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Impacts of Determining Economic Life of Large-Scale Infrastructure Projects on Their Economic Effectiveness

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The paper deals with the refinement of the Cost-Benefit Analysis methodological procedure for the assessment of the economic effectiveness of large-scale transport infrastructure projects. The basic input is economic Cash Flow which consists of investment costs, operating income, operating expenses, societal benefits, and harms as well as the investment residual value. According to the methodological guidelines, the currently evaluated project period is considered to be 30 years including the investment phase starting in the first year of the construction, the relevant part of the operational phase, and the residual value of the project in the last year of the assessed period. The evaluation of the economic effectiveness of projects is largely influenced by the determination of the construction economic life. A procedure for calculating the residual value of the project while respecting the gradual implementation of partial constructions was established as part of the research. A case study based on the research sample of several investment construction projects of the highway sections in the Czech Republic demonstrates how this methodological procedure affects the economic effectiveness of the project.

Keywords: cost-benefit analysis, transport infrastructure, decision-making process, economic efficiency, residual value

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INTRODUCTION

The assessment of the economic effectiveness of transport infrastructure projects is carried out based on the Cost-Benefit Analysis (CBA) which is described in the Guide to CBA of Investment Projects (Sartori, 2014). The economic Cash Flow (CF) of transport infrastructure projects is simulated and modelled according to the relevant calculation formula, which includes economic investment and operating costs, revenues, societal benefits, and the residual value of the project at the end of the evaluated period. Regarding the fact that most of the acquired fixed assets have longer economic life than the length of the assessed project period (in the case of transport infrastructure 30 years), it is the residual value of these assets that plays a significant role in assessing the project economic effectiveness.

The aim of the research is assessment how the methodical procedure of the residual value calculation as well as the setting of individual input variables affects the amount of the residual value and thus the overall project economic effectiveness. The authors firstly present the basic calculation formulae for determining the residual value, secondly they define the input variables and the importance of applying their values at the time of the project. The impacts of the changes in the calculation of the residual value on the assessment of the economic effectiveness of the project are demonstrated in four project case studies and the recommendations are proposed.

SCIENTIFIC LITERATURE REVIEW

Assessing the socio-economic effectiveness of public investment projects is one of the key steps in the decision-making process of providing funding for their implementation. The demands on the economic effectiveness of transport infrastructure projects are high and justified due to the scope of these investments. Beysekara (Abeysekara et al., 2021) states that "transport infrastructure investments constitute 31% of the world's capital investments", it is therefore highly desirable that the funds spent on these investments are efficient and the projects that are not economically effective are not implemented.

The CBA method is widely used to assess the economic effectiveness of transport infrastructure projects. Mackie et al. (2014) state that "Cost-benefit analysis has become a widely used and well-developed tool for evaluation of suggested transport projects" and they present the role and the position of the CBA in the planning process of the project of the transport infrastructure implementation.

Laird et al. (Laird and Venables, 2017) note the general impact of transport infrastructure projects on national economies, stating that "the case for major transport investment is frequently made in terms of impact on economic performance". According to the authors, a relatively wide group of impacts which includes "user benefits, proximity and productivity effects, investment and land use impacts and employment effects should be evaluated. Jones et al (2014) also note, that CBA is a formal process for evaluating a project that evolved from the economic constructs of consumer surplus and externality.

The decision on the implementation of the transport infrastructure project often has a significant political dimension. Annema et al. (2017) point out that "the Cost-Benefit Analysis results of transportation policy proposals in the Netherlands are related to the decision to implement or abandon the proposal" and they address the issue of whether the key results of the economic analysis are crucial for the planned project or whether the decision on the project implementation is influenced by its political feasibility.

Ansar et al. (2016) focus on the dark side of transport infrastructure project implementation. The authors concentrate on the process of managing transport investment projects, specifically in the China environment, and state that "poorly managed infrastructure investments are the main explanation of surfacing economic and financial problems in China". The paper emphasizes the importance of quality economic analysis and subsequent project management so that the project does not finally turn into a burden on the economy.

Tomek et al. (Tomek and Vitásek, 2016) focus on the development and ongoing modification of the economic effectiveness evaluation methods of transport construction projects, where the authors state that "it is appropriate to analyse and possibly modify existing methods for evaluating the economic effectiveness of road construction at the scientific level, with the support of the real practice experience", which is partly the subject of the research results presented in this article, in which the authors propose a refinement of the methodological procedure taking into account the economic life of the individual partial constructions.

Another alternative approach - Multicriteria Analysis should be mentioned within the presented paper, which is focused mainly on the use of the CBA method for the evaluation of transport infrastructure investment projects. Marleau Donais et al. (2019) see Multicriteria Analysis as a suitable complement to the CBA method and state that "decision processes related to transport projects have become more complex due to the multidimensional aspects and to the variety of stakeholders involved, often with conflicting points of view". The authors also mention that "to support rigorous decision-making, multicriteria decision analysis (MCDA) is, in addition to CBA, often used by governments and cities".

The theory of Multicriteria Analysis is explained in more detail in the paper by Ward et al. (2016). The authors add that they "highlight the important role/value of the multi-criteria mapping of stakeholder policies and agendas affecting project decision-making as a means of defining and scoping the boundaries of the project exercise under study and the trade-off decision-spaces for stakeholder dialogues and negotiations in their search to arrive at mutually agreed actions and outcomes".

Very important, but often neglected in practice, is the ex-post evaluation of transport infrastructure projects. Welde et al. (Vignetti et al., 2020) state that "by the combination of the traditional ex-post Cost-Benefit approach with a qualitative analysis" and, in the conclusions of research 12,501, state that "ex-post CBA, when appropriately implemented and integrated with qualitative evidence, represents a powerful tool for supporting decision-making processes and for policy lessons". The ex-post analysis is also addressed by Heather et al. (Welde and Volden, 2018).

In addition to the basic calculation formula, the economic effectiveness of transport infrastructure projects has two other significant variables, namely the concept of the length of the evaluated period and the value of the discount rate for determining the time value of money and calculating the current values of future CF. Methodological approaches used in the Czech Republic changed over the years; until 2017, the evaluated period was considered to be 30 years consisting of the operational phase of the project, to which the investment phase lasting the expected years of construction was added (Directorate of Roads and Motorways, 2014). The current methodological procedures resulting from the Departmental Methodology (Ministry of Transport of the Czech Republic, 2017) give priority to an evaluated period of 30 years consisting of the project investment phase and its relevant part of the operational phase (up to 30 years). At first glance, it seems that the operational phase (i.e. generating the societal impacts of the project) is shorter compared to the previous approach, however, this negative phenomenon is eliminated by changing the method of calculating the residual value of the project. The original methodology used the residual value based on an even depreciation of created fixed assets (buildings and operating equipment), the current one monitors the performance of the project beyond the evaluated period until its overall economic life is exhausted. Heather (Jones et al., 2019) presents three methodological procedures for calculating the residual value, Straight-Line Depreciation Method, where residual value is equal to the non-depreciated amount of the asset, Annuity and Perpetuity Methods as the difference between discounted costs and benefits, after the end of the project (economic) life, as an annuity or in perpetuity is another method sometimes used for calculating residual value and Component Method which calculates residual value for each infrastructure component and then sums the components to get the total residual value. The authors of this article follow up on these outputs and further develop them.

MATERIALS AND METHODS

The research question to which this answer is sought is how significantly the methodological procedures for calculating the residual value will affect its final value, which is an essential variable for calculating the economic efficiency of public investment projects. The authors focused on the analysis of the residual value determined by two methods, which have been applied in recent years in the assessment of the economic effectiveness of the transport infrastructure project in the Czech Republic. One of the above-mentioned methods is the Straight-Line Depreciation Method (Directorate of Roads and Motorways, 2014) and the second Residual Performance Potential Method which deals with the calculation of the residual performance of the project until the end of its overall economic life (Ministry of Transport of the Czech Republic, 2017).

The Straight-Line Depreciation Method calculates the residual value based on the depreciation of assets (buildings and equipment) in the years of operation. The total residual value of the construction is determined by the sum of the residual values of the individual buildings and equipment. The total residual value can be determined based on the following relations **Eqs. 1**, **2**.

$$RV_{total} = \sum_{i=1}^{n} RV_i \tag{1}$$

Where:

RV_{total} Total residual value of the construction in EUR.

RV_i Residual value of the building or equipment i in EUR,

i Building i - n.

$$RV_i = \frac{[WL - (Y - y + 1)]}{WL} \times C_i \tag{2}$$

Where:

RV_i Residual value of the building or equipment i in EUR.

WL_j Whole life j of the relevant building or equipment i in years.

Y Last year of the evaluated project period,

y First year of the entire construction operation.

C_i Undiscounted costs of the building or equipment i in EUR.

The Residual Performance Potential Method of the project determines the residual value based on the remaining investment performance, which represents the net present value of cash flows in the remaining years of the economic life of the construction project beyond the evaluated project period. Economic life is determined as a weighted average of the value of costs incurred for individual types of buildings and equipment and their economic life, where the weights are the total construction costs. The current methodological procedures quantify the residual life of the project as the difference between the total economic life of the project in years and the relevant length of its operational phase determined from the year of commissioning of the whole project, as stated in relation **Eq 4**. The economic life of the construction can be quantified according to the relation **Eq 3**.

$$WL_{total} = \frac{\sum_i^n C_i \times WL_i}{C_{total}} \tag{3}$$

Where:

WL_{total} Total whole life of the construction.

WL_i Whole life of the relevant building or equipment i in years.

C_i Undiscounted costs of the building or equipment i in EUR.

C_{total} Total undiscounted construction costs in EUR.

$$RL = WL_{total} - OL_{total} \tag{4}$$

Where:

RL Residual life in years, OL Length of the operational phase in years.

$$RV_{total} = \sum_{t=1}^{y} \frac{ANCF}{(1+r)^t} \tag{5}$$

Where:

$ANCF$ Average net incremental CF of the project,

r Discount rate in %/100, t Year of the residual life of the project, y Year of the economic life of the WL building.

Economic Life

Both examples of calculation of the residual value are based on a significant technical and economic parameter, namely the length of the economic life of the project and the subsequent determination of the project residual life after the end of its evaluated period.

The authors point out that some large-scale infrastructure projects are so extensive that they are implemented gradually as partial constructions. These partial fixed assets start to be worn out prior to the completion of the investment phase of the entire project. The authors discuss how this fact affects the assessment of the economic effectiveness of the project with discounted cash flows, i.e. with respect to the money time value.

Data

The research approach is demonstrated in four Czech large-scale road infrastructure projects. **Table 1** describes the basic parameters of selected projects which contain the above-described partial stages - gradually implemented partial constructions. The table contains a basic technical description of the project, the total investment and total construction costs of

TABLE 1 | Basic description of investment projects.

Project	Basic Project Description	Total Investment Costs EUR (mil.	Total Construction Costs EUR (mil.)	ENPV EUR (Mil.)
D/11 Jirny–Poděbrady	Construction of a 32,780 km of motorway, 6 level crossings, modifications of 25 bridges	292.28	268.90	275.14
I/53 Znojmo–Pohořelice	Modernization of the class I road in the length of 32 km, 6 level crossings, 16 bridges, modification of related class II roads in the length of 11.26 km and 10 bridges	136.40	120.81	103.27
D/6 Nové Strašecí–Karlovy Vary	Construction of a 97,78 km of motorway, 9 level crossings modifications of 101 bridges	1 134.06	1 021.04	289.95
I/53 Opatovice–Mohelnice	Construction of a 94,21 km of motorway, 11 level crossings, modifications of 90 bridges, 2 tunnels	1 904.91	1 770.07	3 746.26

TABLE 2 | Project variable values, incl. original residual values and residual life.

Project	Number of Partial Constructions	Length of the Project Implementation in years	Total Economic Life of the Project in years	Length of Residual Life in years
D/11 Jirny–Poděbrady	4	4	38	10
I/53 Znojmo–Pohořelice	5	9	45	24
D/6 Nové Strašecí–Karlovy Vary	11	8	50	28
I/53 Opatovice–Mohelnice	9	16	61	47

the project, and the value of the economic net present value, ENPV.

Table 2 supplements the data of **Table 1** on the number of partial constructions, the length of the project implementation, the total economic life of the project, and the length of the residual life of the project in years.

METHODS

As mentioned above, the residual value of large-scale road infrastructure projects in the Czech Republic is addressed in two ways within the evaluation of the economic effectiveness of projects, the Straight-Line Depreciation Method and the Residual Performance Potential Method.

The innovative methodological approach is based on considering the time lag for starting to draw on the costs of depreciation of partial structures, which are put into operation before the carrying out of the whole construction is completed.

Within the Straight-Line Depreciation Method, the length of the operating phase is included in the calculation of the residual value, see relation **Eq 6**, variable y_i. The total economic residual value is determined according to the above-stated relation **Eq 1**; however, its sum includes the adjusted values according to relation **Eq 6**. Partial constructions include a relevant timeline in the calculation, i.e. the first year of their operation.

$$RV_{ik} = \frac{[WL - (Y - y_{ik} + 1)]}{WL} \times C_{ik,\,undiscounted} \tag{6}$$

Where:

RV_i Residual value of the building or equipment i in EUR within the partial construction k.

WL_j Whole life j of the relevant building or equipment i in years.

Y Last year of the evaluated project period, y_{ik} First year of operation of the building or equipment i for partial construction k.

C_{ik} Undiscounted costs of the building or equipment i in EUR for partial construction k,

k Partial construction *one* to k.

$$RV_k = \sum\nolimits_1^k RV_{ik} \tag{7}$$

$$RV_{total} = \sum\nolimits_1^k RV_k \tag{8}$$

Within the Residual Performance Potential Method, a gradual calculation of the average economic life of the project is proposed as a weighted arithmetic average of the economic life of partial constructions, where the weights are the total undiscounted construction costs. Relation **Eq 3** can be used to calculate the economic life of partial construction. In this case, the economic life of the entire project assets can be determined as follows:

$$WL_{total} = \frac{\sum_{x=1}^{y} RL_{stage} \times C_{stage}}{C_{total}} \tag{9}$$

The residual value of the project is subsequently calculated using the original relations **Eqs. 4**, **5**.

TABLE 3 | Impact of the change in the project service life length on project effectiveness.

Project	Original Life in years	Modified Life in years	Change in the Length of the Life in years	Change in the Length of the Life in %	Original ENPV in EUR (mil)	Modified ENPV in EUR (mil)	Change in the ENPV in EUR (mil)	Change in the ENPV in %
D/11 Jirny–Poděbrady	10	11	1	+10.00	275.03	281.03	−6.00	2.18
I/53 Znojmo–Pohořelice	24	23	1	−4.17	103.42	102.37	1.05	−1.02
D/6 Nové Strašecí–Karlovy Vary	28	27	1	−3.57	289.87	284.70	5.17	−1.78
I/53 Opatovice–Mohelnice	47	41	6	−12.77	3,746.26	3,719.45	26.81	−0.72

RESULTS AND DISCUSSION

The proposed calculation method was demonstrated in four large-scale investment projects for the construction of motorways and I class roads in the Czech Republic, whose original variables are stated in **Tables 1**, **2**. The original life is taken from basic parameters of the partial projects, the modified life, which takes into account the real time of the start of the operation of the partial construction objects of the projects, are calculated according **Eq 9**. The original value of NPV is taken from the official economic analysis of partial projects, the modified values of NPV are calculated using newly established residual values according to **Eqs. 4**, **5** considering modified lifetimes. The relations defined above were used to determine the values stated in **Table 3**. A 5% discount rate was considered to determine the Economic Net Present Value.

The results presented in **Table 3** show the impact of the change of the total economic lifetime of the projects caused by the taking into account the real time, when partial construction objects of the project enter the operation. **Table 3** shows that the change in the economic effectiveness of the project happens due to a change in the residual value calculation. The significance of the difference is given both by the total life of the project assets and the length of the investment phase within the evaluated period. Changes in the economic life range up to 13%, the impact on the resulting indicator is around 1%; however, in monetary terms, the amount of money spent on the projects is not negligible.

CONCLUSION

This article refines the methodological procedure for calculating the residual value of a public investment project assessed by the CBA method. The authors discuss and demonstrate on a sample of investment projects the effect of the time lag for the start of drawing on the costs of depreciation of assets, which are gradually implemented before the end of the investment phase of the project, on the overall basic economic effectiveness indicator - ENPV. Although in percentage terms these are not large values, in monetary terms this shift may be significant, especially for large investment projects. A more accurate determination of the residual value also more precisely reflects the actual value of the assets at the end of the assessed period. Effectiveness in residual value is closely related to the proper quality of the services provided by the infrastructure, ensures Value for Money, and maximizes the returns on investment (Tassopoulos and Theodoropoulos, 2014). The novelty of the methodological procedure consists in the analysis and the determination of more detail for the elaboration of the model of economic CF of transport infrastructure projects, which can have a significant influence on the decision-making on their financing. The informative capacity of the outputs is limited by the number of researched projects, but a certain trend is evident from the outputs, which leads to the answer to the research question whether or not the surveyed facts have an impact on the evaluation of economic efficiency of investment projects. The expansion of the project portfolio is expected in the future, which will enable subsequent statistical surveys.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization JK and VH; methodology JK and VH; validation JK and VH; formal analysis JK and VH; investigation JK and VH; resources JK, VH, and JF; data curation JK, VH, and JF; writing—original draft preparation JK and VH; writing—review and editing JK and VH; visualization JK; supervision JK; project administration. JK; funding acquisition JK All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Abeysekara, B., Perera, P., Chhipi Shrestha, G. K., Gunaruwan, L., Kumarage, A., Sadiq, R., et al. (2021). Improving the Capital Deployment Efficiency: An Infrastructure Investment Planning Process in Transportation Project. *Res. Transp. Econ.* 88, 101048. doi:10.1016/j.retrec.2021.101048

Annema, J. A., Frenken, K., Koopmans, C., and Kroesen, M. (2017). Relating Cost-Benefit Analysis Results with Transport Project Decisions in the Netherlands. *Lett. Spat. Resour. Sci.* 10 (1), 109–127. doi:10.1007/s12076-016-0175-5

Ansar, A., Flyvbjerg, B., Budzier, A., and Lunn, D. (2016). Does Infrastructure Investment Lead to Economic Growth or Economic Fragility? Evidence from China. *Ecopol* 32 (3), 360–390. doi:10.1093/oxrep/grw022

Directorate of Roads and Motorways (2014). *User Manual for the Czech Road Assessment, Incl. Annexes A-D.* Praha: Novický's.

Jones, H., Moura, F., and Domingos, T. (2014). Transport Infrastructure Project Evaluation Using Cost-Benefit Analysis. *Procedia - Soc. Behav. Sci.* 111, 400–409. doi:10.1016/j.sbspro.2014.01.073

Jones, H. (2019). "Residual Value of Infrastructures," in *Industry, Innovation and Infrastructure. Encyclopedia of the UN Sustainable Development Goals*. Editors W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, and T. Wall (Cham: Springer). doi:10.1007/978-3-319-71059-4_17-1

Laird, J. J., and Venables, A. J. (2017). Transport Investment and Economic Performance: A Framework for Project Appraisal. *Transp. Policy* 56, 1–11. doi:10.1016/j.tranpol.2017.02.006

Mackie, P., Worsley, T., and Eliasson, J. (2014). Transport Appraisal Revisited. *Res. Transp. Econ.* 47, 3–18. doi:10.1016/j.retrec.2014.09.013

Marleau Donais, F., Abi-zeid, I., Waygood, E. O., Lavoie, R., and Lavoie, R. (2019). A Review of Cost-Benefit Analysis and Multicriteria Decision Analysis from the Perspective of Sustainable Transport in Project Evaluation. *EURO J. Decis. Process.* 7 (3-4), 327–358. doi:10.1007/s40070-019-00098-1

Ministry of Transport of the Czech Republic (MoT Cz) (2017). *Departmental Guideline for the Evaluation of Economic Effectiveness of Transport Construction Projects*. Retrieved from http://www.sfdi.cz/pravidla-metodiky-a-ceniky/metodiky/.

Sartori, D. (2014). *Guide to Cost-Benefit Analysis of Investment Projects, Economic Appraisal Tool for Cohesion Policy 2014-2020*. Belgium: European Commission. Directorate-General for Regional and Urban policy. ISBN 978-92-79-34796-2.

Tassopoulos, E., and Theodoropoulos, S. (2014). Residual Value and its Importance in Concession Agreements for Infrastructure Problems. *Eur. Res. Stud.* 17 (2), 32–40. doi:10.35808/ersj/417

Tomek, R., and Vitásek, S. (2016). Improvement of Economic Effectiveness of Road Highway Projects. *Procedia Eng.* 164, 395–401. doi:10.1016/j.proeng.2016.11.636

Vignetti, S., Giffoni, F., Pancotti, C., and Pagliara, F. (2020). Analytical Framework for Ex-post Evaluation of Transport Projects: Lessons Learnt on Retrospective CBA. *Pap. Reg. Sci.* 99 (3), 683–703. doi:10.1111/pirs.12501

Ward, E. J., Dimitriou, H. T., and Dean, M. (2016). Theory and Background of Multi-Criteria Analysis: Toward a Policy-Led Approach to Mega Transport Infrastructure Project Appraisal. *Res. Transp. Econ.* 58, 21–45. doi:10.1016/j.retrec.2016.08.003

Welde, M., and Volden, G. H. (2018). Measuring Efficiency and Effectiveness through Ex-Post Evaluation: Case Studies of Norwegian Transport Projects. *Res. Transp. Bus. Manag.* 28, 33–39. doi:10.1016/j.rtbm.2018.05.001

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