one control point.

Remote traffic control can be of two types, too. The first is line traffic remote control, the second type of remote control from dispatcher centers. We can consider two different systems for dispatcher centers system. In the first system,

can be identified using local dispatchers. The second system does not use local dispatchers. The local dispatchers places are permanently or even only for part of the day occupied by a deputy dispatcher, who serves to reduce the workload of the central dispatcher.

The traffic management resilience on the network with local dispatcher is higher. The local dispatchers have other functions and in many cases they are not able to take over the function of central control centers completely or without a qualitative decline.

1.3 Remote control of rail and crisis situations

The traffic control point is a place where the control of interlocking for several line sections is concentrated. Control of the interlocking to the one place brings benefits mainly in the operating costs reduce. The disadvantage of the system represent an infrastructure critical element from the operation of railway traffic scope.

1.4 Current solution of central control center failure

The railway traffic control system depend on the use of the local dispatchers.

System without local dispatchers

Remote traffic control without local dispatchers is less resilient to crisis. Takeover is only possible locally. In the event of a CTC failure, the station will be occupied by a dispatcher who controls train runs by the emergency service desk.

System with local dispatchers

In the case of high intensity of rolling stocks movements in the assigned area, the local dispatcher may not be able to process the given volume of traffic in the required quality. This issue is currently not addressed.

Partial conclusion

The number of operated interlocking elements does not differ in the system with local or without local dispatchers. The load of dispatchers is usually lower with local support, but the usable power capacity is the same. Calculations on the replacement of the central dispatchers will not affect the presence of locals dispatcher. However, local dispatchers will affect the overall resilience of the system to crisis.

The fact that the operating time of the interlocking systems is always be longer than dispatchers physical preconditions is no longer right. From the

interdisciplinary analysis, it was found that a similar issue is being addressed in the area of air traffic dispatchers utilization.

1.5 Current situation in the crisis management

The approach proposed in the dissertation is can be also used for non-crisis situations, due to the profitability and sustainability of the proposed solutions.

Current state of crisis planning and management in railway transport in the Czech Republic

In the Czech Republic, the protection and renewal of the railway infrastructure is solved by the system of Technical Railway Renewal. In order to determine the decisive conditions for the renewal of the railway infrastructure, it is necessary to know the limiting conditions for the renewal of the railway infrastructure. In the Czech Republic, the system can be implemented in 3 days using construction and technical concessions for short-term or temporary restoration. According to the plans, it is not necessary to renew the signalling equipment in its entirety. However, with the damage to the dispatch sites, the question is whether it is possible to provide the necessary staffing at the required locations if the equipment is not restored. Issues relating to signalling equipment should be further addressed by the Technical Railway Renewal System.

Summary of subchapter

Rail transport, and the system of train running control, has changed in recent years. The current system is no longer adequate, as it is based primarily on dealing with military crisis. However, the likelihood of a non-military crisis is now increasingly likely. New elements of critical infrastructure are being created. There is a need to protect the new elements and prepare for the possibility of their failure.

Current state of scientific knowledge in the Czech Republic

Only a few subjects are involved in research in the field of crisis management in the Czech Republic. There is no research in the field of security equipment in relation to crisis situations. Thus, in the Czech Republic, large-scale damage to safety equipment is not addressed on a scientific level.

Current state of scientific knowledge in foreign countries

In the case of scientific knowledge in the field of the workload of dispatechers in railway traffic, the identified sources are very vague.

The scientific knowledge was evaluated in air traffic dispatchers workload. *Smith* (2003) solves the problem of dispatchers using the BCMS with

stochastic inputs. However, the evaluation is related to air traffic dispatchers and the exact values of the inputs are not given. Evaluation using stochastic methods is relatively frequently inflected.

He (2019) just uses the fuzzy logic method to evaluate the level of air traffic control and evaluates fuzzy logic as a suitable tool. However, *He* (2019) turns his attention further in the paper to fuzzy-neuron systems.

Current status of the crisis planning abroad

Access to information related to crisis planning is complicated. As a rule, it is sensitive data related to national security, and therefore the literature is only vaguely referring to it.

From the available sources, it was found that there is generally no rapid recovery system abroad, most of the time the approach is higher resilience of the rail transport system.

Interdisciplinary evaluation of the transport control

For the work of thedispatchers, air traffic was used for comparison. Air regulations are internationally applicable and, like rail transport, airspace traffic is controlled by dispatchers.

2 Dissertation Objectives

The aim of this paper is to determine how traffic management within the CTC can be made more resilient. In particular, to increase resilience at the level of rail traffic management, given the current state of automation of traffic management and the use of existing human.

In order to fulfil the objectives of the dissertation, namely to increase the resilience of long-distance traffic control, it is necessary to determine how many routes (movements of railway vehicles) one dispatcher is able to serve in the required quality.

3 Dissertation Methods

First, it is necessary to determine what activities the CTC dispatcher performs. Once this has been established, a decision can be made to transfer the activity in a systematic way.

3.1 Data support

Measurement and evaluation of the dispatchers work controlling the movement of railway vehicles, the dissertation evaluates outputs from real operation and also outputs from a simulation program.

Evaluation of the performance of dispatchers, it is essential to know the time between tasks.

Comparison of the section with other the railway network sections in the Czech Republic

The section for data validation was selected on the 1st railway corridor, namely in the section between the stations Poříčany and Kolín. Due to the possibility of comparison with other sections with inhomogeneous timetables and the possibility of verifying the universal application of the proposed solution, this double-track section is evaluated.

For comparison purposes, the author considers compare with a controlled section without the locally located dispatcher with similar traffic volume to be appropriate. This section is Prosenice - Hranice na Moravě. This section does not have locally located dispatchers. The locally located dispatcher can act as a back-up workplace.

Partial Conclsion

The dispatcher who control the train movements has a very uneven workload. The work of the dispatcher controlling the movements of railway vehicles can be evaluated according to different methods.

3.2 Use of fuzzy logic

Fuzzy logic is also suitable for evaluating the dispatchers work.

Fuzzy logic

Fuzzy logic is all about the relative expression of state. For real events, fuzzy logic may be more appropriate than ordinary logic. This is because fuzzy logic

accounts for states that are not sharply bounded. Logic is unable to account for values beyond 0 and 1.

Zadeh (1973), describe fuzzy logic with two distinct meanings. In a precise sense, fuzzy logic and its logical system is an extension of multi-valued logic. Although, in a broader sense, fuzzy logic is almost synonymous with fuzzy set theory. Fuzzy logic is based on a common description of the world works, where the information in ordinary human communication is not exact.

The basis of fuzzy logic is the fuzzy set. A classical set can be described:

$$A = \{x | x > 6\} \qquad (1)$$

Fuzzy inputs

Each time period is needed to be determined with the relevant membership function. This data is crucial to decide how much time the dispatcher controlling the movement of rail vehicles has to decide on the movements of rail vehicles.

In the case of dispatchers controlling the movements of rail vehicles, a verbally expressed situation was described as "how often the movement of rail vehicles was disrupted against the plan (against the timetable)."

Fuzzy operators

The fuzzy operator is used in cases where it is necessary to obtain a single value that represents the result of the predecessor of this rule. The value is then applied to the output function.

Implication method

After assigning the correct weight for each criterion, the implication method is implemented. As a result, the fuzzy set is represented by the membership function.

Aggregation of all outputs

Aggregation is the process by which the fuzzy sets representing the outputs of each rule are combined into a single fuzzy set.

Defuzzyfication

The fuzzy process helps evaluate the rules during each step, the final desired output for each variable is usually a single number. The process practically demonstrates the application of fuzzy logic to traffic management and the workload of dispatchers controlling rail vehicle movements.

3.2.1 Fuzzy Logic application to Traffic Control process

Fuzzy logic was applied in the dissertation because it better describes the activities of dispatchers controlling the movement of railway vehicles. Input values

cannot be quantified accurately. The known variables can be used to create a list of rules against which the system is further evaluated.

An important factor is the quality of train running. There is considerable unevenness in the activities carried out by the dispatcher controlling the movement of railway vehicles. The evaluation was based on the number of activities that needed to be performed at a given time, as well as the time from the start of the simulation run to account for fatigue. From the trace, it was evaluated that the experience of the dispatcher was weighted more heavily than his exhaustion. The weights are determined by the expert system and, when validated, most closely match the real values obtained.

3.3 The dissertation solution

The technical point of trains running control from CTC is sufficiently secured. The weak element is becoming the staff who control the traffic (dispatchers). For the purpose of this work, the scientific method of fuzzy logic was chosen to determine the load of dispatchers controlling traffic.

3.4 System design based on fuzzy logic

The design and simulation of solutions for the dissertation were performed in the Fuzzy Logic Toolbox, which extends the MATLAB computing environment with tools for designing systems based on fuzzy logic.

3.5 Determining the number of activities for dispatchers

Initially, a value of 15 seconds between activities was chosen as the auxiliary time. According to the results of the defuzzyfication, it is not possible to determine one time period for the movements of the rail vehicles in order to maintain the full quality of the stringing. If the inter-task gap is increased by 10 seconds to 25 seconds the quality increases to almost 93% even in the most serious variant. The transport infrastructure capacity decreases. In the case of the 25 seconds per activity threshold, this threshold is shifted from 15 seconds.

Usually is necessary to supplement the dispatcher with another employee (usually a locally located dispatcher), to whom part of the activities will be deployed so that the dispatcher controlling the operation can perform the given activities correctly.

3.6 Possibility to transfer the central dispatcher function to local dispatcher or regional dispatcher center

The transfer of the dispatcher's function from one place to another must reflect the distribution of the functional parts of the signalling equipment.

Technical conditions

The dispatcher always only manipulates with the control elements of the signalls, remotely from the CTC. If the function of the dispatcher is therefore transferred from the control room to the station, it is therefore technically possible to transfer the function of controlling the signalling equipment elsewhere. Rail traffic control is a closed computer network, it is not possible to control traffic from anywhere, but only from predefined locations. Another advantage is that the logical core of the signalling system is located in the junctions. It is hardware protected, too and does not allow a situation to be created that threatens the safety of the movement of train running.

Staff requirements

At present, it is necessary that the interlocking is operated by an employee. A condition for the dispatcher's activity is his medical, psychological and professional competence.

3.7 Costs spring from the dissertation proposal

Reducing the potential cost of operations is not a good solution by moving staff to one location, as it again increases the criticality of the infrastructure element in question.

4 Verification of the proposed solution

Unfortunately, it is not possible to verify the proposed solution in real operation. In this paper only a calculation verifying the CTC failure mathematically is presented.

4.1 Verification of the proposed solution on the section controlled with locally situated dispatchers

The section from the station Praha - Holešovice and Kralupy nad Vltavou was selected for verification of the proposed solution. When applying the rule given in the dissertation, it results that the number of routes that can be served by a given traffic controller in a given time is exceeded only in the case of the peak hour. Thus, not only in the case of CTC failure, but regularly it is necessary to transfer the activities of the dispatcher controlling traffic from CDP to another employee between 7 am and 8 am. The appropriate solution here seems to be to transfer the control of train journeys from one of the selected services to a locally located dispatcher, who is there for these cases. However, in the event of an crisis

situation where the CTC is unable to control traffic on the designated infrastructure, traffic management is taken over fully by the local dispatcher. During peak hours, the local dispatcher is unable to serve all stations with sufficient quality. It is therefore desirable at that moment to reduce the load on the local dispatcher by taking away some of the tasks he performs.

Lockout in a selected junction

One solution is to close the selected junction. However, this will reduce the capacity of the transport route. This will not make the work of the dispatcher easier, it will only reduce the necessary train operations to a smaller number of junctions. There is no doubt that the closure of the service is a compromise solution and that the capacity of the route decreases when the junction is closed.

Transfer of dispatcher's activities to another location

In the case of a good scheduling of activities in crisis situations, it is possible to ensure operation on the railway network without lack of train running. For the assessed area, the duties of the dispatcher controlling the operation was removed to the local dispatcher for the regional line, namely in the section Kralupy nad Vltavou, Předměstí to Zvoleněves. This is a regional line with very low traffic intensity. Due to this low intensity, if the given conditions are met, it is possible to transfer traffic control from the area under the supervision of the dispatcher controlling traffic from CTC and there will be no overload of the dispatcher controlling traffic on the line controlled from local dispatcher centre.

Sub-conclusion of the section

The local dispatcher is an element that increases the resilience of traffic management. The presence of a local dispatcher may not be sufficient backup in the event of a CTC failure. Delegation of duties to a dispatcher managing another line may serve as a backup. The necessary local knowledge increases the cost of training such a dispatcher. The increase in the resilience of the infrastructure in question is unquestionable.

4.2 Verification of the proposed solution on the section controlled from CTC without locally situated dispatchers

The option without local dispatchers is not ideal because the regional line dispatchers will not be able to take over the operation of the lines completely without the support of local dispatchers.

Comparison of the section Prague, Bubeneč - Libčice nad Vltavou with the section Prosenice - Drahotuše

The Prosenice - Drahotuše section was selected for the dissertation. This section is without locally situated dispatchers. The movements of railway vehicles are more evenly distributed here.

CTC duties transfer without locally based dispatchers

The possibility of lockout in definated junction would be possible as in the case of the section with local dispatchers, too. The transfer of the duties of the dispatcher controlling the traffic from the CTC would take place in the same systematic way. The only difference is that there is no locally located dispatcher, which is an element that increases the overall resilience of traffic control from CTC.

4.3 Chapter conclusion

The logic of delegation of CTC dispatcher activities does not differ whether or not the system uses locally located dispatchers. However, that if local dispatchers are used, the stability of the CTC control system during off-peak hours is such that on many of the controlled sections there is no need for the support of entities other than local dispatchers.

5 Contributions of the dissertation

The dissertation benefits is in remote traffic control from CTC during crisis situations. Thesis show a new method to determine the workload of controllers. However, contrary to the author's expectations, this benefit is also for normal operations, not only for a potential crisis situation.

The dissertation shows how the existing traffic management system can be supplemented or even partially replaced, which is the contribution of this thesis. The possibility of replacing the control dispatcher increases the resilience of rail traffic management as a whole.

The level of knowledge in terms of the work and workload of controllers has increased, thanks to the dissertation. The workload of the controlling dispatcher has been accurately quantified and limits for his quality and mistake-free work have been set. Furthermore, a partial proposal for the evaluation of these limits of controllers was developed.

5.1 Discussion

Readiness for crisis situations is essential, it must follow the society needs and respect technical developments. It is by assessing the work of controllers that it is possible to determine how much of the controllers' activities need to be transferred. The theoretical contributions of the dissertation are in terms of readiness for crisis situations. Thanks to the dissertation, it is possible to quantify the replacement personnel number for traffic management in crisis plans.

Knowing of the activities number for a specified time period is benefit too. It can be determined at which control in junctions will be transferred and where. Another practical benefit is the determination of the number of activities that do not overload the controllers managing the traffic. By determining the number of activities that do not overload the controllers, it is possible to better comply with hygiene standards in labour law terms.

The proposed solution also has its disadvantages. One of the disadvantages is the remote communication between dispatchers. Another disadvantage is the need to maintain additional buildings. Without the CTC, the dispatcher usually does not have accurate information about what is happening outside his area.

Automated path construction systems are currently being tested. It will reduce the workload of traffic controllers. The logic for determining the activities for controllers will have to be redesigned. However, the calculation logic using fuzzy logic will still be functional and, if the input data is modified, will be applicable in the new system.

Literatura

[1] Act No. 239/2000 Coll., on the Integrated Rescue System

[2] Act No. 241/2000 Coll., on Economic Measures for Crisis Situations and on Amendments to Certain Related Acts

[3] Act No. 77/2002 Coll., on the joint stock company České dráhy, the state organisation Railway Infrastructure Administration and on the amendment of Act No. 266/1994 Coll., on railways, as amended

[4] BĚHOUNEK, Libor. Jak je důležité být fuzzy. *Matematická fuzzy logika – Behounek-Fuzzy* [online]. Olomouc: Ústav informatiky AV ČR, 2012, 21. 6. 2012 [cit. 2020-3-10]. Available: http://www.cs.vsb.cz/duzi/Behounek-Fuzzy.pdf

[5] ČERNÁ, A. a J. ČERNÝ.: *Teorie řízení a rozhodování v dopravních systémech*, Institut Jana Pernera; Pardubice 2004; 150 s.; ISBN 80-865-3015-9

[6] CHOW. A., HEYDECKER B., FUJIYAMA T., XU F., GHASEMPOUR T.: *Developing and Evaluating Dynamic Optimisation for Train Control Systems*; Founders: Railway Safety & Standard Board (RSSB) and Network Rail; United Kingdom of Great Britain and Northern Ireland, internal document of RSSB

[7] DORA, J. M., LANE J., WOODROFFE G.: *Operations and Management to adapting to extreme climate change*; United Kingdom of Great Britain and Northern Ireland, internal document of the Network Rail

[8] DUŠEKL L.: *Vliv lidského faktoru na celkovou propustnost železniční dopravní cesty*; Pardubice 2010; Diploma thesis

[9] DVOŘÁK Z., SOUŠEK R., SVENTEKOVÁ E., LEITNER B., ČIŽLÁK M.; *Riadenie rizík v železničnej doprave*; Institut Jana Pernera 2010, Pardubice; 286 s.; ISBN 978-80-86530-71

[10] ESARR1_E2.0_RI. *ESARR 1 - Safety Oversight in ATM*. 2.0. Bruxelles, Belgie: Safety Regulation Unit EUROCONTROL Rue de la Fusée, 96 B-1130 Bruxelles, 2009.

[11] ESARR2_E3.0_RI. *ESARR 2 Reporting and Assessment of Safety Occurrences in ATM*. 3.0. Bruxelles, Belgie: Safety Regulation Unit EUROCONTROL Rue de la Fusée, 96 B-1130 Bruxelles, 2009.

[12] ESARR3_E1.0_RI. *EUROCONTROL Safety Regulatory Requirement - ESARR 3 Use of Safety Management Systems by ATM Service Providers*. Bruxelles, Belgie: Safety Regulation Unit EUROCONTROL Rue de la Fusée, 96 B-1130 Bruxelles, 2000.

[13] ESARR4_E1.0_RI. *EUROCONTROL Safety Regulatory Requirement - ESARR 4 Risk Assessment and Mitigation in ATM*. Bruxelles, Belgie: Safety Regulation Unit EUROCONTROL Rue de la Fusée, 96 B-1130 Bruxelles, 2001.

[14] ESARR5_E2.0_RI. *Safety Regulatory Requirement - ESARR 5 ATM Services' Personnel*. 2.0. Bruxelles, Belgie: Safety Regulation Unit EUROCONTROL Rue de la Fusée, 96 B-1130 Bruxelles, 2002.

[15] FUJIYAMA T.: *Tomorrow's Railway and Climate Change Adaptation*; Founders: Railway Safety & Standard Board (RSSB) and Network Rail; United Kingdom of Great Britain and Northern Ireland, internal document of RSSB and Network Rail

[16] Fuzzy Logic toolbox. *Fuzzy Logic toolbox, user guide* [online]. Natick, MA, USA: The MathWorks, 1995 - 1999 [cit. 2021-02-04]. Available: http://faculty.petra.ac.id/resmana/private/matlab-help/pdf_doc/fuzzy/fuzzy_tb.pdf

[17] Government Regulation No. 432/2010 Coll. on Criteria for Designating Critical Infrastructure Elements

[18] HE, J., CHEN, X., CHEN, X., LIU, Q.*; Distributed production planning based on ATC and MOILP considering different coordination patterns*, Journal of Intelligent Manufacturing, 27, 2019 (5), pp. 1067-1084. ISSN: 10845-014-0935-2

[19] HENDERSON A., MAYNARD J., DORAN M. V.: *Making the Trains Run On Time: The Development of a Self-Regulating, Real-Time Model Railroad System;* The 20th World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI

2016, Orlando, USA, 2016; Univeristy of South Alabama, s. 104 – 109; ISBN – 13: 978-1-941763-46-9

[20] HUM.ET1.ST03.1000.GUI-01. *Guidelines for Personal and Career Development Processes*. Bruxelles, Belgie: Traffic Organization Unit EUROCONTROL, Rond Point Schuman 6 B-1040 Bruxelles, 2000.

[21] KOMEŠTÍK, Michal. *Koordinace výluk na železniční infrastruktuře*. Pardubice, 2014. Diploma thesis. Dopravní fakulta Jana Pernera Univerzity Pardubice.

[22] Ministerstvo dopravy České republiky, odbor krizového řízení; *Strategie krizového řízení v dopravě do roku 2018*, 26 s., [online], [cit. 2016-10-01]. Available: cep.mdcr.cz/odd540/doc/strategie_kr_2018.doc

[23] *Outputs from the electronic control panel function,* Praha: CDP Praha, 2018.

[24] PONÍŽIL J.: *Práce výpravčích DOZ ve stanicích řízených z CDP Přerov*, Pardubice 2015; Bachelor Thesis

[25] *Portál provozování dráhy: Pomůcky GVD* [online]. Olomouc: OLTIS Group a.s., Dr. Milady Horákové 1200/27a, 779 00, Olomouc, 2020 [cit. 2020-03-21]. Available: https://provoz.szdc.cz/Portal/ViewArticle.aspx?oid=397961

[26] *Portál provozování dráhy: Přístup na ŽDC* [online]. Olomouc: OLTIS Group a.s., Dr. Milady Horákové 1200/27a, 779 00, Olomouc, 2020 [cit. 2020-8-20]. Available: https://provoz.spravazeleznic.cz/Portal/ViewArticle.aspx?oid=1792708

[27] *Portál provozování dráhy: Prohlášení o Dráze* [online]. Olomouc: OLTIS Group a.s., Dr. Milady Horákové 1200/27a, 779 00, Olomouc, 2020 [cit. 2020-8-15]. Available: https://www.szdc.cz/documents/50004227/50162921/szdc-prohlaseni-o-draze-2019-c-r-4-zmena.pdf

[28] *Předpis SŽDC (ČD) Z1: Předpis pro obsluhu staničních a traťových zabezpečovacích zařízení*. IIQ 2007. Praha 1: Odbor Řízení provozu a organizování drážní dopravy České dráhy, 2007.

[29] *Prováděcí nařízení pro trať s dálkově ovládaným zabezpečovacím zařízením: trať: Praha, Libeň - Kolín*. Praha: Správa železniční dopravní cesty, státní organizace, Dlážděná 1003/7, 110 00 Praha 1.

[30] *Prováděcí nařízení pro trať s dálkově ovládaným zabezpečovacím zařízením: trať: Přerov – Ostrava, Svinov*. Praha: Správa železniční dopravní cesty, státní organizace, Dlážděná 1003/7, 110 00 Praha 1.

[31] *Prováděcí nařízení pro trať s dálkově ovládaným zabezpečovacím zařízením: trať: Praha, Holešovice – Kralupy nad Vltavou*. Praha: Správa železniční dopravní cesty, státní organizace, Dlážděná 1003/7, 110 00 Praha 1.

[32] *Prováděcí nařízení pro trať s dálkově ovládaným zabezpečovacím zařízením: trať: Rokycany - Nezvěstice*. Praha: Správa železniční dopravní cesty, státní organizace, Dlážděná 1003/7, 110 00 Praha 1.

[33] ROSENBERGER J.M., SCHAEFER A.J., GOLDSMAN D., JOHNSON E.L., KLEYWEGT A.J., NEMHAUSER G.L., *A stochastic model of airline operations*, Transportation Science, Volume 36, Issue 4, Pages 357 – 377, November 2020,

ISSN: 0041-1655

[34] SCHAEFER A.J., JOHNSON E.L., KLEYWEGT A.J., NEMHAUSER G.L., *Airline crew scheduling under uncertainty*, Transportation Science, Volume 39, Issue 3, Pages 340 – 348, August 2005, ISSN: 0041-1655

[35] ŠEBESTA, Milan a Rudolf SCHWARZ. *Management Rizik s Pravděpodobnostním přístupem*. Brno: Vojenská akademie v Brně, 2003. Without ISBN.

[36] *Služební předpis ŠŽDC (ČD) D23: Předpis pro stanovení provozních intervalů a následných mezidobí*. Účinnosti od 1. 7. 2002. Olomouc: JERID spol. s r.o., 2002.

[37] SMITH P.J., BEATTY R., SPENCER A., BILLINGS C., *Dealing with the challenges of distributed planning in a stochastic environment: Coordinated contingency planning*, IAA/IEEE Digital Avionics Systems Conference – Proceedings, Volume 1, Pages 5.D.1/1-5.D.1/82003 The 22nd Digital Avionics Systems Conference - Proceedings, Indianapolis, IN, 12 October 2003 - 16 October 2003, 61845, ISSN: 2155-7209

[38] SOUŠEK R. a kol.: *Doprava v krizových situacích*, Institut Jana Pernera, o.p.s., Pardubice 2008, 252 str., ISBN 80-86530-46-9

[39] SOUŠEK R., VISKUP P. a kol.: *Nový systém obnovy železniční infrastruktury za krizových stavů*; Institut Jana Pernera, 2011; 142 s.; ISBN 978-80-86530-75-8

[40] SOUŠEK R.: *Dopravní infrastruktura jako kritický prvek národní infrastruktury z hlediska zabezpečení základních funkcí státu*, Ministerstvo dopravy ČR, Projekt 2004 – 2007; MD ČR 1F44E/015/030

[41] SOUŠEK R.: *Komplexní systém řízení kolejové dopravy v krizových situacích*; Ministerstvo dopravy a spojů ČR, Projekt 2001-2005; MDS ČR CE 802030105

[42] SOUŠEK R.: *Metodika hodnocení kritičnosti dopravní infrastruktury*; Ministerstvo dopravy ČR, Projekt 2009 – 2010; MD ČR 117/2009-030/CRS/1

[43] SOUŠEK R.: *Návrh výstavby smluvního systému údržby a obnovy krizové železniční infrastruktury s podporou informačních systémů, využitelného pro řešení krizových stavů a specifikace úlohy státu, samosprávných orgánů a soukromoprávních subjektů při jeho zajišťování*; Projekt Ministerstva dopravy ČR, 2009 – 2010; MD ČR 1F84C/003/030

[44] SOUŠEK R.: *Teoretické řešení krizových situací v dopravě*; Projekt 2003-2004; GAČR103/03/1077

[45] SOUŠEK. R. a kol.: *Doprava a krizový management*; Institut Jana Pernera 2010; 260 s.; ISBN 978-80-86530-64-2

[46] SOUŠEK. R., KOPČÁK P.: *Krizové řízení v železniční dopravě*; Institut Jana Pernera 2004; 150 s.; ISBN 80-86530-06-X

[47] ŠUSTR, Martin. *Vzdálené řízení dopravy v krizových situacích*. Pardubice, 2017. Expert Thesis. Dopravní fakulta Jana Pernera Univerzity Pardubice.

[48] *SŽDC (ČD) D32 Předpis pro přepravu uranového koncentrátu, čerstvého a vyhořelého paliva*, Olomouc: JERID spol. s r.o., 2006

[49] *SŽDC D17 Předpis pro hlášení a šetření nehododvých událostí v železničním*

provozu, Praha, SŽDC, 2018

[50] *SŽDC D24 Předpis pro zjišťování propustnosti železničních tratí,* Praha: Nakladatelství dopravy a s spojů, 1965

[51] *SŽDC D31 Směrnice pro přepravu zásilek s PLM, zásilek dlouhých nebo težkých*, Praha: SŽDC, 2015

[52] *SŽDC D33 Předpis o vojenské přepravě po železnici*, Olomouc: JERID spol. s r.o., 2001

[53] *SŽDC D7/2 Předpis pro organizování výluk na síti SŽDC*, Praha: SŽDC, 2013

[54] *SŽDC D7: Předpis pro operativní řízení provozu*. Praha: SŽDC, 2014.

[55] *SŽDC E4 Směrnice pro provoz záložních zdrojů elektrické energie*, Praha: SŽDC, 2010

[56] *SŽDC O3 Předpis pro obnovu rozrušené železniční sítě za válečného stavu*, Praha: SŽDC GŘ O25, 1962.

[57] *SŽDC O4 Předpis pro technickou ochranu a obnovu železnic za branné pohotovosti státu*, Praha: Nakladatelství dopravy a s spojů, 1962.

[58] *SŽDC O5 Předpis pro organizaci a činnost obnovovacích jednotek ČSD za branné pohotovosti státu*, Praha: Nakladatelství dopravy a s spojů, 1962.

[59] *SŽDC SM124 Směrnice pro zjišťování kapacity dráhy*, Praha: SŽDC, 2019.

[60] TOMEK M., SEIDL M., MILATA I., SVENTEKOVÁ E., KAŠPAR V., MONOŠI M.: *Riešenie krízových situácií v dopravnej infraštruktúre*; Žilinská Univerzita v Žilině 2005; výzkumný projekt č. KEGA 3/101503

[61] US DHS: *The National Strategy for Physical Protection of Critical Infrastructures and Key Assets*; Washington D.C.: U. S. Department of Homeland Security, the White House, February 2003. 96 s. [online], [2016-10-01]. Available: https://www.dhs.gov/national-strategy-physical-protection-critical-infrastructure-andkey-assets

[62] VICHEREK T.: *Dopravní inteligence pro automatizaci železniční dopravy*; Pardubice 2013; Disetration Thesis

[63] VISKUP P.: *Zabezpečení technické ochrany a obnovy železniční sítě v krizových situacích civilními stavebními organizacemi*; Pardubice 2015; Disertation thesis

[64] VOLEK: *Modelování a řešení rozhodovacích situací*; Univerzita Pardubice, Pardubice 2010; 106 s.; ISBN: 978-80-7395-311-9Institut Jana Pernera; Pardubice 2004; 150 s.; ISBN 80-865-3015-9

[65] ZADEH, L.A. *Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems.* State University of New York at Binghamton, USA, 1996, 840 s, ISBN: 978-981-4499-81-1

[66] ZADEH, L.A., *Outline of a New Approach to the Analysis of Complex Systems and Decision Processes*. IEEE Transactions on Systems, Man, and Cybernetics., 1, 1973, s 28 – 44, ISSN: 2168-2909

[67] ZEMAN A.: *Posouzení pracovní náročnosti Centrálního dispečerského pracoviště*; Pardubice 2008; Diploma thesis

[68] ZIMMERMANN M., FREJINGER E., MARCOTTE P., *A strategic Markovian traffic equilibrium model for capacitated networks*, Transportation Science, Volume 55, Issue 3, Pages 574 – 591, May 2021, ISSN: 0041-1655

Publikační činnost doktoranda související s tématem disertační práce

Publication in the Web of Science Database

[I] ROZOVÁ D., ŠUSTR M., ŠOHAJEK P. *Continuity of activities for railway undertaking*. In: 23rd International Scientific Conference on Transport Means - Transport Means - Proceedings of the International Conference. Palanga, Lithuania: Kaunas University of Technology, 2019, p. 1508 – 1511. ISSN 1822-296X

[II] ROZOVA, D., SUSTR, M., ALWICKER, A., PLUHAR, M. *Methods for Evaluation of Business Continuity Management System in Transport* In: In: 5rd International Conference on Traffic and Transport Engineering (ICTTE): Proceedings of the Third International Conference on Traffic and Transport Engineering (ICTTE). Belegrade, Serbia: Assoc Italiana Ingn Traffico Trasporti Res Ctr, 2018, p. 118 – 124. ISBN: 978-86-916153-4-5

[III] ROZOVA D., SUSTR M., SOUSEK R., SOHAJEK P. *Crisis management in the railway transport and their additions* In: 22nd International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Trakai, Lithuania: Kaunas University of Technology 2018, p. 1043 – 1049. ISSN: 1822-296X

[IV] SUSTR M., ROLNIK T.: *Operation of remote-controlled railway section during the crisis situations*. In: 21th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Juodkrante, Lithuania: Kaunas University of Technology, 2017, p. 935 - 938. ISSN 1822-296X.

[V] PLUHAR M., SUSTR M.: *Railway Lockouts in the Czech Republic and possibility of their optimization*. In: 21th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Juodkrante, Lithuania: Kaunas University of Technology, 2017, p. 878 - 880. ISSN 1822-296X.

[VI] DYBAL, J; ENGLICH, J; SOUSEK, R; SUSTR, M. *Extension of the New Temporary Railway Bridge in the Czech Republic, Draft of the Reinforcement*. In: 20th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Juodkrante, Lithuania: Kaunas University of Technology, 2016, p. 1051 - 1057. ISSN 1822-296X.

[VII] SUSTR, M; SOUSEK, R; KOLONICNY, A; NEMEC, V. *Transport Modelling of Citizens Evacuation*. In: 3rd International Conference on Traffic and Transport Engineering (ICTTE): Proceedings of the Third International Conference on Traffic and Transport Engineering (ICTTE). Belegrade, Serbia: Assoc Italiana Ingn Traffico Trasporti Res Ctr, 2016, p. 1026 – 1030. ISBN: 978-86-916153-3-8

[VIII] FUCHS, P; NEMEC, V; SOUSEK R; SZABO, S; SUSTR, M; VISKUP, P. *The Assessment of Critical Infrastructure in the Czech Republic*. In: 19th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Kaunas, Lithuania: Kaunas University of Technology, 2015 p. 418 – 426. ISSN: 1822-296X

[IX] DYBAL, J; ENGLICH, J; SOUSEK, R; SUSTR, M. *Draft of the New Temporary Railway Bridge in the Czech Republic*. In: 19th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Kaunas, Lithuania: Kaunas University of Technology, 2015 p. 712 - 716. ISSN: 1822-296X

[X] SUSTR, M;; VISKUP, P; FUCHS, P. *Monetary Costs of Transport Process Members, in the Railway Transport Caused by Irregularity* In: 20th International Scientific Conference on Transport Means: Transport Means - Proceedings of the International Conference. Juodkrante, Lithuania: Kaunas University of Technology, 2016, p. 1058 - 1063. ISSN 1822-296X.

Publication in the Scopus Database

[XI] ŠUSTR M., SOUŠEK R., NĚMEC V., ŘEHA D., NOVÁK M., ENDRIZALOVÁ E., MRÁZEK P. ZHARKOVA V., STRÁDAL O., FÖZÖ L. *Assessment of critical infrastructure for air transport in the Czech Republic* In: WMSCI 2019 - 23rd World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, Volume 2, Pages 28 – 31, 2019 23rd World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2019, Orlando, 6 July 2019 - 9 July 2019, 152460, ISBN: 978-195049209-1

[XII] SOUŠEK R., ŠUSTR M., FUCHS P., ENDRIZALOVÁ E., NOVÁK M., MÜLLEROVÁ J. *Evaluation of risks in air transport* In: WMSCI 2018 - 22nd World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, Volume 3, Pages 149 – 153, 2018 22nd World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2018, Orlando, 8 July 2018 - 11 July 2018, 140272, ISBN: 978-194176391-9

[XIII] FUCHCS P., SOUŠEK R., ŠUSTR M., ROZOVÁ D., ŠOHAJEK P. *Critical infrastructure in the railway transport system* In: WMSCI 2018 - 22nd World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, Volume 1, Pages 182 – 186, 2018 22nd World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2018, Orlando, 8 July 2018 - 11 July 2018, 140272. ISBN: 978-194176381-0

[XIV] SOUŠEK R., ROZOVÁ D., NĚMEC V., ŠUSTR M. *Business continuity management system in the transport* In: WMSCI 2017 - 21st World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, Volume 2, Pages 185 – 190, 2017 21st World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2017, Orlando, 8 July 2017 - 11 July 2017, 130927. ISBN 978-194176364-3

[XV] VISKUP P., SOUŠEK R., ŠUSTR M. *Provision of technical protection of the railroads in crisis situations by the private construction companies* In: WMSCI 2017 - 21st

World Multi-Conference on Systemics, Cybernetics and Informatics, ProceedingsVolume 2, Pages 191 – 196, 2017 21st World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2017, Orlando, 8 July 2017 - 11 July 2017, 130927. ISBN: 978-194176381-0

[XVI] ŠUSTR M., PLUHAŘ M., SOUŠEK R., FUCHS P., NEDELIAKOVÁ E. *Methodologies for the crisis states in the Czech Republic* In: WMSCI 2016 - 20th World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, Volume 2, Pages 242 – 246, 2016 20th World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI 2016, Orlando, 5 July 2016 - 8 July 2016, 126203, ISBN: 978-194176343-8

Abstract

Dissertation thesis deals with the crisis situation in the railway transport in relation with the Central Rail Operating Centres and in relation with a remote control of railways. Currently created Rail Operating Centre is an element of the Crisis infrastructure. It is important that, this system does not reduce the overall resilience of the railway infrastructure system, especially during times of crisis. The current crisis plans address the recovery of damaged transport infrastructure only for the reconstruction and building of railway lines using technical concessions. Current crisis plans not calculate with the interruption of the functionality of rail traffic control. This dissertation deals with the ensuring of Railway Traffic Management by Rail Operating central Control Centres due to the possibility of disrupting their operation by delegating to lower levels of control.