Impact of the Railway Infrastructure Revitalization Projects on the Severity of Occurrences

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Abstract. Revitalization of railways represents a very important part of the railway infrastructure development. Railway infrastructure reconstruction and revitalization projects bring a number of positive impacts - benefits in addition to the negative impacts of temporary traffic restrictions or often relatively high investment costs. While benefits in terms of operating cost savings, reduced transport time or mitigation of negative environmental impacts are commonly included in the economic analysis evaluating the economic efficiency of the project, the benefits resulting from improving safety and reliability of the railway infrastructure, which are also associated with the modernization of the railway infrastructure, are currently not included in the economic analyses. The paper is focused on the presentation of a partial output of the research project, which deals with the evaluation of increasing railway infrastructure safety and reliability due to the implementation of railway infrastructure revitalization projects. The presented part of the research deals with the evaluation of the implementation impact of the railway revitalization project on the safety and reliability of railway operation and focuses on empirical verification of the basic assumption that the implementation of the railway revitalization project, including modernization of signalling systems, will reduce the incidence of occurrences in terms of their number and severity. Methodologically, the research is based on a comparison of the situation before and after the implementation of the railway infrastructure revitalization project. Specifically, the research focuses on the change in the incidence of occurrences and their economic impacts, including impacts on public health, operating costs, damage amount, as well as impacts on the traffic flow and potential delay, due to the implemented measures increasing the railway infrastructure safety and reliability which form a common part of the railway infrastructure revitalization projects. The results are expressed in monetary units and are drawn from and presented on the two pilot railway infrastructure revitalization projects.

1. Introduction
Implementation of investment projects in the field of transport infrastructure represents a significant interference both with public resources associated with the implementation itself and subsequent infrastructure operation. It represents almost always a very costly investment and operation activities which require a significant allocation of public national or multinational resources. In the case of transport projects, the efficiency of the public resources management is assessed using appropriate methodological documents, usually based on a cost-benefit analysis (CBA). In the case of transport infrastructure investment projects, the economic evaluation is primarily based on the Guide to Cost-Benefit Analysis issued by the European Commission in 2014 [1] and the Departmental Methodology published by the Ministry of Transport in 2017 [2]. In particular, the latter document addresses in detail...
the way of assessing the economic efficiency of the transport construction projects with a focus on the road, railway and significant water transport structures. The methodology includes partial procedures for defining and determining the inputs into the economic efficiency calculation, including the evaluation of socio-economic impacts, however, not all relevant impacts are addressed by the methodology. The paper focuses on the presentation of partial outputs of the research project focused on the evaluation of the benefits associated with the implementation of projects aimed at increasing the safety and reliability of the railway infrastructure. Specifically, the paper analyses the impact of the implementation of the project dealing with increasing railway infrastructure safety and reliability on the number and severity of occurrences in the subject location. An occurrence means an accident or incident associated with railway operations. The analysis is based on the comparison of the situation before and after the project implementation as well as on detailed statistical data on the Czech railway infrastructure.

2. Present state references
The paper focuses on the assessment of changes in the number and overall impact of occurrences on the railway infrastructure due to the implementation of measures to increase the safety and reliability of the railway transport. The general issue of economic impact assessment of public projects is methodically addressed by the Guide to Cost-Benefit Analysis issued by the European Commission in 2014 [1]. This Guide focuses on the general evaluation of all public investment projects; however, a separate section is also devoted to the issue of the economic evaluation of transport infrastructure projects. On the national level of the Czech Republic, the economic evaluation of transport (and thus also railway) infrastructure projects is methodically outlined by the Departmental Guideline of the Ministry of Transport of the Czech Republic [2]. This methodology deals in partial segments also with partial transport modes, i.e. also with the specifics of the evaluation of railway infrastructure projects. In addition to the aforementioned methodologies, the issue of risk within the railway infrastructure is also addressed by the material [3], which deals with the critical infrastructure resilience to risks. The causes of the risk are discussed in the material [4], which states that the so-called "human factor" including traffic violations by drivers ranks among the leading triggering factors of accidents. The paper assesses natural factors contributing to the accident occurrences. The issue of the errors that cause railway occurrences is described in detail in the material [5]. The risk factors to be identified and described in the risk management on railways are addressed by the paper [6]. The papers [7] and [8] discuss in more detail the influence of the human factor on the incidence of occurrences on the railway infrastructure. The paper [9] analyses a series of control checks for back analysis testing the accident occurrences and highlights the opportunity to perform quantitative risk analysis comparing alternative designs of railway systems by analogical analysis methods. A comprehensive approach to risk management of emergencies is the subject of paper [10], a proactive approach to rail traffic management to minimize occurrences is subsequently addressed in paper [11]. The experience of drivers in dealing with occurrences and the possibilities of minimizing their impacts are described in detail in the paper [12].

3. Methodology
The research carried out on the project “Evaluation of Increased Safety and Reliability of Railway Infrastructure after its Modernization or Reconstruction” examines the impact of the implementation of certain constructions on the number and severity of occurrences on the railway infrastructure as presented in this article.

The data on the transport infrastructure occurrences are taken from the occurrence statistics provided for this purpose by the railway infrastructure operator in the Czech Republic, Railway Infrastructure Manager, state organization. [13]

Comparison of statistical data was created on the basis of the national occurrence statistics from 2009–2018 period, each of which contains approximately one thousand occurrences per year, which are specified according to various criteria and supplemented by a description containing:
- Place and time of origin,
- Description of the occurrence,
- Cause of the occurrence,
- Material damage caused by the occurrence,
- Damage to life or health,
- Others.

The total amount of data reported for each occurrence varies from year to year, the more current the data is, the more descriptive it is. In 2018, the table describing occurrences contains over 100 columns describing an occurrence. Based on a detailed examination, the 2009–2010 statistics were excluded from the analysis due to incomplete information on occurrences. On the basis of statistics from 2011–2018, an average annual summary of occurrences was created, divided according to the cause of occurrence. The results of this framework analysis are shown in Table 1.

Since the statistics include also suicide-related occurrences and it is certain that the implementation of whatever possible measures will not limit them, these occurrences were excluded from the calculations. The statistics for an annual average of occurrences excluding suicide-related ones is listed below.

| Cause                  | Human factor | Technical | Others | Combination | Total   |
|------------------------|--------------|-----------|--------|-------------|---------|
| Number                 | 535          | 201       | 87     | 4           | 827     |
| Death                  | 40           | 1         | 1      | 0           | 41      |
| Severe injury          | 58           | 1         | 0      | 0           | 59      |
| Minor injury           | 109          | 4         | 4      | 0           | 117     |
| Material damage (€)    | 6,448,700    | 2,670,894 | 339,694| 45,281      | 9,504,569|
| Costs (€)              | 274,774      | 122,494   | 49,912 | 9,521       | 456,701 |

Part of the research presented in this article carries out the analysis of the impact of the project of the implementation of safety systems on a number of occurrences in a specific section of the railway infrastructure. For these purposes, two already implemented projects were chosen, by means of which the real impacts of construction implementation were assessed. The comparison was made specifically for two constructions carried out during the reference period:

- Revitalization of the Bludov – Jeseník railway track
- Revitalization of the Opava East - Olomouc main train station

As part of the analysis, the impacts of implementation of the measures leading to increased safety and reliability of the railway infrastructure on the number and severity of occurrences in the researched sections were demonstrated on the above-mentioned projects.

From the methodological point of view, the research determines the numbers and severity of occurrences in the period before and after the project implementation. It is possible to determine the impact of a particular project on the safety and reliability of the railway infrastructure in the researched area by comparing these results.

The severity of occurrences is determined using the results obtained in the previous part of the research and is based on the following characteristics:
• Impacts on health,
• Delay of passenger trains; and
• Delay of freight trains.

Incident impact on health is based on the average number of casualties (dead, injured) and the unit cost associated with death, serious or minor injuries. Unit costs associated with traffic accidents are taken from the Departmental Methodology of the Ministry of Transport and are described in more detail in Table 2.

**Table 2. The cost associated with traffic accidents**

| Traffic accident   | Unit cost €/person |
|--------------------|--------------------|
| With death         | 839,306            |
| With serious injury| 202,968            |
| With minor injury  | 26,202             |

Source: Departmental Methodology of the Ministry of Transport [2]

Determination of the impact associated with the delay of passenger trains is based on the average overall delay of passenger trains due to incident occurrence. The resulting average train occupancy for the entire railway network was set at 66.55 persons per train, the average value of the passengers' time can be estimated at € 11.33/person-hours.

Determination of the impacts associated with the delay of freight trains is based on the average overall delay of freight trains due to the incident occurrence. The resulting average train freight weight for the whole rail network in relation to this data was set at 455 tonnes/train. The average value of freight transport time value was set at € 0.246/tonne-hour.

4. Results and discussions

As mentioned in the methodological part, the comparison of the number and severity of occurrences before and after the implementation of the project aimed at increasing safety and reliability of the railway infrastructure was carried out for two constructions implemented during the monitored period:

• Revitalization of the Bludov – Jeseník track (in the Krnov – Cvilín track section);
• Revitalization of the Opava East - Olomouc main train station (in the Bludov – Hanušovice track section)

Relevant information on those sections of the railway infrastructure for which the researched projects were carried out was taken from the occurrence database [13]. Information on the analysed tracks is given in the following tables. Table 3 presents the data relevant to the Bludov – Jeseník revitalization project.
Table 3. Summary of occurrences in the Krnov – Cvilín track section

| Year | Total number of occurrences | Costs (€) | Deaths | Injuries | Passenger train delay (min.) | Freight train delay (min.) |
|------|-----------------------------|-----------|--------|----------|-----------------------------|---------------------------|
| 2011 | 5                           | 27,554    | 2      | 3        | N/A                         | N/A                       |
| 2012 | 5                           | 43,145    | 0      | 1        | 603                         | 0                         |
| 2013 | 3                           | 222,374   | 0      | 6        | 1,219                       | 0                         |
| 2014 | 3                           | 5,023     | 0      | 0        | 201                         | 0                         |
| 2015 | 3                           | 33,463    | 0      | 2        | 690                         | 0                         |
| 2016 | 4                           | 27,727    | 1      | 3        | 762                         | 0                         |
| 2017 | 4                           | 1,404     | 1      | 0        | 237                         | 0                         |
| 2018 | 1                           | 265       | 0      | 0        | 203                         | 0                         |
| Total| 28                          | 360,955   | 4      | 15       | 3,915                       | 0                         |
| Total without crossings| 16                          | 15,311    | 2      | 27       | 1,311                       | 0                         |
| Before construction implementation | 10                          | 12,691    | 2      | 1        | 569                         | 0                         |
| After construction implementation | 1                           | 265       | 0      | 0        | 203                         | 0                         |
| Annually before implementation | 2.0                          | 2,537     | 0.4    | 0.2      | 142.3                       | 0.0                       |
| Annually after implementation | 0.7                          | 177       | 0.0    | 0.0      | 135.3                       | 0.0                       |

Table 4 presents the data relevant to the Opava East – Olomouc main train station revitalization project.

Table 2. Summary of occurrences in the Bludov – Hanušovice track section

| Year | Total number of occurrences | Costs (€) | Deaths | Injuries | Passenger train delay (min.) | Freight train delay (min.) |
|------|-----------------------------|-----------|--------|----------|-----------------------------|---------------------------|
| 2011 | 4                           | 21,422    | 0      | 0        | N/A                         | N/A                       |
| 2012 | 3                           | 301,305   | 0      | 3        | 1,008                       | 0                         |
| 2013 | 3                           | 24,884    | 0      | 0        | 560                         | 0                         |
| 2014 | 2                           | 1,442     | 0      | 0        | 182                         | 0                         |
| 2015 | 1                           | 7,763     | 0      | 0        | 93                          | 0                         |
| 2016 | 1                           | 53,140    | 0      | 0        | 12                          | 0                         |
| 2017 | 0                           | 0         | 0      | 0        | 0                           | 0                         |
| 2018 | 1                           | 6,860     | 0      | 0        | 352                         | 0                         |
| Total| 15                          | 416,819   | 0      | 3        | 2,114                       | 93                        |
| Total without crossings| 11                          | 92,141    | 0      | 0        | 1,549                       | 0                         |
| Before construction implementation | 9                           | 32,141    | 0      | 0        | 1,549                       | 0                         |
| After construction implementation | 1                           | 6,860     | 0      | 0        | 0                           | 0                         |
| Annually before implementation | 2.0                          | 7,142     | 0.0    | 0.0      | 442.6                       | 0.0                       |
| Annually after implementation | 0.7                          | 4,573     | 0.0    | 0.0      | 0.0                         | 0.0                       |

Tables 3 and 4 show the impact of implemented measures for increasing safety and reliability of the railway infrastructure on the number and severity of occurrences. In the analysis, the severity of
occurrences is expressed using material damage (costs), health and life impacts and delay in passenger and freight transport. The key differences are particularly evident in the last two rows of each of the tables, where the average annual impact of occurrences before and after the measure implementation is expressed. For the sake of completeness, it should be emphasized that when comparing the impact of occurrences before and after the project implementation, the suicide-related occurrences (including suicide attempts), occurrences at railway crossings and occurrences incurred during the project implementation were not taken into account.

Using the unit impacts of occurrences specified in the methodological part, the overall benefits of the implemented measures were determined. Impact evaluation is presented in Tables 5 and 6.

**Table 5. Evaluation of the impacts associated with the Krnov – Cvilín track section implementation**

| Impact                        | Total number of occurrences | Costs (€) | Deaths | Injuries | Passenger train delay (min.) | Freight train delay (min.) |
|-------------------------------|----------------------------|-----------|--------|----------|------------------------------|----------------------------|
| Annually before implementation| 2.0                        | 2,537     | 0.4    | 0.2      | 142.3                        | 0.0                        |
| Annually after implementation | 0.7                        | 177       | 0.0    | 0.0      | 135.3                        | 0.0                        |
| Difference                    | 1.3                        | 2,360     | 0.4    | 0.2      | 7                             | 0                          |

The overall impact of the project on the number and severity of occurrences after the evaluation carried out using the unit data specified in the methodological part of the paper, was set at € 378,764.92 annually for the Bludov – Jesenik track revitalization project in the Krnov - Cvilín track section.

**Table 6 Evaluation of the impacts associated with the Bludov – Hanušovice track section implementation**

| Impact                        | Total number of occurrences | Costs (€) | Deaths | Injuries | Passenger train delay (min.) | Freight train delay (min.) |
|-------------------------------|----------------------------|-----------|--------|----------|------------------------------|----------------------------|
| Annually before implementation| 2.0                        | 7,142     | 0.0    | 0.0      | 442.6                        | 0.0                        |
| Annually after implementation | 0.7                        | 4,573     | 0.0    | 0.0      | 0.0                          | 0.0                        |
| Difference                    | 1.3                        | 2,569     | 0      | 0        | 442.6                        | 0                          |

The overall impact of the project on the number and severity of occurrences after the evaluation carried out using the unit data specified in the methodological part of the paper was set at € 8,131.08 annually for the Opava East – Olomouc main train station track revitalization project in the Bludov – Hanušovice track section.

It results from the analysed data after the implementation of both monitored projects, that there was a decrease in the number of occurrences and thus in the costs related to their incidence. At the same time, a significant decrease in traffic restrictions caused by the occurrence incidence appeared in the Bludov – Jesenik track revitalization project. However, it should be noted for both monitored constructions that the statistical sample of occurrences will be extended in the next phase of the research by data from 2019 and subsequently from 2020 for the additional verification of the analysis outputs.

**5. Conclusions**

The paper was created in order to present a partial output of a research project focused on the evaluation of increased safety and reliability of the railway infrastructure due to the implementation of railway signalling system projects. Following the outcomes of the previous research, a comparison of the number and severity of the incidents occurring on the railway infrastructure before and after the project
implementation was made, which also included a part aimed at increasing the safety level. The comparison was carried out for two specific projects, which were implemented during the 2011–2018 monitoring period, specifically of the Bludov – Jeseník track revitalization project (in the Krnov – Čvílin track section) and the Opava East – Olomouc main train station track revitalization project (in the Bludov – Hanušovice track section). The information on the number and severity of occurrences was taken from the occurrence database carried out for the 2011–2018 period. After excluding the information of the occurrences at railway crossings and suicide-related ones from the database (these occurrences were not taken into account throughout the research), evaluation of relevant incidence of occurrences before and after the project implementation and subsequently the changes in the number and severity of occurrences caused by the project implementation were derived. For both projects, a positive change was achieved; more significant benefits were derived for the first project, when the annual savings were set at € 378,764.92. For the second project, the annual savings were set at € 8,131.08. The difference in the impact of individual projects is mainly due to the reduction in health damage, which does not occur in the second project. Subsequent research will focus on updating the database of occurrences by the 2019 period and the subsequent extension of the analysis at other projects implemented on the railway infrastructure in the period under research.

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