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Socio-Economic Impacts of Occurrences on Railways

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Abstract

The paper presents partial outputs of an applied research project aimed at evaluating the socio-economic impacts of occurrences emerging on the railway and their reflection into the economic evaluation of railway construction projects. The article builds on the research results presented within previous scientific articles where the unit impacts of sub-categories of occurrences on the Czech railways were determined using a detailed Database of Occurrences for the 2011-2018 period. These impacts were related both to one railway station and one kilometre of the wide line for the occurrence sub-categories. The values obtained were subsequently verified on case studies of specific railway infrastructure projects implemented in the Czech Republic. The results of the case studies raised the need to create an alternative methodology for the evaluation of socio-economic impacts, which would more accurately reflect the real situation on the railway. The aim of the paper is to modify the originally designed methodology for evaluating the socio-economic impacts of occurrences into a new methodology, which would relate the impacts of occurrences only to a standard kilometre of wide line, i.e. without taking account of separate impacts of occurrences on one railway station. The proposed methodology was verified on a case study, which compares the real values of socio-economic impacts emerging on the railway in the period under research, the values determined using the original methodology and the values determined according to the newly modified methodology.

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1. Introduction

The presented paper builds on previous results of applied research carried out within the research project of the Technology Agency of the Czech Republic "TL02000278 Evaluation of increased safety and reliability of railway infrastructure after its modernization or reconstruction". The issue of economic evaluation of transport infrastructure projects is very important since the implementation of these projects is associated with high investment costs, topped up by similarly significant operating costs for maintenance, repairs and reinvestment during the operational phase of the project. Given that the financing of these projects is provided from public sources, it is necessary to clearly demonstrate the potential for socio-economic benefits of each of these projects. The evaluation of the economic effectiveness of projects is generally based on the principles of Cost-Benefit Analysis (CBA). The basic methodological basis for it is currently represented by the Guide to CBA of Investment Projects [1]. The Departmental Methodology of the Ministry of Transport [2] was approved as a basis for the purposes of economic and financial evaluation of transport infrastructure projects in the conditions of the Czech Republic. It methodically addresses the economic evaluation of the road, railway and transport-significant water transport structure projects. The methodological steps make it possible to take into account most of the common impacts associated with individual types of projects. However, in the case of railways, the Departmental Methodology does not address the benefits associated with increased safety and reliability of railways due to the implementation of projects increasing the safety of the corresponding track section. Previous research was aimed at identifying the socio-economic impacts of sub-categories of occurrences that emerge on the railway and which can be prevented by the implementation of appropriate safety measures. The result of the current research is therefore the determination of the average impact of the occurrence of a corresponding occurrence category and occurrences for all categories in total on one kilometre of wide line and one railway station, all divided into national and regional lines. These indicators have been used in subsequent steps as a basis for determining future savings associated with the prevention of occurrence emergence. The subject of the presented paper is the simplification of the above-mentioned model and the relation of the socio-economic impacts of occurrences to one kilometre of the wide line without considering the impact on the railway station, which should result in the simplification of the whole evaluation process. The results of previous research are presented in articles [3-5]. The article compares the results of the original and newly designed procedure with the actual impacts of occurrences taken from the Database of Occurrences emerging in the Czech Republic in the 2011-2018 period. The comparison is carried out on a case study of six railway modernization projects.

2. Present state reference

The key tools for evaluating the effectiveness and socio-economic impacts of public investment projects, including railway infrastructure projects, as was already mentioned in the introduction of this paper, are methodological tools both at the European Union level [1] and at the level of individual member states, which is the Departmental Methodology in the case of the Czech Republic [2]. However, the issue of socio-economic evaluation of railway infrastructure projects can also be found in the scientific literature. Article [6] deals with the evaluation of railway implementation and modernization projects using the CBA principle, paper [7] deals with the detailed economic evaluation through the evaluation of internal costs and impacts. The safety and risks associated with the railway network and the projects implemented on it is subject to articles [8] and [9], a case study focused on the risk rate of the railway in the Russian Federation is presented by Petrova in her article [10]. The issue of occurrences emerging on the railway represents another important area addressed. Evans provides a summary of major occurrences emerging on European railways in his article [11]. A systematic analysis of occurrences emerging on the railway network is presented in the paper [12]. Klockner and Toft present the issue of modelling the occurrences on a railway line in their paper [13]. The analysis of the causes of occurrences on the railway line and possible preventive measures are presented in the material [14]. The influence of the human factor on the occurrence emergence and the degree of uncertainty on the railway network is addressed by articles [15] and [16].

3. Methodology

The methodology of dealing with the presented research is based on the results achieved within the current research project. In terms of data, the entire research is based on a very comprehensive Database of Occurrences [17], which includes an overview of detailed information on occurrences emerging on the railway network in the Czech Republic during the 2011-2018 period. The categories of occurrences which can be hypothetically prevented by implementing appropriate safety devices have been defined considering the nature of the research and its objectives. Selected categories of occurrences are listed in Table 1.

Table 1. Categories of occurrences

Designation	Description
A1	Collision of railway vehicles resulting in death or injury to at least 5 persons or large-scale damage
A2	Derailment of a railway vehicle resulting in death or injury to at least 5 persons or large-scale damage
A3	Collision of a railway vehicle with an obstacle in the passage resulting in death or injury to at least 5 persons or large-scale damage
B1	Collision of railway vehicles resulting in consequences minor than in a serious accident
B2	Derailment of a railway vehicle resulting in consequences minor than in a serious accident
B3	Collision of a railway vehicle with an obstacle in the passage resulting in consequences minor than in a serious accident
C1	Collision of railway vehicles resulting in consequences minor than in a serious accident or accident
C2	Derailment of a railway vehicle resulting in consequences minor than in a serious accident or accident
C3	Collision of a railway vehicle with an obstacle in the passage resulting in consequences minor than in a serious accident or accident
C6	Unauthorized movement of the railway vehicle behind a signalling device prohibiting driving resulting in consequences minor than in an accident
C12	Unsecured movement of a railway vehicle resulting in consequences minor than in an accident
C16	Failure of signalling systems resulting in consequences minor than in an accident
C19	Unspecified incident, arising in connection with the movement of the railway vehicle resulting in consequences minor than in an accident

Source: Database of Occurrences 2011-2018 [17]

The average socio-economic impacts of one occurrence for each of the corresponding categories were determined within the research using detailed information on individual occurrences.

Those occurrences of the defined categories that emerge as a result of the human factor were considered in the context of the research. The determined average socio-economic impacts of occurrences according to individual sub-categories range within the interval of EUR 2,464 (category C6) to EUR 2,672,916 per occurrence (category A3) with the mean of EUR 388,461 and the median of EUR 32,369 per occurrence. Data related to individual categories were published in the research article [5].

The average number of occurrences according to the sub-categories per year was determined using the data from the Database of Occurrences [17]. Furthermore, summary quantitative information on the railway transport network in the Czech Republic was determined. This information is shown in Table 2.

Table 2. Overview of the input data for the final calculation

Input quantity	Value
Total length of national lines (in 2015)	4,738 km
Total length of regional lines (in 2015)	4,361 km
Total no. of stations on the national lines (in 2015)	1,245
Total no. of stations on the regional lines (in 2015)	1,380
Ratio of occurrences at the station *	94.85%
Ratio of occurrences on the track *	5.15%

*Values taken from source [5]

The average annual impact of occurrences of the corresponding sub-categories on one kilometre of wide line and one railway station, both divided into national and regional lines, were determined by the combination of the above-mentioned information. Equation (1) was used for their calculation.

$$TI = \frac{\sum_{i=A1}^{C19}\left(O_{i,j,k} \times UI_{i,j,k}\right)}{Q_{j,k} \times t} \tag{1}$$

Where:

- TI Total impact of occurrence per year in €
- O_i Number of occurrences per evaluated period t
- i Category of occurrence according to Table 2
- UI_i Unit impact of occurrence according to Table 3
- $Q_{j,k}$ Quantity of stations/tracks
- j Category of the railway line (1 – national, 2 – regional)
- k Category of sections of the railway line (1 – Railway track, 1 – Railway station)
- t Evaluated (reference) period in years

The average annual impact of occurrences across all sub-categories for national and regional lines ranges from EUR 2.06 to EUR 865.21 per station with the mean of EUR 139.72 and the median of EUR 75.45 per station and from EUR 0.04 to EUR 12.35 per km of track with the mean of EUR 2.05 and the median of EUR 1.24 per km of track.

The total expected annual socio-economic impact of occurrences was determined as the sum of the impacts of the individual sub-categories. The total values are given in Table 3.

Table 3. Values of the overall socio-economic impacts of occurrences

Part of the railway network	**Value**
Station – national line	2,922.72 €/station/year
Station – regional line	431.35 €/station/year
Track – national line	41.67 €/km/year
Track – regional line	7.39 €/km/year

4. Results

Approaches to the annual impact of occurrences determination within the evaluated section of the railway network line were determined within the previous research. This information is intended to determine the expected savings on the evaluated line section due to the reduction in the frequency of occurrences as a result of the safety equipment implementation project. Two approaches were determined within the research. The detailed approach is based on the obtained information on the real average impact of occurrences in the section under research, this information was taken from the Database of Occurrences. The second, simplified approach uses the average values taken from Tables 4 and 5 and information on the number of kilometres of the section under research and the number of railway stations. However, when determining the average values from the number of kilometres and the number of railway stations, the researchers faced the need for detailed knowledge of all railway stations and possible measures that are implemented within the section. In general, this is not a problem as the analysts usually have this information available, however, in the case of fast calculations, some more detailed information may be missing. Therefore, in the framework of this article, the authors considered the possibility of using an approach that does not reflect the impacts of occurrences on a railway station, but solely on a kilometre of wide line. The division into national and regional lines was kept.

Table 4 presents the results of the calculation of the average annual impact of occurrences by sub-category per one kilometre of the wide line.

Table 4. Calculation of the expected annual impact of sub-categories of occurrences on one km of wide line

Occurrence category	National/ regional	Total number of occurrences 2011–2018	Number of occurrences per year and km	Unit impact of occurrence in €	Expected annual impact in € per km of track
A1	national	12	0,000316589	757,756.47	234,95
	regional	2	0,000052765	757,756.47	39,16
A2	national	3	0,000079147	1,004,436.36	77,86
	regional	1	0,000026382	1,004,436.36	25,95
A3	national	2	0,000052765	2,729,166.45	141,04
	regional	0	0,000000000	2,729,166.45	0,00
B1	national	37	0,000976150	107,414.17	102,69
	regional	7	0,000184677	107,414.17	19,43
B2	national	34	0,000897003	60,647.57	53,28
	regional	7	0,000184677	60,647.57	10,97
B3	national	14	0,000369354	75,614.37	27,35
	regional	3	0,000079147	75,614.37	5,86
C1	national	75	0,001978683	6,003.73	11,63
	regional	4	0,000105530	6,003.73	0,62
C2	national	395	0,010421064	3,877.39	39,57
	regional	82	0,002163360	3,877.39	8,22
C3	national	254	0,006701140	4,290.53	28,16
	regional	80	0,002110595	4,290.53	8,87
C6	national	637	0,016805614	2,516.13	41,41
	regional	86	0,002268890	2,516.13	5,59
C12	national	104	0,002743774	3,394.95	9,12
	regional	37	0,000976150	3,394.95	3,25
C19	national	222	0,005856902	4,515.41	25,90
	regional	14	0,000369354	4,515.41	1,63

Table 5 presents the total values for all occurrence categories.

Table 5. Values of the overall socio-economic impacts of occurrences ($ETAI_l^*$)

Section of the railway network	Value of $ETAI_l$*
Track – national line	792,98 €/km/year
Track – regional line	129,55 €/km/year

*Expected total annual impact of occurrences emerging on the wide line

The case study works with data concerning the following six projects.

Table 6. Overview of projects used in a case study

No.	Project description [1]	Start	Finish	Line type	Track TTP-No [2]	From (km)	To (km)
1	Track No. 280 Hranice na Moravě - Střelná, section Teplice nad Bečvou – Hustopeče nad Bečvou	28/05/2015	30/06/2016	NA	308	6.2	15.4
2	Revitalization of track No. 323 Frýdlant nad Ostravicí – Valašské Meziříčí	01/06/2015	30/06/2016	REG	302A	61.1	101.1
3	Track No. 230 Kolín – Havlíčkův Brod, section Golčův Jeníkov – Vlkaneč	01/09/2015	02/01/2016	NA	324	257.6	266.7
4	Track No. 340 Brno – Uherské Hradiště, section Brno-Černovice – Brno-Slatina	10/09/2015	11/12/2015	NA	318A	2.2	6.1
5	Track No. 280 Hranice na Moravě - Střelná, section Valašské Meziříčí - Jablůnka and Vsetín – Horní Lideč	20/04/2015	13/08/2015	NA	308	38.0	19.1
6	Revitalization of track No. 281 Valašské Meziříčí - Rožnov pod Radhoštěm	01/07/2015	31/08/2015	REG	304G	5.2	13.2

Notes:

[1] Track No. according to the official timetable of the Czech Railway Infrastructure Administration (SŽDC)

[2] Track No. according to the track ratio tables of the Czech Railway Infrastructure Administration (SŽDC)

The average annual impacts of occurrences were determined for the corresponding projects using the procedures described above. The first row, "Detailed approach", is based on real occurrences that emerged in the addressed section from 2011 until the date of its implementation start. The second row, "Average approach (track + station)", is based on the average annual impacts of occurrences related to one kilometre of wide line and one railway station, both divided into national and regional lines. The third row, "Average approach" (track), represents the result of an approach where the occurrence impact is related only to one kilometre of the railway line, divided into national and regional lines. The results of the partial calculations can be seen in Table 7.

Table 7. Determining the average impact of occurrences: projects 1 – 6 (EUR per year)

Approach	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Detailed approach	1,377	4,121	3,325	1,870	9,164	840
Average approach (track + station)	3,306	4,177	3,301	3,084	9,555	922
Average approach (track)	7,291	5,172	7,199	3,073	14,972	1,038
Number of km of the line	9.20	39.92	9.08	3.88	18.88	8.01

$ETAI_l$	792,98	129,55	792,98	792,98	792,98	129,55

5. Discussion

The results presented in Table 7 show that in the case of projects researched within the case study, a more accurate approach appears to be one that takes into account both the number of kilometres and the number of railway stations located in the section under research and is subject to the implementation of the equipment to increase safety and reliability project and thus reduce the occurrence emergence probability. Therefore, if detailed information on the project which includes the total number of kilometres of the modernized line as well as the total number of modernized stations is available, this approach can be definitely recommended. Its use can also be supported by the previously determined information that approximately 95% of occurrences emerge at railway stations and only 5% on the wide lines. However, also the approach based on relating the average impact of an occurrence on a kilometre of the wide line without considering an individual unit impact on one railway station cannot be totally rejected. On the contrary, it can be recommended for initial calculations, when the details of the project are not yet known and it is necessary to rely entirely on the total length of the modernized line.

The last consideration concerns the question of whether it is appropriate to prefer a detailed approach based on the occurrences that actually emerged within the section during the relevant period, or rather prefer the approaches based on average values (taking into account both the number of kilometres of the line and the number of stations or solely the kilometres of the line) when determining the annual impacts of occurrences on the researched section of the line. At first glance, the answer seems clear, real values should always be more accurate. However, it is necessary to realize for what purposes the presented calculations are intended. The purpose of the developed analysis is to determine what impacts caused by occurrences are prevented by the implemented measures. So for these purposes, it is not so important what occurrences in the researched section occurred in the past, but which hypothetically could have occurred and which will not occur thanks to the implementation of appropriate measures. From this perspective, the use of average values seems to be more efficient and better corresponding to the evaluated reality.

6. Conclusions

The presented paper introduces the results of partial research carried out within the project of applied research aimed at taking into account the socio-economic benefits associated with increasing the safety and reliability of the railway in the economic analysis of railway infrastructure projects. The aim of the paper was to compare a simplified approach to evaluating the socio-economic impacts of occurrences which is based on identifying the average annual impact of sub-categories of occurrences on one kilometre of wide line with previously determined and slightly more complex approaches. The research carried out shows that this simplification is possible, however, it shows a higher level of inaccuracy compared to previously determined procedures, and therefore its use can be recommended especially for the initial and indicative calculation of socio-economic impacts of occurrences within the corresponding railway section. The identified outputs will be used in the follow-up research, in which the methodological procedure for taking into account the evaluated benefits in the economic analysis of projects on the railway network will be completed and case studies are expected to be carried out to verify them.

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