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Benefits of Increased Railway Safety and Reliability and their Evaluation

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Abstract: The paper focuses on the presentation of key results of the project of applied research oriented on evaluation of the increased safety and reliability of the railway network due to the implementation of relevant railway network projects and their projection into the investment project socio-economic evaluation using Cost-Benefit Analysis. The subject research described in the article is the design and verification of the functionality of the methodological procedure for the evaluation of these benefits for their further use in the assessment of public projects on railways. The methodological part summarizes the basic outputs of the previous research. These outputs were subsequently applied at the formulation of basic rules for the assessment of benefits connected with increased railway reliability and safety, which were later processed into the form of simplified methodological procedure. The simplified approach uses average data on the occurrence impact for the entire railway network, broken down into line and station sections. The functionality of individual approaches was checked on case studies of actually implemented projects.

Keywords: benefits; economic efficiency; occurrences; railways; safety and reliability; social impacts

1 INTRODUCTION

The article is oriented on the introducing of the final outputs of the research activities oriented on the evaluating the benefits connected with increased user level of the railways as an output of the carrying out of appropriate measures. The key output is a methodological procedure for evaluating the benefits connected with increased safety and reliability level of the railways designed to complement the socio-economic analysis of construction projects in the field of railways. This paper presents the key principles, approaches, methods and values which form the basis of the methodological approach. The contribution is based on the outputs of previous already published articles [1-4]. These results are reached using an extensive database of extraordinary events [5], which involves nearly 6,000 occurrences from 2011-2018 arising in the Czechia and represents a key data set for the subsequent analysis and final synthesis of information into the final version of the methodological procedure for the socio-economic impacts of classified occurrences evaluation. In addition to the above-mentioned Database of Occurrences, statistical data on the Czech railway network [6-9] were used as inputs. The presented paper presents the final unit impact values of sub-categories of occurrences related to the year and transport performance unit (train kilometre) usable within the simplified methodological approach. The functionality of the proposed methodological procedure was consequently checked on two railway infrastructure projects oriented on the modernization divided into a line and station sections.

The benefits described above will be used for the socio-economic evaluation of rail-way infrastructure projects using Cost-Benefit Analysis which is explained in many scientific texts. The Guide to CBA [10] can be considered a basis for the evaluation of transport infrastructure project at the European level. The Departmental Guideline of the Ministry of Transport [11], which developed an approach for the economic and financial assessment of projects of road transport, rail transport and transport-significant water structures is used for the evaluation of transport infrastructure projects at the national level of the Czech Republic. The Guidelines include a comprehensive socio-economic evaluation of these types of projects, including an evaluation of external impacts. by the way, the issue of the impact connected with increased railway user level resulting from the implementation of the projects increasing the level of safety equipment was not ad-dressed by the Guidelines. From the aspect of the methodology, attention should be paid to an extensive study for the evaluation of the Rail Baltica railway corridor [12], which carried out a comprehensive economic evaluation including an assessment of safety change due to the transfer of the part of road transport to the railway. However, the evaluation of the increased transport safety and reliability due to the implementation of modern safety equipment was also not considered in it.

The evaluation of safety and its development in the field of railways transport in re-cent years represents an important issue. The document "Report on Railway Safety and Interoperability in the EU 2020" [13] presents an important source of information regarding this area. The following conclusions were drawn within the field of railway safety in the EU:

- The safety level in terms of the fatal accident rate has been continuously improving since 1990, with an average annual reduction of more than 5%.
- The safety level monitored for 2018 was historically the highest (overall decrease in serious accidents since 2010).
- The "internal" accident (collisions, derailments and fires in rolling stock) level is more or less stagnant.

The material [13] presents a development in the number of serious injuries and deaths due to occurrences across all European Union countries. This trend can be associated with the presented continuous increase in the railway safety level in the European Union.

As already mentioned, a key approach to considering the positive impacts connected with increased reliability ad safety in railway network is the Cost-Benefit Analysis (CBA).

The CBA is generally one of the key tools for the economic evaluation of railway infrastructure projects. The issue of the ex-ante and ex-post evaluation of projects increasing the railway network safety level is addressed, for example, by a paper [14]. Olsson et al. [15] deal with the utilization of the Cost-Benefit Analysis in tranport infrastructure projects at the international level and focus in their article on the comparison of the approaches to economic evaluation between selected countries. Siciliano et al. [16] apply the CBA approach to innovative transport services and evaluation of the effectiveness of their use. Carteni & Henke [17] provide a practical example of using CBA analysis to evaluate the economic benefits of a tourist railway implementation in northern Italy. A very important area to be presented in connection with the presented research is the issue of railway safety assessment. Evans [18] deals with the economic context associated with the railway network and its safety. Oertli [19] deals with the evaluation of the impacts caused by railway noise and presents the possibilities of inclusion the impacts connected with the reduction of level of noise into the CBA. The issue of time, especially train delays, is the subject of the paper by Tseng et al. [20] who explain the impacts of train unreliability and subsequent changes in timetables on the economic evaluation carried out in the form of CBA. Johnsen [21] and Petrova [22] are interested with the risk management in rail transport and railway infra-structure in their articles.

Evans [23] in his study deals with a detailed analysis of serious railway accidents throughout Europe in the 1980-2009 period. The procedures of systematic analysis of railway occurrences are introduced in the paper by [24]. In their contribution, Klockner and Toft [25] address a comprehensive socio-economic assessment of railway emergencies, Read et al. [26] focus on the causes of occurrence emergence on the railway network, the main attention is paid to the social environment and its impact on the human factor. Prevention of the arising of extraordinary events on the railway and its impact on their emergence is the subject of the paper [27].

Even extraordinary events as a result of human factor or technical mistake are considered in the research project, extraordinary events in the form of suicides or accidents at level crossings in relation to the previous research ([1], [2]) were excluded from the research. Understanding the impact of people on the arising of extraordinary events on the rail-way in Australia were addressed by Baysari et al. [28], a similar issue, however, from the Indonesian environment, was addressed by Iridiastadi and Ikatrinasari [29]. The use of Human Factor Analysis for the classification and assessment of railway safety in the United Kingdom was presented in the article [30]. The model for assessing the probability of a railway occurrence emergence due to the human factor was presented by Lombardi et al. [31]. The impact of engine drivers' cognitive abilities on the potential occurrence emergence was the subject of the text by Hani Tabai et al. [32].

2 MATERIALS AND METHODS

The main objective of the presented research is the formulation of the methodological approach oriented on considering the positive impacts connected with increased user standard of the railway caused by the safety equipment consideration in the economic evaluation of transport infrastructure projects. The key input for the methodological approach is the unit economic impact of the extraordinary event per appropriate measure unit and the year.

2.1 Relevant Occurrences

The expected impact of the implementation of measures to increase the safety and reliability of the railway network lies in the reduction of the number of occurrences emerging on the railway network, i.e. on the wide line and in the station.

The methodological procedure considers the specific categories of occurrences, which can be avoided or decreased with the realization of specific projects. From this reason, this approach doesn´t consider occurrences emerging at level crossings and the occurrences like suicides. While suicides cannot be avoided by any safety measure, in the case of railway crossing the possibility to avoid exists, e.g. by improvement of safety measures. But these kinds of projects have been already solved by specific methodological approach. The occurrence structure is based on the occurrence classification used in the Data-base of Occurrences [5] and divides occurrences into

- A Serious accidents,
- B Minor accidents,
- C Incidents.

These categories can be divided into subcategories A1-A3 (accidents with impact on health of 5 persons or with big loss), B1-B3 (lower impacts then in the case of serious accidents) and C1-C19 (small impact).

Detailed information on occurrence subcategories is available in the papers [1, 3].

2.2 Determination of Benefits of Extraordinary Events

Within the relevant categories of occurrences there were determined the overall socio-economic occurrence impacts, like impacts on health, losses on property or costs caused by delays of passenger or cargo trains. For the evaluation of these benefits and costs the principles of the CBA analysis were used (e.g. the financial valuation of impact of accidents on health, or the financial valuation of time delays due the accidents – people and freight). The theoretical background of the calculation is explained in the Departmental Guidelines [11].

Table 1 Values of impacts per one extraordinary event according to category (CA 2018)

EE Cat.	Values of impact (€)
A1	913,964
A2	847,877
A3	2,415,941
B1	130,822
B2	90,538
B3	78,651
C1	7,473
C2	5,446
C3	7,043
C6	3,370
C12	4,479
C19	9,388

The detailed principle of the socioeconomic impact calculation is presented in the paper [1], the average total economic impacts per one occurrence caused by a human factor according to the above-listed categories are shown in the papers [2, 3]. Final result of the determination of unit impact of extraordinary events of specific categories caused by human or any other factor is presented in the Tab. 1.

2.3 Costs and Benefits of Extraordinary Events on Wide Lines and in Railway Stations

Costs related of sub-categories of Extraordinary Events must be related to the railway, the wide lines and stations. From the Database of Extraordinary Events [5] it was possible to derive that 94 % of them appear in stations and 5,15 % of them appear on broad lines. Detailed calculation has been already presented in the paper [3].

The size of the railway network is defined in train kilometres for both, train kilometres on wide line and train kilometres in railway stations.

Information on average annual transport performance on the railway network is used for further calculations. The size of the network is given in Tab. 2.

Table 2 The size of the railway transport in the Czech Republic

Input quantity	Value
Number of train kilometres in railway stations (2018)	27.025 mil. tkm/year
Number of train kilometres on wide track (2018)	144.932 mil. tkm/year
The proportion of extraordinary events at the railway station	94.85%
The proportion of extraordinary events on the wide line	5.15%

To calculate the annual costs of the partial categories of extraordinary events, the key relationship for the calculation was defined in the following form:

$$TI_{ik} = \frac{O_i \times R_k}{Q_k \times t} \times UI_i \quad (1)$$

Where:

TI_{ik} Total annual cost (impact) of extraordinary event of sub-category i per train-kilometre of the wide line (k = 1) or railway station (k = 2) in CZK/tkm

O_i Number of occurrences of the category i in period t

i Sub-category of extraordinary event

UI_i Unit cost of extraordinary event according to table 2

Q_k Number of train-kilometres on the wide line (k = 1) in in the railway station (k = 2)

R_k The rate of extraordinary events on the broad line (k = 1) and in the railway station (k = 2)

k Sub-category of parts of the railway network: 1 – track, 2 –station

t Reference period (years)

The evaluated period corresponds to the period from which the data from the data-base of occurrences were analysed. This is the period 2011-2018, i.e. 8 years.

The calculated annual costs for each relevant sub-category of extraordinary event per one thousand train-kilometres of wide line and one thousand train-kilometres of the railway station are presented in Tab. 3.

Table 3 Calculated annual cost of sub-categories of extraordinary events (CA 2018)

OC category	Number of OC per year and mil. tkm in station	Number of OC per year and mil. tkm of wide line	Unit impact of OC in €	Average annual impact per 1000 tkm in station in €	Average annual impact per 1000 tkm of wide line in €
A1	0.06581	0.0006657442	913,964	60.15	0.61
A2	0.07458	0.0007545101	847,877	63.24	0.64
A3	0.01316	0.0001331488	2,415,941	31.80	0.32
B1	0.21059	0.0021303813	130,822	27.55	0.28
B2	0.31589	0.0031955720	90,538	28.60	0.29
B3	0.24569	0.0024854449	78,651	19.32	0.20
C1	0.40363	0.0040832309	7,473	3.02	0.03
C2	3.36506	0.0340417183	5,446	18.33	0.19
C3	4.59350	0.0464689427	7,043	32.35	0.33
C6	3.19395	0.0323107835	3,370	10.76	0.11
C12	0.62300	0.0063023781	4,479	2.79	0.03
C19	2.60606	0.0263634689	9,388	24.47	0.25

The total calculated annual costs of extraordinary events were defined as the sum of partial sub-categories. The final values are shown in Tab. 4.

Table 4 Values of total costs of extraordinary events (CA 2018)

Part of the railway network	Value
Railway station	321,95 €/1000 tkm/year
Wide line	3,26 €/1000 tkm/year

The original approach to the calculation of costs developed and published by the author's team in the paper [3] assumed that the impacts of extraordinary events (railway network includes wide line and stations) will be related to the kilometer of broad line and one station, both broken down into the national and regional level. However, in the practical verification, this method proved to be very general and insufficient, as it did not consider the transport performance in the individual sections. However, the traffic performance in the addressed sections of the railway network has a significant impact on the total number of occurrences of all categories. For this reason, the original procedure was abandoned and replaced by the method based on expressing the impact of extraordinary event on a unit of transport performance (train-kilometre) presented above.

3 RESULTS

The subject of the paper is the suggestion of a methodological procedure for the determination of socio-economic impacts associated with increased user standards in the form of bigger reliability and safety of the railways due to the implementation of projects introducing appropriate safety equipment. When formulating the procedure, it was necessary to consider the availability of information on the addressed railway infrastructure and its history in relation to the number of occurrences and the expected impact of the planned measures on the frequency of occurrences after their implementation.
The author team developed two approaches to evaluate the solved benefits – detailed and simplified. Both approaches are shortly introduced in [33], detailed description of the simplified approach is in following chapters. This paper is oriented on the utilization of the average values described above within the simplified approach.

3.1 Utilization of the Unit Annual Costs of Partial Sub-categories of Extraordinary Events

If the categories of occurrences that shall be eliminated as a result of a project involving measures increasing railway safety and reliability are known, the Tab. 5 can be used. This table provides the average unit annual costs of subcategories of extraordinary events per one train kilometre (tkm) in the railway station or per one tkm on a wide line. It is assumed within the simplified approach that due to the implementation of the corresponding measures; the share of *k* occurrences of the corresponding category shall be eliminated. The savings associated with the elimination of a specific category of occurrence are determined separately according to the following relations.

Solutions within railway stations:

$$S_{aks} = N_s \times EAI_{ks} \times k \quad (2)$$

Where:
S_{aks} Annual savings when eliminating *k* category of extraordinary events at the railway station
N_s Number of tkm on railway stations per year in the assessed area
EAI_{ks} Expected annual impact of the *k* category of occurrences emerging at the station (see Tab. 3)
k Coefficient of decrease in the number of extraordinary events caused by implemented measures

Solutions within railway line sections (wide line):

$$S_{akl} = N_l \times EAI_{kl} \times k \quad (3)$$

Where:
S_{akl} Annual savings when eliminating *k* category of extraordinary events on the wide line
N_l Number of tkm on wide line per year in the assessed area
EAI_{kl} Expected annual impact of the *k* category of occurrences emerging on the wide line (see Tab. 3)
k Coefficient of decrease in the number of extraordinary events caused by project realization

The annual savings were calculated as the sum of annual savings for the specific sub-categories of extraordinary events and were consequently used as an economic cash-flow in the CBA processing.

3.2 Utilization of the Overall Costs of Extraordinary Events

In the absence of information on subcategories of occurrences that shall be eliminated as a result of the implementation of a project involving measures increasing railway line safety and reliability, the Table 6 can be used Table 6 presents the average annual costs of extraordinary events for all sub-categories together. Costs are related to one train kilometre in a railway station or to one train kilometre of a wide line as well. It is assumed within the simplified approach that due to the implementation of the corresponding measures; the share of *k* occurrences shall be eliminated. The savings associated with the elimination of occurrences were determined according to the following relation.

Solutions within railway stations:

$$S_{as} = N_s \times ETAI_s \times k \quad (4)$$

Where:
S_{as} Annual savings when eliminating extraordinary events arising at the railway station
N_s Number of tkm on railway stations per year in the assessed area
$ETAI_s$ Expected annual cost of extraordinary event at the station (see Tab. 4)
k Coefficient of decrease in the number of extraordinary events caused by project realization

Solutions within line sections (wide line):

$$S_{al} = N_l \times ETAI_l \times k \quad (5)$$

Where:
S_{al} Annual savings when eliminating extraordinary events arising on the wide line
N_l Number of tkm of wide line per a year in the assessed area
$ETAI_l$ Expected annual cost of extraordinary event on the wide line (see Tab. 4)
k Coefficient of decrease in the number of occurrences due to implemented measures

Calculated savings were consequently used as an economic cash-flow in the CBA processing. The coefficient of decrease in the number of occurrences due to the implemented measures *k* is assigned value 1. It is therefore assumed that the implementation of the addressed measures will prevent 100% of occurrences. The methodological procedure, which is based on the presented research and which is intended to support the economic analysis of projects in railway infrastructure, mentions the possibility of reduction of eliminated occurrences in the case that the given situation can be expected due to the project characteristics and the addressed transport network part. The percentage of possible reduction is left to the individual consideration of analysts familiar with the situation of the evaluated project.

The authors of this article, however, within their research activities, further focused on the average values of reducing the occurrence frequency due to the project implementation on the railway network. This reduction in frequency was determined based on a statistical comparison of a sample of projects on railways and including the implementation of measures aimed at increasing railway safety and reliability. The change in the number of occurrences in the corresponding section of the railway line caused by the realization of measures intended to improve reliability and safety on railways was monitored within the statistical comparison. The comparison in the article was carried out on a sample of 33 railway infrastructure projects for the situation prior to the measure implementation and after its implementation [4]. The coefficient *k* is equal to 10.77 % resulting from the detailed calculation stated in the cited article. The stated value was determined as an average value for all categories of occurrences. Looking at partial categories of extraordinary events, the following values of the coefficient *k* were calculated:

- Category A 27.23 %,
- Category B 37.77 %,
- Category C 9.82 %.

However, in the case studies presented below, the *k* coefficient was not used. The authors of the article are aware of the fact that on the one hand, this is more or less an indicative calculation showing the decrease of number of extraordinary events, but on the other hand, is not statistically conclusive. If necessary, in practice, a more detailed calculation which considers both the fact that the transport infrastructure project was implemented in the addressed section, which specific measures to increase safety and reliability were implemented and against which type of occurrences it was aimed at, can be designed and performed.

3.3 Case Study

The proposed methodological procedure was checked on a case study and the possibilities of the interpretation of the results resulting from the defined calculations were assessed. The proposed methodological procedure was verified on two projects of implementation of the measures increasing safety and reliability of the railway network. Verification was performed for a detailed approach as well as for both variants of the simplified approach.

The basic characteristics of the projects and the results of the calculations are given in the following part of the paper.

Project 1 Revitalization of the section of the national railway line No. 310A Opava East – Krnov – Olomouc

- Length of the section with an increase in the level of track interlocking equipment – station: 6.039 km,
- Length of the section with an increase in the level of the track interlocking equipment – wide line: 27.090 km,
- Number of freight trains per day: 2.79,
- Number of passenger trains per day: 38.6.

In the case of the station sections revitalization, it is assumed that due to new station interlocking equipment, occurrences of specific categories will be prevented. In the case of the revitalization of line sections, it is assumed that due to the new track interlocking equipment, occurrences of categories next selected categories will be prevented.

The expected annual savings associated with the improvement of user standards in terms of reliability and safety of the railway network were determined for the evaluated project using both versions of the simplified approach based on the input data and mathematical relations given in the outputs of this article.

The outputs are shown in Tab. 5.

Table 5. Annual positive impacts connected with improvement user standards in terms of reliability and safety - Project 1

Approach	Simplified	
Part of the network	According to categories	Overall impact
Stations (CZK/year)	523,090	705,863
Tracks (CZK/year)	21,086	32,032
Totally (CZK/year)	544,176	737,895

Project 2 Revitalization of the section of the national railway line No. 311 Bludov – Hanušovice

- Length of the section with an increase in the level of track interlocking equipment – station: 2.672 km,
- Length of the section with an increase in the level of track interlocking equipment – wide track: 18.748 km,
- Number of freight trains per day: 3.95,
- Number of passenger trains per day: 24.11.

In the case of the revitalization of station sections, it was assumed that due to new station interlocking equipment, occurrences of specific categories will be prevented. In the case of the revitalization of line sections, it is assumed that due to new track interlocking equipment, occurrences of next selected categories will be prevented.

The expected annual savings associated with the improvement of user standards in terms of reliability and safety of the railway network were determined for the evaluated project using both versions of the simplified approach based on the input data and mathematical relations given in the outputs of this article.

The outputs are shown in Tab. 6.

Table 6. Annual benefits associated with increasing railway safety and reliability - Project 2

Approach	Simplified	
Part of the network	According to categories	Overall impact
Stations (CZK/year)	156,906	211,731
Tracks (CZK/year)	9,893	15,029
Totally (CZK/year)	166,799	226,760

4 DISCUSSION

It is necessary to distinguish two points of view of the results of case studies within the discussion. The first view focuses on the differences in the results obtained by the individual defined approaches. A significant difference between the results obtained by de-tailed and simplified approaches was determined in both evaluated projects. However, the differences do not indicate the methodological shortcomings of the individual approaches, they clearly indicate the different principles on which the individual approach-es are based. The detailed approach uses the specific data about the evaluated section. It is therefore based on historical data on extraordinary events arising in the past. The approach builds on the assumption that similar occurrences with the same frequency as in previous years, may emerge in the future. On the contrary, both variants of the simplified approach are based on average annual values for the entire railway network broken down into a wide line and a railway station, both related to a unit of transport performance, i.e., train-kilometres. The detailed approach is therefore connected with the specific situation of a specific area of the railway network, while simplified approaches work with average values for the entire railway network. This information results in the recommendations regarding the use of individual approaches. The detailed approach is particularly suitable for those sections of the railway network which are specific to certain factors and whose characteristics indicate an increased incidence of occurrences of certain categories. On the contrary, the simplified approach can be effectively applied in the case of standard railway sections, which in the historical perspective do not deviate significantly from the average emergence of occurrences on the entire railway network. There are obvious reasons for the differences between the sub-variants of the simplified approach. When calculating according to categories, the methodological approach allows excluding those categories of occurrences which cannot be affected by the planned measures from the evaluation. The calculated benefits are thus reduced in accordance with the actual situation in the section. An approach using the overall impacts does not allow for this reduction, so it can be considered an easier way of evaluating bene-fits, however, at the same time, less accurate.

The second point of view is focused on the results of the calculation of benefits for individual evaluated projects. The benefits for Project 1 appear to be significantly higher than for Project 2. However, the reasons clearly lie in the scope of the projects, i.e., sections (line and station) that are subject to modernization, and transport performance annually carried out within the evaluated sections. With the growing scope of modernized sections and the growing number of trains passing through the modernized section every year, the number of potential occurrences that can be prevented by the implemented measures as well as realized benefits grow. It is also worth mentioning that in the case of Project 1, the benefits determined by the detailed approach are lower than the benefits determined by the simplified approach, and in Project 2 it is exactly vice versa. This difference highlights the recommendations provided in the previous section of the discussion.

The authors of the article believe that from the point of view of the international use of the proposed procedures, the general principles of determining unit benefits as well as the principles of the detailed and simplified approach can be used without problems even outside the Czech railway network. It can be recommended to adapt the input quantities to the values of the corresponding environment when using this calculation internationally.

5 CONCLUSIONS

The article is oriented on the infroduction of key resutls of a research activity oriented on evaluating of positive impacts related with increased user standards in terms of reliability and safety of railways due to the carrying out of modernization projects on the railway network. The paper builds on the previous research activities of the author team and presents the final version of partial methods for the evaluation of the impacts connected with reducing of extraordinary events. This is a detailed approach based on the use of historical data on occurrences emerging within the evaluated section and two variants of a simplified approach, which is based on average data for the entire railway network. In terms of input data, both approaches use a Database of Extraordinary events managed by the Administration of Railways and the Departmental Guidelines [11]. The presented approaches were consequently checked using two case studies focused on the modernization of the railway network, Finally, calculations and results were presented and discussed in this paper.

Both the detailed and simplified approaches are planned to be developed into individual methodological procedures to supplement the Departmental Guidelines [11] which shall subsequently serve to take into account the impacts connected with the increase of user standards in terms of reliability and safety of railways in the economic evaluation of railway infrastructure projects. For these purposes, the methodological procedure was examined by the representatives of the Railway Administration and, after incorporating the comments, it shall be handed over to the representatives of the State Fund for Transport Infrastructure, which is the implementation guarantor of the research project.

The addressed issue will be the subject of further research. The research team expects to continuously update the data in connection with new information that continuously appears in the Database of Occurrences. In addition, the research team expects to examine further possibilities of making the methodological procedure more detailed, i.e., considering the division of lines into national or regional, possible reassessment of average passenger train occupancy or average freight train occupancy or refinement of the *k* coefficient calculation.

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