Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 58 (2021) 119–126

Transportation Research Procedia

www.elsevier.com/locate/procedia

14th Conference on Transport Engineering: 6th – 8th July 2021

Criteria for optimizing a road network

Francisco J. Regalado López[a,*], José Magín Campos Cacheda[b], Sergi Saurí Marchán[c]

[a]*Universitat Politècnica de Catalunya – BarcelonaTECH, C. Jordi de Girona 1-3, B1-102C, 08034 Barcelona, Spain*
[b]*Universitat Politècnica de Catalunya – BarcelonaTECH, C. Jordi de Girona 1-3, B1-204, 08034 Barcelona, Spain*
[c]*CENIT – CIMNE, C. Jordi de Girona 1-3, C-3 Plaça Telecos, 08034 Barcelona, Spain*

Abstract

Cost-benefit analysis (CBA) is the most widely used tool for appraisal of transportation infrastructure projects, but there isn't generalize guidelines about its implementation, there can be found different approaches that suit the perspectives of each evaluating entity. This document, it shows three different guidelines that used in practice for road transportation infrastructure projects, in which there are some different costs and benefits considered informing decision makers about the project appraisal. The costs and benefits with market values have been the predominant ones in the CBA, but there is a transition to use without market values, however, there are no generalized methodologies, so more research will be needed.

Keywords: Cost-benefit analysis;Multicriteria analysis;Proyect appraisal;Economic assesment

1. Introduction

The constant growing world population causes a greater demand for transport infrastructure causing the need for improvements or new infrastructure projects, the problem is limited financial resources (Jones et al., 2014). Their economic impact can be transformative, in particular for those with a low income level (Feick & Roche, 2013; Younis, 2014). Transport infrastructures are key in ensuring the accessibility of passengers and goods, helping to shorten distances and time, but have negative effects such as the investment spending, becoming physical barriers, the congestion and noise, active planning helps to minimize negative externalities (Banister, 2011; Koglin & Rye, 2014; Meunier et al., 2014). The ability to choose the best projects, relies on the quality of data used, the tools for its evaluation and choose the correct variables (Broniewicz & Ogrodnik, 2020). Within the European context, the most

* Corresponding author. Tel.: +34-934-017-088
E-mail address: francisco.javier.regalado@upc.edu

10.1016/j.trpro.2021.11.017

used tool for the evaluation of transport projects is the CBA, in which it is very clear the variables to be used when it comes to direct impacts that are easily translated into monetary terms, but not much with indirect impacts where there are no market values available (Bristow & Nellthorp, 2000).

2. European context

The transport infrastructure for the European Union (EU) is essential since it is a single market, so it must have a solid transport network that links its members, without it the internal market would be affected. The dilemma that exists between policies that promote economic growth and consequently the generation of more transportation infrastructure projects and environmental policies that require reducing environmental impact (Villa et al., 2020). Investments have focused on improving the quality of transport, accessibility, mobility and safety, while covering the demand (European Commission, 2014). Transportation contributes to externalities that in contrast to benefits, are not assumed by the users of the infrastructure and, therefore, not considered in the decision-making process. Internalizing these costs means making such effects part of the decision-making process, using market-based instruments is considered an effective way of limiting the negative side effects of transportation (European Commission, 2019). According to (Odgaard et al., 2005) in 25 European countries the CBA is used to a greater extent according to the type of element to be evaluated, which is complemented with another type of analysis. Table 2, shows the distribution of analysis used in the countries of the study, it can be seen that the countries mostly use the CBA for purely convertible effects to monetary terms:

Table 1 Type of analysis by effect.

Effects	CBA	MCA	QM	QA	NA
Construction Cost	25	4	1	1	0
Disruption from construction	10	1	0	6	11
System operating cost and maintenance	24	4	2	2	0
Passenger transport saving	24	4	3	2	0
User charges and revenues	17	1	1	3	6
Vehicle operating costs	23	4	1	0	2
Benefits to goods traffic	17	2	1	1	8
Safety	24	4	3	1	0
Noise	13	3	7	8	3
Air Pollution - Local/Regional	14	2	5	7	3
Climate change	8	1	3	7	10

Ref: Adapted from (Odgaard et al., 2005)

In 2016, total external costs in EU countries amounted to €726 billion and congestion costs to €271 billion with a total of €987 billion, representing 6.6% of GDP. Road transport is the mode with the highest impact on external costs, accounting for 83%, when including aviation and maritime modes; 97.5%, when excluding them. Considering accidents, congestion, climate change, air pollution, environmental damage and noise (European Commission, 2019).

3. Cost-benefit analysis

CBA is a technique developed in the field of economics, mathematics, statistics, and operations research, which seeks to provide guidance to decision-makers on the formulation of public policies (Nilsson et al., 2008). The CBA was the first formal economic evaluation method to be applied to potential projects, through indicators shows a comparative description of the potential costs and benefits of the projects. Currently, during the analysis not only the cash flow is considered but also the economic, environmental and social impacts, both positive (benefit) and negative (costs), quantified in monetary terms adjusted for the present value of money (Dimitriou et al., 2016). The CBA is the dominant method in the economic evaluation of projects since the 1970s (Macharis & Bernardini, 2015). Despite its wide use, there is still no universal standard CBA model, each organization or country defines its own specific requirements for evaluation, although with similar criteria (Vickerman, 2017). The methodological advantages of using the CBA are; decision makers have more information to appraise the projects according to its effects. The CBA can be a good discussion platform for those involved in economic research, design and planning of infrastructure, improving the quality of information for decision-making, helping to support final decisions. Among the negative points, the CBA lacks transparency for the final reports to society, as well as its difficulty to worth environmental impacts without market value. Although it may seem to have few negative points, the area of work is controversial and of great economic impact (Annema et al., 2007).

4. Review of CBA guidelines

This section provides the costs and benefits that are included in the CBA guidelines by government agencies for the evaluation of transport projects, as a tool to support decision making in road projects, which are: CBA Guide for EC, United States (US) and New Zealand (NZ) investment projects.

4.1. The CBA Guide for transport investment projects of the EC

The CBA Guide of Investment Projects (CBA Guide) for transport projects for the EU aims to provide guidance on the common rules for the European-wide use of the BCA for large projects, referring to works, with a total cost of more than 50 million Euros. Having the intention to ensure; the improvement in the movement of people and goods in order to obtain better accessibility, mobility and safety, improving the quality and safety of infrastructures; better linkage between EU member states, promoting the single market and meeting transport demand, developing transport infrastructures and improving transport services; promote national or regional economic development by investing in newly created, extended or linked infrastructures (European Commission, 2014).

4.2. The U.S Department of Transportation's CBA Guide for Investment Projects.

The application of the CBA in highway projects is to ensure that funding is directed to projects that contribute to the economic growth of the users and the nation as a whole. Through an efficient transportation system, requiring repairs, expansions and modernizing aging facilities but also new projects to ensure that they continue to meet the needs of the population and the marketplace. (USDOT, 2018).

4.3. The N.Z. Transportation Agency's CBA Guide.

The purpose of applying CBA to highway projects is to establish a quality transportation system that promotes the well-being and livability of society through new, upgrade or extension of road projects. The CBA should identify economic effects (including social and environmental) in decision-making, whether or not it can be quantified, establishing consistency, transparency and compatibility between activities to help assess their economic efficiency (NZ Transport Agency, 2020a).

Table 2 Guideline's summary.

	EC	US	NZ
Transport mode	General	Road	Road
Discount rate (%)	3 - 5	7	4
Economic performance indicators	VAN, B/C, ERR	VAN, B/C	VAN, B/C
Decision indicator	VAN	VAN, B/C	B/C
Time horizon (years)	Up to 30	Upgrade: 20 New project: 30	Up to 40
Risk assessment	Sensitivity (Monte Carlo)	Sensitivity (Monte Carlo)	Sensitivity (Monte Carlo)

Ref: Own elaboration with data from (European Commission, 2014; NZ Treasury, 2015; USDOT, 2018)

4.4. Review of stages in the application of the CBA

The reviewed guidelines have a similar structure, although they differ in the number of steps in which their application is applied, it can be divided into 3 stages:

- Determination of the project: Describes the context of the project, establish the objectives, introduce the alternatives and define the base case for measure the incremental cost and benefits.
- Identification of costs and benefits: Costs and benefits are identified with/without market prices, usually divided into financial and economic analysis, discounted over the analysis time horizon to obtain the project's performance indicators.
- Analysis of results and report: The results are analyzed and the alternatives ranked. A report is prepared showing the results of the CBA in which the project's performance indicators are shown, as well as the data used to obtain them.

4.5. Economic analysis

- Travel time
  - EC: Travel time savings can be derived from the construction of new or improvement of existing transport infrastructure, tell apart between work and non-work travel time estimation (European Commission, 2014). US: Estimated travel time savings will depend on engineering calculations and their effects on the operations of the improved infrastructure and the local area transportation network. These improvements can reduce travel time for drivers and passengers, including both in-vehicle time and waiting time (USDOT, 2018). NZ: Productivity and utilization of the network are related to the efficient use of the land transport network, seeking to optimize it instead of maximizing its use. The monetization of network productivity is measured through changes in travel time and financial costs of transport use (NZ Transport Agency, 2020a).
- Vehicle operating costs
  - EC: Vehicle operating costs are defined as costs borne by vehicle owners to operate vehicles, including fuel consumption, lubricant consumption, tire deterioration, repair and maintenance costs (European Commission, 2014). US: Operating cost savings commonly result from improved transportation infrastructure projects, resulting in lower fuel consumption and other operating costs (USDOT, 2018).
- Accidents
  - EC: Transport activities involve a risk to users of suffering an accident (European Commission, 2014). US: Transportation infrastructure improvements help to reduce the likelihood of death, injury, and property damage by reducing the number of crashes and/or their severity (USDOT, 2018). NZ: There are three variables to consider, the first is the "social cost of death and serious injury" which includes the cost to the user, the cost to the health system and the costs of delay in the network. In accidents, not only the user is impacted, but also the family and friends who may be affected by the accident. The second is "System safety", which focuses on investment aimed at improving system safety. The third is "Perception of safety and security", physical

attributes such as lighting, safety cameras and speed controls that enhance the feeling of safety (NZ Transport Agency, 2020a).

- Noise
  - EC: Noise pollution can be defined as "unwanted external sound that has negative effects on human health" with local impact (European Commission, 2014). US: Noise pollution is caused by high levels of ambient sound that cause annoyance or harm to people and animals (USDOT, 2018). NZ: Noise and vibration have significant effects on human health, mainly with sleep disruption and stress. Humans are sensitive to vibration and noise, which can come from the construction, operation, maintenance and use of land transport infrastructure (NZ Transport Agency, 2020a).
- Air pollution
  - EC: Transport investments can significantly affect air quality, reducing or increasing the level of pollutant emissions (European Commission, 2014). US: The economic damages caused by exposure to air pollution are borne by society rather than by users that generate those emissions. Transportation projects can reduce overall fuel consumption and thus can produce climate and other environmental benefits (USDOT, 2018). NZ: The effects of air emissions from road transport that impact human health are monetized by assigning a cost to each tonne of pollutant as a proxy for the harm caused to people exposed to air pollutants (NZ Transport Agency, 2020a).
- Climate change
  - EC: Economic cost of positive or negative variations in Greenhouse Gas (GHG) emissions. The main emissions are carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) that contribute to global warming (European Commission, 2014). US: GHG emissions have long-lasting even intergenerational impacts, unlike all other benefit categories (USDOT, 2018). NZ: Road transport is the largest contributor to emissions, the number of vehicles emitting GHGs emissions should be identified, get their fuel consumption and thus emissions can be monetized (NZ Transport Agency, 2020a).
- Benefits to existing and additional users
  - US: The main benefits of a project will arise in the "market" that the project would improve, with its users experiencing them directly. Users attracted by the improvement are willing to pay less for use it than the original users (USDOT, 2018). NZ: User experience can include comfort, simplicity, convenience, crowding, travel time and network condition (NZ Transport Agency, 2020a).
- Modal diversion
  - US: Improvements in transportation infrastructure or services may attract additional users of alternative routes or modes of transportation (USDOT, 2018). NZ: It is critical to know the variables that may encourage or discourage a user from selecting a transport mode. (NZ Transport Agency, 2020a).
- Agglomeration economies
  - US: Transportation infrastructure improves connections between communities, people and businesses by reshaping the economic space of a region. The economic theory of agglomeration suggests that firms and households enjoy a more efficient exchange of information and ideas, access to larger and more specialized workforce (USDOT, 2018). NZ: Changes in productivity result from of agglomeration, where scale and spatial concentration enables an increase of productivity (NZ Transport Agency, 2020a).
- Resilience
  - US: Incorporating resilience benefits requires an understanding of the expected frequency of each stressful event and its economic impacts on infrastructure (USDOT, 2018). NZ: These are system vulnerabilities and redundancies, are about reducing the risk of exclusion of communities from social and economic opportunities due to system disruptions. (NZ Transport Agency, 2020a).
- Quality of Life
  - US: Transportation projects can provide benefits that can be as varied as improved pedestrian connectivity, increased accessibility to remote communities, and other localized amenities. (USDOT, 2018). NZ: The impact of transport mode on physical and mental health is related to users transport mode choice (NZ Transport Agency, 2020a).

- Increased in property values.
  - US: Transportation projects improvements can increase the accessibility or improve the attractiveness of land parcels near infrastructure, resulting in increased land values (USDOT, 2018). NZ: The role of the transportation system is enabling and maintaining the normal functions of a community, with others or areas of the same community that may suffer a disconnection with the rest of the community (NZ Transport Agency, 2020a).
- Water pollution
  - EC: Pollution of water bodies occurs by discharging pollutants directly or indirectly without adequate treatment, affecting seriously the water quality, biodiversity and society (European Commission, 2014). NZ: Transport infrastructures during their life cycle can have a major impact on water flow and its quality, having short or long term effects, impacting the natural or artificial environment (NZ Transport Agency, 2020a).
- Impact on soil and biodiversity
  - EC: The presence of chemicals or soil disturbance due to industrial activity or improper waste disposal has long-term social and economic effects on society (European Commission, 2014). NZ: Natural resources underpin the economic and social area of our society, during the different stages of the life cycle of transport infrastructures impact biodiversity (NZ Transport Agency, 2020a).
- Impact on landscape
  - EC: This is the loss of recreational or aesthetic value and not only for rural environments, also there may be urban areas that may be affected (European Commission, 2014). NZ: The relationship between people and landscape can be explained as a reflection on their relationship (NZ Transport Agency, 2020b).

Table 3 Cost and Benefits in CBA Guidelines

Variable	EU	Methodology	US	Methodology	NZ	Methodology
Travel time	✓	✓	✓	✓	✓	✓
Vehicle operating costs	✓	✓	✓	✓		
Accidents	✓	✓	✓	✓	✓	✓
Noise	✓	✓	✓	X	✓	✓
Air pollution	✓	✓	✓	✓	✓	✓
Climate change	✓	✓	✓	✓	✓	✓
Benefits to existing and additional users			✓	✓	✓	✓
Modal diversion			✓	✓	✓	✓
Agglomeration economies			✓	X	✓	✓
Resilience			✓	X	✓	X
Quality of life			✓	X	✓	X
Increase in property value			✓	X	✓	✓
Water pollution	✓	X			✓	X
Impact on Soil and biodiversity	✓	X			✓	X
Impact on the landscape	✓	X			✓	✓

Ref: Own elaboration with data from (European Commission, 2014; NZ Transport Agency, 2020a; USDOT, 2018)

5. Conclusions

During the evaluation of projects in the part of the economic analysis may be have difficulties in valuing variables (without market values) that can be easily identified. Despite the difficulties there has been significant progress in integrating them into the economic analysis process of the CBA, there are no methodologies for its analysis but given the importance of these variables to be considered in transportation infrastructure projects, future research still needs to be done in the area. Improvements in the CBA and its evaluation guidelines contribute to better informed decisions and investment, hence the importance to interpret these terms into more useful terms for decision makers.

Table 3 shows the costs and benefits of the guidelines reviewed. The EC, US and NZ columns represent the guidelines by country and the Methodology column represents the existence of guidelines to analyse the cost or benefit by country. In the European case, the costs and benefits have market values, or are easily converted, to avoid the calculation having multiple methodologies that may hinder the evaluation in the possible case of needing EC resources to finance the project. In the U.S. case, some costs and benefits without market value are mentioned, encouraging the evaluator to use their own method with caution and relying on projects carried out previously. The New Zealand case has a greater consideration of non-market value costs and benefits, which they intend to integrate in their CBA, encouraging the evaluator to develop their own method for the time being, but mentioning that a centralized methodology will be provided in future editions of the manuals.

The guidelines reviewed have a similar structure in the application of the CBA, so it can be said that are guidelines with a classic CBA core, differing in the types of costs and benefits taken into account. An important consideration is the update of the guides, NZ (2020) and US (2018), while the last update of the CBA Guide is from 2014 with the experience gained in the previous policies goals, it is expected that there will be a next update that studying at great length the impacts of difficult monetization, given the beginning of the new stage of the EC cohesion policies.

References

Annema, J. A., Koopmans, C., & Van Wee, B. (2007). Evaluating transport infrastructure investments: The Dutch experience with a standardized approach. Transport Reviews, 27(2), 125–150. https://doi.org/10.1080/01441640600843237

Banister, D. (2011). Cities, mobility and climate change. Journal of Transport Geography, 19(6), 1538–1546. https://doi.org/10.1016/j.jtrangeo.2011.03.009

Bristow, A. ., & Nellthorp, J. (2000). Transport project appraisal in the European Union. Transport Policy, 7(1), 51–60. https://doi.org/https://doi.org/10.1016/S0967-070X(00)00010-X

Broniewicz, E., & Ogrodnik, K. (2020). Multi-criteria analysis of transport infrastructure projects. Transportation Research Part D: Transport and Environment, 83(April), 102351. https://doi.org/10.1016/j.trd.2020.102351

Dimitriou, H. T., Ward, E. J., & Dean, M. (2016). Presenting the case for the application of multi-criteria analysis to mega transport infrastructure project appraisal. Research in Transportation Economics, 58, 7–20. https://doi.org/10.1016/j.retrec.2016.08.002

European Commission. (2014). Guide to Cost-benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020. In Publications Office of the European Union (Issue December). https://doi.org/10.2776/97516

European Commission. (2019). Handbook on the External Costs of Transport. In European Commission. https://www.cedelft.eu/en/publications/2311/handbook-on-the-external-costs-of-transport-version-2019

Feick, R., & Roche, S. (2013). Understanding the value of Transport Infrastructure. International Transportation Forum Task Force Report 2013, 15–29.

Jones, H., Moura, F., & Domingos, T. (2014). Transport Infrastructure Project Evaluation Using Cost-benefit Analysis. Procedia - Social and Behavioral Sciences, 111, 400–409. https://doi.org/10.1016/j.sbspro.2014.01.073

Koglin, T., & Rye, T. (2014). The marginalisation of bicycling in Modernist urban transport planning. Journal of Transport and Health, 1(4), 214–222. https://doi.org/10.1016/j.jth.2014.09.006

Macharis, C., & Bernardini, A. (2015). Reviewing the use of multi-criteria decision analysis for the evaluation of transport projects: Time for a multi-actor approach. Transport Policy, 37, 177–186. https://doi.org/10.1016/j.tranpol.2014.11.002

Meunier, D., Quinet, A., & Quinet, E. (2014). Project Appraisal and Long Term Strategic Vision. Transportation Research Procedia, 1(1), 67–76. https://doi.org/10.1016/j.trpro.2014.07.008

Nilsson, M., Jordan, A., Turnpenny, J., Hertin, J., Nykvist, B., & Russel, D. (2008). The use and non-use of policy appraisal tools in public policy making: An analysis of three European countries and the European Union. Policy Sciences, 41(4), 335–355. https://doi.org/10.1007/s11077-008-9071-1

NZ Transport Agency. (2020a). Land transport benefits framework and management approach guidelines.

NZ Transport Agency. (2020b). Non-monetised benefits manual (Issue July).

NZ Treasury. (2015). Guide to Social Cost Benefit Analysis (Issue July). http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/guide/

Odgaard, T., Kelly, C., & Laird, J. (2005). Current practice in project appraisal in Europe Analysis of country reports. In Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO) (Issue 2005). http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Developing+Harmonised+European+Approaches+for+Transport+Costing+and+Project+Assessment#0

USDOT. (2018). Benefit-Cost Analysis Guidance for Discretionary Grant Programs. June, 32. https://www.transportation.gov/sites/dot.gov/files/docs/mission/office-policy/transportation-policy/284031/benefit-cost-analysis-guidance-2018_0.pdf

Vickerman, R. (2017). Beyond cost-benefit analysis: the search for a comprehensive evaluation of transport investment. Research in Transportation Economics, 63, 5–12. https://doi.org/10.1016/j.retrec.2017.04.003

Villa, J. C., Boile, M., & Theofanis, S. (2020). Trade and transportation evolution in the European Union. In International Trade and Transportation Infrastructure Development (pp. 149–180). https://doi.org/10.1016/b978-0-12-815741-1.00005-x

Younis, F. (2014). Significance of Infrastructure Investment for Economic Growth. Munich Personal RePEc Archive, 72659, 1–35.