Cost-Benefit Analysis of Road Infrastructure Projects

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Abstract

The paper deals with the Cost-Benefit Analysis of road safety investment projects. Improving road safety can be much more effective when the data collected from road accidents can be merged with economic assessments based on the costs of the proposed interventions and the resulted benefits to society. In this paper, we performed such an evaluation for a list of black spots on the national road network in Romania, following the appropriate methodological literature, and based on statistics provided by the National Highway Company in Romania.

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1. Introduction

Regardless of the project type, decisions are always critical to the project's success. To facilitate the decision process, several analytical tools like economic evaluations are useful to provide a clearer perspective on a project's feasibility and success chances, by analysing data. According to Allen (1991), projects that initiate investments involve the spending of present wealth and other resources with the aim of generating added benefits, whether in the form of profits, cost savings, or social benefits. For an investment to be worthwhile, the forthcoming benefits expected, in a form of any kind, should compare adequately favourably with the prior expenditure of the resources needed to attain them. Investment appraisal recognizes both the resources needed and the expected benefits and makes this assessment. Economic evaluation is a vital part of investment evaluation which is concerned with aspects that can be quantified, measured, and compared in monetary terms. The purpose of investment appraisal is to deliver information for making good investment decisions. The results of an economic evaluation of a project are considered in combination with various other project implications to reach the appropriate decision. This is essential to plan and allocate the long-term use of valuable or scarce resources and to ensure sustainability.

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Road safety is at the centre of several key issues. Traffic accidents can have serious economic and public health consequences. These include the loss of production capacity and income or human resources. If you add in property damage, medical care, and related rehabilitation, the burden caused by traffic accidents becomes considerable. Worldwide, the cost of traffic accidents represents between 1% and 3% of the gross national product of each country. If there is no rapid progress in road safety, traffic accidents will become the fifth leading cause of death by 2030 (World Health Organisation, 2009). In the current article, we are going to present and apply specific methods for evaluating road safety investment projects from an economic point of view. The financial toll that road accidents cause on a country's budgeting and costs, not to mention human lives, determine a stringent need for any type of infrastructure investment projects to be studied also from the economic point of view, to prove that it is worth implementing. The most appropriate approach for conducting an economic road safety investment project appraisal is the Cost-Benefit Analysis (CBA) methodology. As a research methodology, a case study was used to analyse existing qualitative and quantitative data. The article includes a brief literature review on CBA, a section describing the research methodology and a section presenting the results of the analysis. The paper ends with conclusions that summarize the main findings.

2. A literature review on CBA

Cost-benefit analysis is a formal analysis of the impact produced by an intervention. It aims to assess whether the advantages (benefits) of the intervention exceed its disadvantages (costs) (Thomas et al., 2009). CBA is an analytical tool, with high practical implications (Abelson, 2020), that is used to estimate the socio-monetary effect (in terms of benefits and costs) associated with the implementation of certain policy actions and/or projects (Mishan, Quah, 2007). The impact must be weighed compared to predetermined objectives and the evaluation is usually made given the sum of all individuals, directly and indirectly, concerned by the action. The goal of CBA is to recognize and monetize all possible impacts of the action or project under study, to determine the related costs and benefits (Edwards, Lawrence, 2021). All influences should be assessed: financial, economic, social, environmental, etc. Usually, costs and benefits are evaluated by considering the difference between a scenario with the project and an alternative scenario without the project (named "incremental approach") (Ministry of Economy and Finance, 2021).

There are several guidelines for performing a CBA, that are recognised worldwide. Abelson (2020) performed a review of seven contemporary official guidelines to CBA published by the UK Treasury, European Commission, U.S. Environmental Protection Agency, New Zealand Treasury, Infrastructure Australia, NSW State Treasury, and Victorian State Department of Treasury and Finance. Regardless of the type of intervention, a manager wants to conduct a CBA on, the terms of “cost” and “benefits” should be well understood and applied for an optimal outcome. The term cost defines the monetary value of expenditures for services, supplies, raw materials, labour, products, equipment, etc. When talking about a CBA, according to (Hayes, 2021) the following costs are involved:

- Direct costs (e.g., the labour involved in the production, inventory, raw materials, manufacturing expense);
- Indirect costs (e.g., electricity, rent, utilities);
- Intangible costs (e.g., impact on stakeholders, employees, or delivery times);
- Opportunity costs (e.g., alternative investments, buying a facility versus building one);
- Cost of potential risks (e.g., regulatory risks, competition, environmental impacts).

The benefits represent the opposite. Benefits are economic values that can be quantifiable in money, such as income, revenue, etc. It can also include money or resources saved or certain avoided flaws.

According to Sartori et al. (2015), the following concepts highlight a CBA:

- Opportunity cost: When there is a need to choose between several mutually exclusive options, the opportunity cost of a good or service is defined as the potential benefit of forgoing the best option. The basic principle of the CBA lies in the observation that, under certain circumstances (such as market failures, information asymmetry, externalities, public goods, etc.), investment decisions based on profit motives and price mechanisms can lead to undesirable social outcomes. Conversely, if the input, output (including intangible), and external impact of an investment project are valued at their social opportunity cost, the calculated return is an appropriate method to measure the project's contribution to social welfare (Sartori et al., 2015).
- Long-term vision: Depending on the intervention sector, the long-term perspective adopted ranges from a minimum of 10 years to a maximum of 30 years or more. Therefore, it is necessary to set an appropriate time frame; forecast future costs and benefits; use an appropriate discount rate to calculate the present value of future costs and benefits; consider the risks of project uncertainty; compute economic performance indicators expressed in currency (Sartori et al., 2015).

The CBA assigns a monetary value to all positive (benefits) and negative (costs) welfare effects of interventions based on a set of predetermined project objectives. It is required to convert these values and then add them together to find your total net income. Overall project performance is measured using indicators, namely, the expected net present value (ENPV) and the economic performance (ERR) expressed in monetary value, to provide comparability and ranking for competing or alternative projects (Sartori et al., 2015).

3. **Research methodology**

The main scope of this paper is to analyse whether the road infrastructure investment projects are worth implementing by analysing the costs of implementation and the benefits that the interventions produce in terms of economic indicators (EIRR, B/C, NPV). The following steps were carried out to conduct the CBA for infrastructure safety.

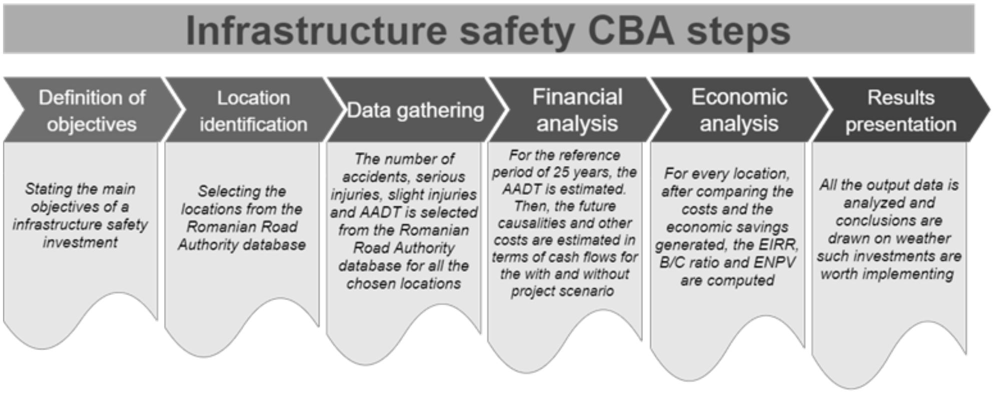

Figure 1. Infrastructure safety CBA steps

The cost-benefit analysis (CBA) of road safety interventions allows joint assessments of the effectiveness of accident reduction measures of varying severity and provides information on their socio-economic returns. To this end, the monetary value is allocated to each type of benefit generated by the measurement, comparing the added value of these benefits (B) with the cost (C) of the measure. The safety benefits are mainly related to road traffic. However, the economic benefits are not only the result of directly improving road safety conditions but also indirect, for example, by transferring passengers to other statistically safer methods, such as rail and air transport. In both cases, this benefit must be calculated in economic analysis, which can distinguish between death, serious injuries, and minor injuries avoided. The economic costs of accidents are determined mainly by the following two parts:

- Direct costs: These costs include the costs of medical rehabilitation, including the cost of rehabilitation that occurred in the year of the accident and future costs of certain people during the rest of the life cycle, plus administrative expenses such as police, courts, private accident investigation, emergency services, insurance costs, etc. (Sartori, et al., 2015).
- Indirect costs: These costs include the net loss of production for society, that is, the value of the goods and services that can be produced if the accident does not occur (Sartori, et al., 2015).

In fatality cases, the assessment of the "loss of production" (that is, the part of the indirect cost) is related to the concept of Value of Statistical Life (VOSL). VOSL is defined as the cost that society considers economically efficient to spend on evading the fatality of an indefinite individual (Sartori, et al., 2015).

As presented by the European Investment Bank (Bricicaru et al., 2021), a country's road infrastructure not only meets the basic needs of the mobility and safe transportation of people and goods but is also considered essential to its growth and development. Public and private investment decisions related to these infrastructures must consider their overall level of security capabilities measurably. The data used for conducting the CBA were extracted from data documents provided during the Road Safety Investment Program in Romania - AA-010269 by:

- CNAIR: Romania's national highway and national roads authority, responsible for planning, design, construction, operation, maintenance, and management of approximately 750 kilometres of highways and more than 17,000 kilometres of national (main) roads.
- The Romanian Road Authority (RRA) within the Ministry of Transport and Infrastructure oversees road infrastructure safety management, according to the EU Directive 2008/96/EC, and deals with road safety and crash data collection, registration, and evidence.

This research emphasizes road sectors in which there were a lot of accidents that are defined in the technical literature as blackspots. The definition of the blackspot in Romania is established by the ARR within Law no. 265/2008 on the management of road infrastructure safety. To identify the blackspots needed for the analysis, CNAIR provided a spreadsheet of accidents that occurred on the Romanian road network in the period between 2017-2019. The main criteria of selection were the number of accidents, so, after studying the database, we have chosen for the current study the top ten locations with the highest number of accidents. For each of the locations, the following data were considered (Table 1): the total number of vehicles involved in the crashes; the total number of deaths, serious injuries, and slight injuries that resulted from the crashes; the annual average daily traffic (AADT); the type of the road (European roads (E), national main roads (1), national secondary roads (2)); the number of lanes of the road and the location environment (built-up/rural area); the county in which the accident occurred.

Table 1. General data regarding accidents and their location. Based on data provided by CNAIR

Location	AADT, 2015	County	Nr. Lanes	Road	Crashes				
					Total	Vehicles involved	Died	Seriously injured	Slightly injured
DN 1km 66+500	21686	PH	2	E	59	128	1	38	107
DN 2km 179+096	8969	VN	1	E	32	58	1	13	37
DN 15Dkm	7341	NT	1	2	30	60	4	12	45

Location	AADT, 2015	County	Nr. Lanes	Road	Crashes				
					Total	Vehicles involved	Died	Seriously injured	Slightly injured
8+910									
DN 73km 4+100	25739	AG	2	E	28	58	1	3	32
DN 2km 174+825	8969	VN	2	E	26	49	2	15	41
DN 7km 26+700	14196	DB	2	1	26	49	6	1	25
DN 15km 327+790	11784	NT	1	1	20	28	3	6	16
DN 7km 119+750	13994	AG	1	E	19	32	1	6	24
DN 2km 122+700	26236	BZ	1	E	18	29	1	4	23
DN 13km 9+600	13065	BV	1	1	16	39	1	6	22

These figures are needed to further develop the financial and economic analyses of each location. Together with the crash data, the Romanian road authority provided data about the traffic growth rate coefficient (Table 2), to estimate the future incidence of the road traffic (AADT) that ultimately allows predicting certain upcoming road phenomena. Furthermore, the "Elasticity accident growth towards traffic growth" was provided and assumed at 5% growth/year.

Table 2. Traffic growth coefficient for European, National main, and National secondary roads. Data provided by CNAIR

Traffic growth	E	1	2
Year	European roads	National main road	National secondary road
2015	1.00	1.00	1.00
2020	1.15	1.13	1.20
2025	1.41	1.38	1.47
2030	1.47	1.44	1.53
2035	1.83	1.78	1.90
2040	2.23	2.17	2.31

Considering the nature of the proposed investment, infrastructure projects aim to improve the safety of the users. All the locations need to be further examined from an engineering point of view. During the Road Safety Investment Program in Romania AA-010269, the locations were studied by technical engineers and for each of them, a customized measure was proposed. From the analysis, three main measures were proposed for the locations (Bricicaru, et al., 2021):

- Channelization and/or traffic signalization improvement
- Roundabout construction

- Overpasses/underpasses construction

Furthermore, for each of the locations proposed for the analysis, and expected collision reduction factor was established, being taken into consideration the proposed measures and the accident reduction factor described in the PIARC (2009).

Table 3. Technical measures and the expected collision factors

No.	Location	Preliminary engineering solution	Expected collision reduction
1	DN 1 km 66+500	Underpass	50%
2	DN 2 km 179+096	Traffic signals/ channelization	65%
3	DN 15 D km 8+910	Roundabout	53%
4	DN 73 km 4+100	Roundabout	53%
5	DN 2 km 174+825	Roundabout	53%
6	DN 7 km 26+700	Roundabout	53%
7	DN 15 km 327+790	Traffic signals + closing the junction	32.50%
8	DN 7 km 119+750	Traffic signals/ channelization	50%
9	DN 2 km 122+700	Traffic signals/ channelization	50%
10	DN 13 km 9+600	Traffic signals/ channelization	53%

Source: (Bricicaru et al., 2021)

Road safety requires an extensive expenditure of money when it comes to both the construction of new roads and the rehabilitation of existing ones (AECOM, 2014). Since the presented research is a simplified CBA, we have chosen three main investment costs that are breaking down as follows:

- Design costs: this includes the planning, designing, and technical assistance costs. The design costs are assumed by CNAIR at the level of 3% of the total capital costs;
- Land acquisition costs: the land acquisition costs (where relevant), to be 20% of the total capital costs;
- Works costs: this includes labour and supervision costs, material and equipment costs;
- Operation and maintenance costs (O&M): for the period after the implementation of the proposed measures, it is assumed by CNAIR to be at 0.5% of the works cost for the over/underpasses measure and at 1.5% of the works cost for the rest of the measures.

Depending on the nature of each location, the costs for rehabilitation differ significantly in respect to the following factors:

- The type of measure implemented:
    - Traffic signalling and/or channelization: Requires little investments, no land acquisition;
    - Roundabouts: Requires medium investments, land acquisition accounted only where needed;
    - Over/underpasses: Requires large investments, involves land acquisition at any location;

- Number of lanes: locations that have two lanes have higher investment costs than the ones that have only one;
- Location environment: In built-up area locations need higher investment than the ones located outside the built-up area.

The selected locations are scattered all over the Romanian road network in different counties of the country. Since each county's road administration has different prices for all the road works needed, especially land acquisition, CNAIR provided some average prices for all the measures and types of locations for the whole country. For each of the locations proposed for the analysis, a simplified CBA was carried out in line with the Sartori et al. (2015). The general elements in respect to conducting the analysis are the following:

- A 25-year reference period AECOM (2014), starting from 2020 till 2045, is in line with the transportation projects timeline. It breaks down as follows: 2020- investment and project identification; 2021- investment and works planning; 2022- investments implementation; 2023 to 2045- road operation.
- Done on an incremental basis by comparing the ”with project scenario” with a ”without project scenario” and by applying discounted cash flows method. The discount rate used is 5% (AECOM, 2014), as recommended for the economic analyses for the 2014 – 2020 planning period. Due to their public use nature, road infrastructure safety projects have no financial benefits. As stated in Thomas et al. (2009), the benefits resulting from these types of projects are assumed to be the prevented accidents that result in the saved lives and injuries of the users. As a direct consequence, the incremental approach methodology takes a clear picture of the cost savings that each measure produces.

4. Data analysis and results interpretation

For each of the locations, CNAIR provided the AADT data for the year 2015. For the following years needed for the reference period, using the data regarding the road type (E, 1, 2) and the traffic growth coefficient also received from CNAIR, we have computed, for each location the AADT value for the reference period years.

The accident growth coefficient (thereafter Agc) is computed regarding each respective year's AADT, and the average AADT between 2017-2019 (the accident data years). It was computed for every location and each year as follows:

$$Agc_{2021} = 1 + (AADT_{2021} / \text{Average AADT}_{(2017\text{-}2019)} - 1) * 0.05 \qquad (1)$$

Road accidents are hard to predict due to their unexpected nature. It involves a lot of factors like human behaviour, weather conditions, infrastructure flaws, time of the day, etc. Since the data received has information about the casualties that happened in the 2017-2019 period, for each type of injury, we have estimated an average yearly number by dividing the total number provided by the number of years (3). After this, already having computed data concerning the Agc, we multiplied the average number of deaths, serious injury, and slight injury with the growth rate from the respective year.

$$\text{Deaths/year}_{2021} = \text{Average deaths} * \text{Agc}_{2021} \quad (2)$$

As per the Romanian CBA guide (AECOM, 2014), a unit cost is provided for every type of casualty reviewed for the year 2010. The future monetary casualty values were updated with the elasticity of 1 to the gross domestic product (GDP) per capita increase for the future years till 2045. The annual growth rates were provided in the (AECOM, 2014) for the years 2011-2040, the last 5 years of the reference period having the same growth as the year 2040. As a result of the calculations, the following costs for the types of casualties were assumed per time horizons summarised in Table 5.

Table 4. Accident cost savings, 2010. Source: AECOM, 2014

Accident	Estimated cost (Euro)
Fatality	635,972
Serious injury	87,963
Light injury	7,114

Table 5. Casualties estimate costs expressed in time horizons. Own source

Year	**Cumulative GDP per capita growth**	**Fatality costs (euro)**	**Serious injury costs (euro)**	**Light injury costs (euro)**
2010	1.00	635,972	87,963	7,114
2020	1.5325	974,611	134,801	10,902
2025	1.8573	1,181,210	163,376	13,213
2030	2.2510	1,431,604	198,009	16,014
2035	2.6963	1,714,795	237,178	19,182
2040	3.1593	2,009,231	277,902	22,475
2045	3.6696	2,333,776	322,791	26,106

The ”without project scenario” presents the situation, in monetary terms, in which no investments and no technical measures are applied to the selected locations. For each location, the number of slight injuries, serious injuries, and fatalities are multiplied with the cost involvement at that specific year, and it is computed as follows:

$$\text{Total accident without project cost}_{2021} = \text{Nr. deaths}_{2021} * \text{Death cost}_{2021} + \text{Nr. slight injury}_{2021} * \text{Slight injury cost}_{2021} + \text{Nr. serious injury}_{2021} * \text{Serious injury cost}_{2021}. \quad (3)$$

The ”with project scenario” showcases the impact of the implementation of certain technical measures on the road network, presented in financial terms. We have multiplied the before explained Without project total accident costs for each year with the remaining percentage of accidents resulting from the percentage of the expected accident reduction factor of each location. The accident cost savings take effect only from 2023 onwards because 2021 and 2022 years are reserved for planning and project implementation.

$$\text{Total accident with project cost}_{2023} = \text{Total accident without project cost}_{2023} * (100\% - \text{Expected collision reduction percentage/location}) \quad (4)$$

The purpose of the economic analysis is to prove that the proposed implementation measures have a positive rate of return, and in other words, are worth implementing. Economic costs are derived from financial costs through the application of conversion factors (CF) to ensure that the prices used in economic analysis reflect the actual economic value of the used resources. These factors consider price distortions caused by market imperfections. Project costs should be divided into the following categories (AECOM, 2014): tradeable goods/services (equipment), non-tradable items/products (material), labour. For 2020, the unemployment rate in Romania was rounded to 4% in the calculation, and according to (Bricicaru, et al., 2021), the share of unemployment benefits and relevant taxes from the base minimum salary in Romania constituted 32%. This results in a CF for labour of 0.6528.

To ensure a proper factor for conversion of financial costs, (Bricicaru, et al., 2021) set some cost share for each type of cost: equipment (20%), material (30%), labour (40%), other (10%). After the calculation of the economic CF, which equates to 0.861, for every location, we have computed the Economic costs involved in the implementation of the project, by multiplying the CF to the costs attributed to every year from the reference period.

$$\text{Economic costs}_{2021} = \text{Investment and O\&M costs}_{2021} * \text{CF} \quad (5)$$

To highlight the safety economic benefits, we have made the difference between the costs implied for each year and the location of the ”without project scenario” and the ”with project scenario”.

$$\text{Safety benefits}_{2021} = \text{Accidents' costs in without project scenario}_{2021} - \text{Accidents' costs in with project scenario}_{2021} \quad (6)$$

The Net economic benefits compare all the economic inflows of the project (economic costs) with its outflows (safety benefits) are calculated for all the reference period years to exhibit the economic impact of the measures (either positive or negative).

$$\text{Net economic benefits}_{2021} = \text{Safety benefits}_{2021} - \text{Economic costs}_{2021} \quad (7)$$

These values are used for the calculation of economic indicators: Economic Internal Rate of Return (EIRR), Economic Net Present Value (NPV), Befit-cost ratio (B/C). In the table below we present the analysed interventions and the NPV benefits (Table 6).

Table 6. Investment costs and present value benefits comparison. Own source

Intervention	Location	Investment costs (euro)	NPV benefits (euro)
Underpass	DN 1 km 66+500	12,500,000	20,229,974.90
Roundabout	DN 2 km 174+825	500,000	13,043,634.59
	DN 15 D km 8+910	400,000	17,747,276.20
	DN 73 km 4+100	600,000	5,101,107.88
	DN 7 km 26+700	700,000	18,449,369.27
Total		2,200,000	54,341,385.94
Signalling	DN 2 km 122+700	100,000	4,914,532.39
	DN 7 km 119+750	120,000	5,695,772.68
	DN 13 km 9+600	120,000	5,967,673.51
	DN 15 km 327+790	120,000	7,066,621.35
	DN 2 km 179+096	120,000	11,336,996.69
Total (traffic signals/ channelization)		580,000	34,981,596.61
TOTAL		15,280,000	109,552,957.45

It can be observed that all the interventions provide very good investment returns. The over/underpass intervention requires the highest level of investment and with a low net benefit. On the other side, the locations that have as a possible solution a roundabout demand a medium investment and provide a very good but average net benefit. While traffic signalling and/or channelization have the least investment costs and at the same time provide the highest benefit growth ratio when compared with the other measures. Below are presented the final CBA results that comprise all three economic indicators for each location (Table 7). All the locations fall into every economic indicator criterion (ENPV>0, EIRR>5%, B/C>1), and most of them, exceed them by far. In the case of the ENPV indicator, all ten locations have positive and very high values averaging 9,721,735.89 euros. When talking about the EIRR, for all locations, the investment proves a very high rate of return, ranging from 13% as far to 556%, with an average of 252%. And computing the B/C ratio, the same as all the other indicators, proved that all the measures proposed for implementation yield a very good ratio. The average ratio between all the sites was 45.76, with the lowest value of 2.05 and the highest one of 106.04.

Table 7. Economic indicators. Own source

Location	ENPV (euro)	EIRR (%)	B/C
DN 73 km 4+100	4,580,120.84	55	9.79
DN 2 km 122+700	4,825,434.97	311	55.16
DN 7 km 119+750	5,588,855.77	302	53.27
DN 13 km 9+600	5,860,756.60	315	55.82
DN 15 km 327+790	6,959,704.44	367	66.09
DN 1 km 66+500	10,341,823.40	13	2.05
DN 2 km 179+096	11,230,079.79	556	106.04
DN 2 km 174+825	12,598,147.49	173	29.28
DN 15 D km 8 +910	17,390,883.52	283	49.80

Location	ENPV (euro)	EIRR (%)	B/C
DN 7 km 26+700	17,841,549.05	140	30.35
Average	9,721,735.89	252	45.76

After the review of the presented above results, it can be concluded based on the CBA analysis for the selected blackspots, taking into consideration the interventions proposed, that the infrastructure projects will provide both economic benefits and contribute to the welfare of the society and save lives.

5. Conclusion

This article provides a detailed practical example of the intricacies and steps of a Cost-Benefit Analysis in the field of infrastructure safety. The outcomes of the calculations have proven that economic appraisals of road safety could have a high impact on these types of projects and can be used at the governmental level to analyze, prioritize, and rank potential investments. There must be made progress in the field of traffic data gathering, as this can become a big setback when it comes to CBA analysis. Unfortunately, not all the data used was recent so there was a necessity to predict most of the basic data used, which can cause the risk of miscalculations and wrong predictions. In conclusion, this is a current topic of discussion since infrastructure plays an important role in our lives and there is a need to prioritize investments and make the best decisions that will provide benefits in the long term.

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