The sensitivity of the economic efficiency of the modernization of railway crossings on the traffic moment

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Abstract. The paper brings partial results of the research project focused on the evaluation of the financial and economic efficiency of investment projects in the area of railway constructions. The general methodology of the evaluation of the financial and economic efficiency and risks of the public investment projects is in detail solved in the Guide to Cost-Benefit Analysis of the Investment Projects issued by the European Commission in 2014. The evaluation of projects in the transport infrastructure in conditions of the Czech Republic comes out from the mentioned Guide and in detail is solved in the Departmental Guidelines issued by the Ministry of Transport of the Czech Republic in 2017. These Departmental Guidelines deal with the evaluation of the key benefits connected with the transport infrastructure. The presented project deals with the detailed evaluation of benefits connected with the increase of the safety and reliability of the railway, which is not included in the Departmental Guidelines. The subject of the paper is to present the results of the research focused on the evaluation of socioeconomic impacts connected with the generation of occurrences on the railway crossings. The objective of the research is the calculation of the marginal values of the traffic model of the railway crossing, where it is possible to expect that the increase of its safety will be efficient from the economic point of view. The key output of the paper is the quantification of impacts of the projects increasing the level of safety of the railway crossings. These impacts include investment costs, costs for the maintenance and repairs and benefits from the increase of the safety on railway crossings. Benefits of projects increasing the safety of railway crossings are represented mainly by the decrease of the number of victims, injuries and material losses appeared following the occurrence on the railway crossing. Results are consequently related to the traffic moment of the railway crossing and there is assessed the value of “costs of the safety” of the railway crossing. Results of the research are presented on the case study of the variant solution of the security of the railway crossing. At the end of the paper, there are described the basic conclusions of the research and the minimal values of the traffic moment of the railway crossing for the assurance of the efficiency of invested resources, separately for regional and state railways are discussed there.

1. Introduction
The subject of the paper is to present the results of the research in the actualization of the socio-economic costs connected with occurrences on the railway crossings and the calculation of expected marginal values of the traffic moment of the railway crossing, when it is possible to expect that the increase of its safety would be efficient from the economic point of view. Increasing of the safety of the railway crossing with the installation of the crossing light signaling equipment is the investment activity, which is the subject of the decision of the approval processes of the state, which is represented by the Railway Infrastructure Administration. The declaration of the economic efficiency of these actions is very important from the aspect of the enforcement and approval of the project.
2. Literature review

The evaluation of the efficiency of the economic activity is an important element for the assessment of its meaningfulness. In the frame of the private sector is this assessment focused mainly on the performance and the maximisation of the added value of the general company [1], the construction company [2] and also the construction company oriented on the realization of construction orders within the transport infrastructure [3]. Within the public sector is the efficiency perceived as financial and economic. The financial efficiency is focused on the evaluation of the efficiency using the financial cash-flow analysis, which is connected with the project. Within the economic efficiency, they evaluate the complex economic impacts on the society, including the impacts, which are not primarily expressed in the financial units. From the methodical point of view is the evaluation of public projects defined e.g. in the „Guide to Cost-Benefit Analysis of Investment Projects“ [4]. This methodology inspires the national methodology for the evaluation of projects in the transport infrastructure called “Departmental Methodology” [5]. The paper is focused on the issue of the economic efficiency of projects of the railway infrastructure, mainly the railway crossings. The general issue of the evaluation of the efficiency on railways is solved e.g. in [6], [7] and [8], the groundwork [9] is consequently focused on benefits connected with the informatization of the railway transport. The behaviour of drivers on railway crossings is in detail solved in [10] and [11], the management of the railway crossings is consequently considered in [12]. The groundwork [13] solves in detail the issue of the management and the control of railway crossings, for which the elements of the utility theory are used. The issue of accidents between cars and trains on railway crossings is solved in the groundwork [14], the decision making process for the realization of automatized systems of the management of railway crossings using the Fuzzy Logic Control is presented in the groundwork [15]. The safety on railway crossings in conditions of the Czech Republic is in detail solved in [16]. The drivers’ behaviour at level crossings is analysed in [17].

3. Methodology

The economic evaluation is the document evaluating the efficiency of constructions and it is the necessary groundwork for the decision making of the investor. In the area of the transport infrastructure, the economic evaluation is usually carried out in the form of the Cost-Benefit Analysis – CBA. The CBA is described in the document issued by the European Commission in 2014 called “Guide to Cost-Benefit Analysis of Investment Projects” [4].

The Cost-Benefit Analysis is the analytical tool for the evaluation of economic advantages or disadvantages of investment decisions based on the evaluation of their costs and benefits aiming to assess their benefit to the change of the level of the welfare. The CBA approach for the evaluation of various projects, mainly projects financed from public resources, is used. The reason is its variability and the ability to include the wide range of socio-economic benefits/costs connected with investments in the analysis. The CBA approach analyses difference, which arises due to the realisation of the project or particular variants of the project comparing to the state without project. From this reason, the correct definition of evaluated scenarios, the state with the project and the state without the project, is an important part of the economic evaluation. The CBA evaluates the project in the long-time horizon, in the case of railways is the evaluation period 30 years and includes the investment phase and the operation phase. The CBA allows the evaluation of the influence of the project on the society as a whole through the calculation of the appropriate indicators and with the help of indicators it allows the assessment of the expected change of the level of the welfare. From the methodical point of view is the economic evaluation based on the Departmental Guidelines [5]. The Ministry of Transport of the Czech Republic approved the Departmental Guidelines on 31st October 2017. Fifteen days later The Ministry of Transport of the Czech Republic issued the Implementing Guidelines. Implementing Guidelines defines the uniform procedure of investors in the evaluation of the economic efficiency of projects financed from public resources as follows.

- Constructions of traffic significant waterways,
• Road and highway structures
• Railways,
• Multimodal transport,
• Urban rail transport,
• Intelligent transport systems.

The General Guideline for Simplified MCA for the Economic Appraisal of Level Crossing) [15] create the Appendix 2 of the Departmental Guidelines and involves the alternative approach to the evaluation of railways. This alternative approach is used in cases, when the standard method of the economic efficiency evaluation does not have sufficient explanatory power.

This methodology it is possible to use for the evaluation of the increase of the safety level of railway crossings, reconstructions of railway crossings, or their repairs or removing in the case, when the standard methodology of the economic evaluation of the project on the railway gives the Benefit-Cost Ratio (BCR) in the interval B/C = (0,5; 1). It means that the projects are under the level of the economic efficiency, however not significantly. Then it is recommended the additional evaluation of non-monetized effects of proposed operations on the railway crossing or the set of railway crossings.

In the case, when the value B/C ≥ 1, the project is efficient from the economic point of view and it is not necessary to do any other alternative evaluation. In the case, when the value B/C ≤ 1, the project is inefficient from the economic point of view and it is not possible to recommend these projects to finance. In the case of reconstructions of the security equipment of railway crossings on tracks with the regular operation, it is possible (according to the directive of the Ministry of Transport of the Czech Republic n. V-2/2012) to vindicate the need of this kind of projects with the text description.

4. Railway crossings
On the Czech railway, there are 7,543 railway crossings, 3,560 of them are secured only with a warning cross; the rest is secured with the safety equipment of the railway crossing. The choice of the corresponding level of the security of the railway crossing from the aspect of the economic efficiency depends on the traffic moment of the railway crossing, which defines its traffic workload. The traffic moment is the function of the number of cars crossing the railway and the number of trains passing the railway crossing.

5. Traffic moment of the railway crossing
The traffic intensity on the railway crossing is expressed with the traffic moment of the railway crossing. The traffic moment is calculated as a multiplication of the road traffic intensity multiplied by ten hours and the average intensity of the operation on the railway per 24 hours. Simply it is possible to state that the higher the traffic moment of the railway crossing is, the bigger is the risk of the collision between the train and the car. The form of the security of the railway crossing significantly influences the risk of this accident. The railway crossing can be secured by warning crosses, the light security equipment with barriers, or without barriers, or the mechanical security equipment.

6. Results and discussion
The research is carried out using the case study focused on the economic analysis of the realization of the investment project aiming to the increase of the safety of the railway crossing. The economic analysis takes into account also the socio-economic impacts. The discount rate used for the calculation of economic indicators is 5 %. In the case study, there are considered the following items:

• Investment costs,
• Costs for maintenance and repairs of the infrastructure,
• Benefits from the increase of the safety,
• Other benefits.

The first step of the economic analysis consists of fiscal corrections. Fiscal corrections are corrections of capital costs into economic costs. Corrections should remove mainly the influence of price distortions caused by market and indirect taxes. Fiscal corrections are connected with investment costs and costs for maintenance and repairs of the infrastructure. Fiscal corrections are done with the multiplying of mentioned cash-flows with fiscal correctors, which are defined in the Departmental Guidelines.

Investment costs are assessed according to the „Proceedings for the evaluation of railways on the level of the feasibility study and project intention“, (issued by the Ministry of Transport in 2018). Average investment costs for the reconstruction of the railway crossing are approximately 10 mil. CZK. The calculation of the average investment costs is displayed in table 1.

Table 1. Average investment costs for the reconstruction of the railway crossing

| Description                                      | 1,000 CZK |
|--------------------------------------------------|------------|
| Project documentation                            | 761.53     |
| Acquisition of lands                             | 0          |
| Constructions                                    | 8,016.14   |
| Machines and equipment                           | 0          |
| Technical assistance and promotion               | 80.16      |
| Technical supervision                            | 360.73     |
| **Total investment costs without reserve in fixed prices** | **9,218.56** |
| Reserve                                          | 801.61     |
| **Total investment costs without reserve in fixed prices** | **10,020.18** |
| VAT (21%)                                        | 2,004.04   |
| **Totally incl. VAT**                            | **12,024.21** |

The residual value of the investment is assessed according to the object composition of the project and the lifetime of partial construction objects as a weight average of lifetimes of particular objects. Weights are investment costs connected with the carrying out of particular objects. The object composition of the reconstruction of the railway crossing is described in table 2 and its dominant part are costs for the security equipment of the railway crossing.
Table 2. Object composition of the reconstruction

| Object structure       | Lifetime | 1,000 CZK |
|------------------------|----------|-----------|
| Security equipment     | 20       | 5,534     |
| Power lines and equipment | 20   | 600       |
| Railway superstructure | 30       | 1,557     |
| Railway bottom         | 60       | 324       |
| Total lifetime of the investment | 24   |           |
| Lifetime of the investment after evaluating period | 0     |           |

From the average lifetime of the project of the modernization of the railway crossing, which is lower, then 29 years long operation phase, is evident that the residual value at the end of the evaluated period is zero.

Costs for maintenance and repairs of the infrastructure are considered as an increase in these costs compared with the variant without the project. Costs for the maintenance after the installation of the light crossing security equipment (LCSE) will increase by the costs connected with the maintenance and the operation of the LCSE for 37,000 CZK per year (25,000 CZK for maintenance, 12,000 CZK for operation). Following the recommendations of the Departmental Guidelines, it will be necessary to expect costs for maintenance and repairs, eventually re-investments, during the complete evaluated period.

Total costs for the maintenance, repairs and re-investment of LCSE will be 9.4 mil. CZK in the case of the railway crossing on the nationwide track and 3.0 mil. CZK in the case of the railway crossing on the regional track. The difference is caused by expected shorter lifecycle LCSE on the nationwide track compared with the regional track. In the case of the regional track, the re-investment is expected after the end of the evaluation period.

The economic benefit from the increase of the safety of the transport is calculated according to the actualized values of socio-economic costs of occurrences on railway crossings and probabilities of their appearance depending on the type of the track and the size of the traffic moment. The benefit from the increase of the safety is expressed based on the increase of the level of the security of railway crossings.

In the variant without project the railway crossing is equipped by warning crosses, in the project variant, it is considered the installation of the light crossing security equipment, including barriers and positive signalization.

In the next part of the paper, there are calculated benefits from the increased safety on the railway crossing with the traffic moment 6,000 (30 trains x 200 cars) for the railway crossing on the nationwide track and regional track. Calculated benefits are in the price level of the year 2019 using average values of traffic moments on railway crossings and average costs for fatalities, injuries and material damages according to the kind of the railway crossing. Values used for the calculation are defined in following tables and were calculated with the use of groundwork provided by the Rail Inspection and partly from the document “Assessment of benefits from the increase of the security of railway crossings”.

Annual monetized costs for fatalities, injuries and material damages in years 2009 – 2012 were taken from the material “Assessment of benefits from the increase of the security of railway crossings”. The values were actualized according to the actually valid economic costs for fatalities and injuries defined in the Departmental Guidelines and are displayed in table 3.
Table 3. Socio-economic costs for fatalities and injuries

| Impact          | CZK / person |
|-----------------|--------------|
| Fatality        | 21,804,128   |
| Serious injury  | 5,279,137    |
| Light injury    | 681,497      |

Source: own elaboration according [5]

Information for the period 2009 – 2017 was calculated based on the statistics of occurrences on railway crossings provided for this reason by the Rail Inspection, table 4.

Table 4. Summary statistics of occurrences on railway crossings for the period 2009 - 2017 (average values per year)

| Period 2009 - 2017 | Number of occurrences | Costs for occurrences in CZK |
|--------------------|-----------------------|------------------------------|
|                    | Nationwide | Regional | Nationwide | Regional |
| Occurrence          |            |          |            |          |
| with fatalities     | 14.3       | 4.8      | 346,443,365| 106,597,959|
| with light injuries | 25.6       | 30.1     | 19,309,081 | 25,291,110 |
| with serious injuries | 14.1     | 8.7      | 84,466,192 | 49,271,945 |
| material damages    | 62,786,462 | 25,152,277 | 62,786,462 | 25,152,277 |

The data include only collisions of trains with cars and cyclists and can be classified according to the character of the security of the railway crossing. By the calculation of total economic costs, it is possible to assess average socio-economic costs for one railway crossing, as described in table 5.

Table 5. Annual monetized costs for fatalities injuries and material damages on railway crossings

| Character of security of the railway crossing | Economic losses (CZK/crossing) | Material damages (CZK/crossing) |
|---------------------------------------------|-------------------------------|-------------------------------|
|                                             | Nationwide | Regional | Nationwide | Regional |
| Security with warning crosses               | 150,815     | 33,780   | 8,249      | 3,663     |
| Security with LCSE with barriers             | 81,621     | 569      | 40,785     | 304       |
| Security with LCSE without barriers          | 249,746     | 80,691   | 21,619     | 13,933    |
| Security with MCSE                           | 13,454      | 0        | 2          | 0         |

LCSE is Light Crossing Security Equipment and MCSE is Mechanical Crossing Security Equipment.

Except for the calculation of the benefit from the increase of the safety, it is possible from data to derive the average value of “costs of the safety“ of the railway crossing regarding the average values of the traffic moment according to the security of the railway crossing. Table 6 shows average traffic moments on various types of the railway crossings.

Table 6. Average traffic moments on various types of railway crossing

| Character of the security of the railway crossing | Crossing on track |
|--------------------------------------------------|-------------------|
|                                                    | Nationwide | Regional |
| Security with warning crosses                      | 847        | 1,346    |
| Security with LCSE with barriers                   | 31,155     | 21,855   |
| Security with MCSE                                 | 3,319      | 2,814    |
With the combination of data from Table 5 and Table 6, it is consequently possible to assess the average value of “costs of safety” of the railway crossing considering average values of the traffic moment, as shown in Table 6.

Table 7. The rate of the average costs and the traffic moment of the railway crossing

| Character of the security of the railway crossing | Economic losses |
|-------------------------------------------------|-----------------|
| Nationwide                                      | Nationwide      |
| Security with warning crosses                   | 178,10          |
| Security with LCSE with barriers                | 2,62            |
| Security with LCSE without barriers             | 8,02            |
| Security with MCSE                              | 4,05            |

Values presented in Table 7 declare that LCSE with barriers and MCSE are the safest possibilities of the railway crossings security and the worse variant is the security with warning crosses.

The calculation of the increase of the safety in the personal transport for a regional and nationwide track is presented in Table 8.

Table 8. The calculation of the increase of the safety in personal transport per railway crossing

| Crossing on | Traffic moment | Traffic moment average | Average costs (CZK) | Costs per crossing (CZK) | Costs saving (CZK) |
|-------------|----------------|------------------------|---------------------|-------------------------|------------------|
|             | real           | VWP                    | PV                  | VWP                     | PV               |
| reg. tacks  | 6,000          | 1,346                  | 21,855              | 37,443                  | 872              |
| nat. tracks| 6,000          | 847                    | 31,155              | 159,065                 | 122,406          |

As evident from the results of the evaluation of the increased safety of railway crossing, the big role in this benefit is played by the location of the railway crossing, especially, whether it is situated on nationwide track or regional track. The benefit for the same railway crossing equipped at present with warning crosses or after the reconstruction with LCSE with barriers is 6.6 times bigger at the railway crossing on the nationwide track than on regional track.

Other benefits are represented by time savings and savings of fuelling in automobile traffic. These benefits are the same for regional and nationwide tracks. Benefits from time savings follow the fact that on railway crossing equipped by the positive signalization the speed limit is 50 km/h. The modernization of the railway crossing security equipment does not bring only the time saving of users of roads, but also the savings in the fuel consumption during braking and restarting. The fuel saving is also connected with the decrease in emissions – the external costs of transport. The total benefit of these benefits is for the whole evaluated period 692,000 CZK.

Using mentioned input variables, the calculation of the economic efficiency of the projects of the increase of the safety of the railway crossing was carried out. The economic analysis was carried out separately for projects on regional tracks and separately for same projects on the nationwide tracks, Table 9.
Table 9. Results of the economic analysis

| Track      | NPV 1,000 CZK | IRR % | BCR  |
|------------|---------------|-------|------|
| Regional   | -4,990        | -2.76 | 0.324|
| Nationwide | 11,069        | 16.09 | 2.499|

Both economic analyses were used in the sensitivity analysis. Inputs stayed the same, the only inputs to change are the number of trains and the number of cars crossing the railway crossing. Within the sensitivity analysis it was evaluated, how much the change of the traffic moment influences the economic efficiency of the project. The sensitivity was evaluated separately for both parts of the traffic moment, the number of trains and the number of cars on railway crossing.

As the project suitable for the realization can be considered the project, which Benefit-Cost Ratio reaches at least 0.5, however, in this case, it is necessary to carry out the multi-criterial analysis, as mentioned in chapter 2.

Within the sensitivity analysis it was found out that in the case of railway crossings on regional tracks, the condition of reaching the minimal value of BCR is satisfied by the railway crossings with the traffic moment 8,000. In the case of the railway crossings on the nationwide tracks, the condition of the reaching of the minimal value of BCR is satisfied by the railway crossings with the traffic moment 1,900.

7. Conclusions
The security of the railway crossings is still a very important topic in the area of the safety of transport, so the conclusions of the research presented in the paper, it is possible to use them as a tentative groundwork in the selection of railway crossings suitable for the modernization of the railway crossing security system. Concurrently, it is necessary to take into account that the presented calculations come out from the typical project of the railway crossing security system, so the real values of the economic efficiency of the specific projects can be different from the values presented in the paper, mainly in the case of projects requiring non-standard technical (more expensive) solutions. From the results of the research, it is possible to derive the significant difference in the efficiency of the realized solutions leading to the increase of the safety of railway crossings. Whereas in the case of the nationwide tracks, the projects look like very efficient, in the case of regional tracks, despite the demonstrably important increasing of the safety, projects are not efficient.

8. Acknowledgement(s)
This paper has been worked out under the project of the Technology Agency of the Czech Republic “TL02000278 Evaluation of the increased safety and reliability of railway infrastructure after its modernization or reconstruction”.

9. References
[1] E. Vítková and T. Semenova, “The Impact of Key Parameters Change on Economic Development of the Company,” Procedia Computer Science, no. 64, pp: 744-749, 2015, ISSN: 1877-0509.
[2] E. Vítková, J. Chovancová and D. Veselý, “Value Driver and Its Impact on Operational Profit in Construction Company,” Procedia Computer Science, Volume 121, pp: 364-369, 2017, ISSN 1877-0509.
[3] T. Semenova, E. Ondrušková and E.Vítková, “Benchmarking of Companies dealing with Transport Infrastructure in Terms of heir Performance,” In ICTTE Belgrade 2016 - Proceedings of the Third International Conference on Traffic and Transport Engineering. Belgrade, Serbia: City Net Scientific Research Center Ltd. Belgrade, pp: 839-844, 2016.
ISBN: 978-86-916153-3-8.

[4] D. Sartori, “Guide to Cost-benefit Analysis of Investment Projects,” Economic appraisal tool for Cohesion Policy 2014-2020, European Commission, Directorate-General for Regional and Urban policy, 2014, ISBN 978-92-79-34796-2.

[5] Ministry of Transport of the Czech Republic (MOT CR), “Departmental Guideline for the Evaluation of Economic Effectiveness of Transport Construction Projects”, 2017.

[6] B. Flybjerg, “Megaprojects and Risk, an Anathomy of Ambition,” Cambridge University Press, 2013, ISBN 978-0-521-00946-1.

[7] B. Farkas, “The Introduction of the Most Powerful Railway of the EU, and its Support with Economic Analyses,” Science and Transport Progress, Bulletin of Dnipropetrovsk National University of Railway Transport, 2(68), 2017, ISSN 2307-3489.

[8] Wang Jianjun, “The Research on Efficiency and Effectiveness of Rail Transport,” IERI Procedia, Volume 3, Pages 126-130, 2012, ISSN 2212-6678.

[9] Yangfan Zhou, Shaokuan Chen, Wei Wei, Yiyi Zhong, “Economic Benefits of Railway Informatization and Its Quantitative Analysis,” Procedia - Social and Behavioral Sciences, Volume 43, pp: 119-124, 2012, ISSN 1877-0428.

[10] S. Kasalica, R. Vukadinović and V. Lučanin, “Study of Drivers’ Behaviour at a Passive Railway Crossing,” Promet (Zagreb), University of Zagreb, Faculty of Transport and Traffic Sciences, 24(3), pp: 193-201, 2012.

[11] Wei, Zilong “Method for evaluating the performance of railway crossing rails after long-term service,” Tribology International, Elsevier, pp: 337-348, 2018.

[12] L. Abramova, “Dynamic Traffic Management at a Railway Crossing,” Avtomobil'nyj Transport (Har'kov), Kharkiv National Automobile and Highway University, 38, pp: 34-38, ISSN 2219-8342, 2016.

[13] L. S. Abramova and S. V. Kapinus, “Traffic control on a railway crossing with elements of utility theory,” Visnik Žitomir's'kogo Deržavnogo Tehnolõgičnogo Universitetu: Tehnični Nauki, Zhytomyr State Technological University, 2(77), pp: 13-17, 2016.

[14] B. Ho, “License plate extraction method for identification of vehicle violations at a railway level crossing,” International Journal of Automotive Technology, Heidelberg: The Korean Society of Automotive Engineers, 12(2), pp: 281-289, 2011, ISSN 1229-9138.

[15] L. Pattanaik, “Decision Support Model for Automated Railway Level Crossing System Using Fuzzy Logic Control,” Procedia Computer Science, Elsevier B.V, 48, pp: 73-76, 2015.

[16] M. Kobosil and J. Novák, “Level Crossing Safety in the Czech Republic,” Acta Polytechnica CTU Proceedings, CTU Central Library, 11, pp: 35-38, 2017.

[17] L. Tey, “Microsimulation modelling of driver behaviour towards alternative warning devices at railway level crossings,” Accident Analysis and Prevention, Elsevier, 71, pp: 177-182, 2014.