A framework for Organizing a Resilient Cost Benefit Analysis for Construction Projects.

Alemu Moges Belaya*, Olav Torpa, Carl Thodesena, James Odecka†

*Norwegian University of Science and technology (NTNU), Department of civil and transport engineering, Høgskoleringen 7A N-7491 Trondheim, Norway.

Abstract

Large public-investment construction projects require advanced decision support systems. The traditional (static) cost benefit analysis (CBA) is one of the early-phase decision support system in construction business. The purpose of this paper is to develop a resilient and dynamic CBA framework for road construction projects. The research systematically reviewed academic quality ensured and rigorous peer-reviewed articles (from web of science and publish or perish databases) and discuss selected Norwegian construction projects. The research identified some key attributes (e.g. resiliency, dynamics, system thinking) that the traditional CBA lacks and the framework developed integrates these attributes to fill the gap. The research has theoretical implication from the methodological improvement perspective (e.g. attempting to integrate complex attributes). The practical implication is to avoid inefficiencies and obtain better regulation in government policies. The results could be used on go/no go decision for the Norwegian Megaproject (E39 ferry-free coastal highway construction).

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Keywords: Resilience; System thinking; Integration; Dynamism; Cost benefit analysis (CBA); Decision support system.

1. Introduction

Public investment in large-scale construction projects need critical decisions at all process steps. One mostly used framework to support such crucial decisions to assess the merits with costs of public projects and policies is

* Corresponding author. Tel.: +4797030354

E-mail address: Alemu.m.belay@ntnu.no
CBA. According to [2] CBA is the process of using theory, data, and models to examine tradeoffs, products and activities for assessing relevant objectives and alternative solutions to assist decision-makers in choosing the most appropriate alternatives. [1] Discussed CBA’s advantages, its essence by clarifying the main concepts and defining the benefits, costs, willing to gain (WTG) and willing to pay (WTP). Much construction research also provided evidences for the extensive benefits of CBA and its various applications in construction projects [15, 40, 41].

Despite CBA’s vast applications in construction, CBA did not escape from criticism, raised concerns and practical challenges while using it. [1] argued that CBA used widely than it is realized, substantial ambivalence within the government and regulatory agencies. The defiance emanates mainly from the concern of transparency, doubts and reliability of CBA especially in the benefit sides. Indeed, literature depicted other specific critiques and diversified opposing views of using CBA in various decision-making processes. CBA preferred for evaluating the economic factors associated with regulations and investment decisions [3]. However, it does not identify proposed measures of benefits, such as harms as death or accidents [4,5]. In this connection, [4] raised the issue of CBA’s inappropriateness to generate accurate estimates and it rather produces inconsistent valuations.

According to [1], another methodological concern in CBA is, it stretches out over time. Time is an important factor to be considered while doing CBA in large public investments. Because time influences human preference and their choices between different alternatives. The ultimate goal of every construction project is to provide efficient service to the public (human). So, understand human preference is paramount and apparently, public/individuals tend to prefer the present benefit to the future. Therefore, the future benefits and costs have to discount by some discount rate. In this regard, it is important to use and formulate the right discount rate based on the type of the project. For example, construction firms should use appropriate rate with construction cost/price index.

Besides to the time and cost index concerns, some research argue on the incapability of CBA to handle complex investment decisions because of the uncertainties surrounding the accuracy and reliability of the analysis [6, 7]. Regardless of the aforementioned critiques on CBA, there is limited efforts from methodological and theoretical development of CBA [4]. Unless the decision makers obtain reliable and more accurate methods, making crucial decisions especially in complex megaprojects would be challenging to keep the optimal balance between the needs and resources [8]. Therefore, to make better decisions (e.g. on financial regulations, policymaking), it would require more attention to the CBA process and methodological improvement than just focusing on its result. Indeed, there are some attempts to improve the decision making process by using cost effectiveness analysis (CEA). According to [9], CBA considers only the monetary costs, benefits accruing to a particular organization, and simply ignores the rest. This implies that there are other non-financial issues to be addressed by CBA.

Apparently, there are newly emerging frameworks (e.g. system thinking/dynamics, resilience, and concurrency) that can help to obtain better decision together with the existing traditional CBA. Some literature showed the relevance of system thinking in construction. For example, [10] investigated the possibility of using system dynamics to model a project level productivity. Parallel research in non-construction field, such as health sector showed the value of system dynamics to enhance traditional CBA [2].

As a contribution, this research would like to identify the research gaps in CBA, develop multi-attribute and resilient CBA framework to address the criticisms from construction literature [2]. Therefore, the framework considers intervening the concept of resiliency as a setback mechanism (adjusting itself with the existing change and situation, such as inflation), system thinking to see the overall performance together with interaction between different variables, agile planning to allow iteration with required managerial flexibility, and enhance project performance proactively.

After intensive reviews on CBA literature, we organize the research questions as follows: how construction projects fill the gaps and overcome the criticisms of CBA to handle complex investment decisions. What is the state of the arts of CBA? How construction projects can integrate other emerging frameworks, such as, the concept of resilience, system thinking?

2. Methodology

To respond to the research questions discussed in the introduction part, we use CBA literature review in construction projects. According to the general literature, review provides possibility to understand what has been
done, show the previous challenges, look at the remedial actions taken, and helps to identify the research gap for those problems that are not solved yet. In general, CBA review allow the research to know the states of art.

Therefore, this research conducted based on systematically reviewed academic quality ensured and rigorous peer reviewed articles on cost benefit analysis with a special focus on construction projects. All matters relevant articles extracted from the subset of indexed articles of web of science mainly from Thomson Reuters and Harzing well-integrated databases (accessed on 02.01.2016.). The research looked at keywords, contents, abstracts and concluding remarks.

2.1. Data Selection, filtering and enrichment
Data selection process conducted in three steps: data cube creation, topical data filtering and filtering by data source.

a) Data Cube Creation

From all web of science publications referenced either in Science Citation Index (SCI) or in Social Science Citation Index (SSCI), we conducted three “title and topic” searches. The terms used in the search engine are cost benefit analysis, road, construction, transport, projects, cost overrun, uncertainty, and risk.

To hit the appropriate articles in the field, we use a combination of three terms at a time and surf from the databases. The three key terms composed of two major and one minor search terms (see table. 1). This helps to narrow down our search and more focused on applications of CBA in similar construction industry. In this connection, we search CBA by title and the other two by topics and the database hits 36,667 with average cites per year 601.

The research chose those search terms and used them in combination to abandon the excessive hits (e.g. searching only cost benefit analysis by title alone hits 6997 and 136,070 by topic). This in turn proofs CBA’s strong academic and practical applications in various fields. For obvious reason of filtering the thematic articles, book reviews, books and at that point doubles eliminated.

Table. 1. Major and minor search terms.

| Major search terms | Minor search term | Total hits in each S |
|--------------------|-------------------|---------------------|
| Cost benefit analysis (a) | Roads (c) | 103 Hits (a,b,c)…S1 |
| Construction (b) | Projects (d) | 507 Hits (a,b,d)…S2 |
| + | Transport(e) | 67 Hits (a,b,e)…S3 |
| | Cost overrun (f) | 17 Hits (a,b,f)…S4 |
| | Uncertainty (g) | 116 Hits (a,b,g)…S5 |
| | Risk (h) | 229 Hits (a,b,h)…S6 |
| **Total hits=1039;** | **Total citation =36667;** | **Average Citations per Year 601.1** |

b) Topical Data Filtering
Data filtering was to exclude articles that are not thematically relevant and completely off topic, such as ones with a Biology or other science background. The researcher filtered the data sets, checking: title, abstract, keywords and journal content.

c) Filtering by data source
In order to create an unbiased data background and to ensure the focus on the academic literature analysis, the research shed data files of non-academic articles like book reviews, news items, editorial material, meeting abstract, and books. Finally, we ended up with 170 articles and proceedings (table 2).


3. Research discussion.

The research discussions base the six-search summaries (S1-S6) identified by using major and minor thematic search terms in construction.

3.1. Summary from search (S1): cost benefit+construction+roads.

This research cluster mainly discuss on various application of CBA, methodological improvements, risk and uncertainties in road construction. For example, [11] uses a system that was devised to assess and evaluate the costs and benefits of different alternatives while using recycled asphalt pavement for various roadways. [12] Extends cost–benefit analysis with social analysis in the planning of public road construction projects. In addition, this seems broader and use system approach. However, although [12] did not specifically discuss system thinking, the approach is well articulated and can be converted into system dynamic models. This is because the causal relationships of various factors of CBA briefly explained. Moreover, it elaborated the economic benefits from investment, the linkage of the relationship to the expenditure, its effects to the private sector, increase the production, boost the economy, the need for the transportation, generate income (profits), and finally increase tax as well as boosts the government income. More importantly, it identified the non-road users (e.g. general public, utility enterprises, etc.) and discuss as the part of the whole system. In connection with the social aspect, [13] conducted a social cost-benefit analysis on the western expansion of Line 3 of the Athens Metro. This research found that the project is not feasible on purely financial criteria. However, by incorporating the monetary values of social and environmental benefits, the project founded desirable and beneficial from a social standpoint. This strengthen the need for system thinking and models that could be adopted by adding or subtracting various attributes.

3.2. Summary from search (S2): cost benefit+construction+project.

The most recent research showed that there are endeavors to embed some of advanced modeling methods (e.g. building information modeling (BIM) use together with the usual CBA). In this regard, [14] developed a model to analyze CBA in the construction project. However, it needs proper guidance to the users to identify CBA items and minimize the error to over or underestimate the cost and benefits. Similarly, [15] proposed to use construction information management systems (CIMSs) and developed a framework to assess tangible and intangible cost and benefits of innovative construction technology application. In holistic way, [16] approached CBA from lifecycle assessment perspective, evaluate economic scale, and looked at the carbon pricing with different household alternatives. CBA also used for evaluating different innovative scenarios on road scheduling, energy efficiency technology application for green building, application of radio frequency identification in construction supply chains [17,18,19]. Regardless of several applications and efforts to improve CBA methodology, there are still several concerns. An interesting issue raised by [20] is what decision could managers make if the cost and benefit ratio are the same? To address this concern, [20] proposed an ideal point method to solve the problem using multi objective model. In support of [20], [21] claims the need for multi-criteria analysis to support CBA because it exposed for four types of errors such as omission error, forecasting error, measurement error, and valuation error [22].

There are other miscellaneous applications of CBA that are directly or indirectly linked with construction projects, such as evaluating the performance of bonds and reports, compare the net welfare gained from different
land rehabilitation measures applied in landslide-damaged, monetary valuation, yield preferences, ethical and political values [23, 23, 25]. Another application by [26] is using CBA to enable contractors to assess the pre- and post-contract evaluations on the true cost of accidents prevention and the benefits. [27] Used CBA to compare the public and private incentives to subsidies for green roofs.

3.3. Summary from search (S3): cost benefit + construction+ transport.

Like the other sectors, CBA has significant application in the transport sectors. For example, [25] used CBA to assess the various bio energy alternatives and address the cost and benefit issues associated with bio energy options in urban transport from economic and social perspectives. It also used for transportation policy making, construction and maintenance comparisons, etc. [28, 29]. In transport, unlike the majority of road construction projects, time considered and taken in to account in CBA [30]. This opens up another investigation to evaluate costs and benefits in certain periods. This could also be a very good indicator to think of system approach to see the costs and benefits over time. However, the decision which method to use, may depend on the project type, size and duration. According to [25] although CBA used as a decision support system in enormous projects, interpretation of the analytic results are problematic & it needs to make a choice between the narrow CBA and the comprehensive CBA.

3.4. Summary from search (S4): cost/time overrun + construction+ project.

In this search category, we found a number of articles discussing about cost and/or time overruns at its wider scope in construction literature. Apparently, most CBA literature overlooked at and interpreted either in cost or time risks. Some linked on the cost factors or project delay attributes that creates the overruns. However, our research found limited literature on the benefit analysis. Herby, our review showed cost and time-overruns studies shed the benefit realization.

3.5. Summary from search (S5): cost benefit + construction + uncertainty.

Much of the literature using the major key search terms together with uncertainty and risk seem similar conceptually and sometimes it looks they repeat themselves. However, our investigation allow us to highlight some wider perspectives of uncertainty and risk. This means some researchers apply uncertainty concepts with mitigation to the larger social impacts. According to [31], the 20 mph zone was effective intervention to reduce causalities from traffic crash and CBA used to quantify uncertainty in the results associated with model parameters. The research compares cost of the construction in high and low causalities zones. Another research by [32] developed a quantitative procedure to identify better mitigation designs of road with a very high probability of sinkhole. Because there are several uncertainty factors in construction, there is a need to develop and use integrated cost–benefit analysis [33]. For example, [34] proposed participatory integrated assessment using Bayesian belief network (BN).

3.6. Summary from search (S6): cost benefit + construction + risk.

There are some efforts to use additional decision support while doing CBA. For example, [35] tested theoretically new techniques of quantitative risk analysis (QRA) based on the well-known Monte Carlo simulation to evaluate transportation projects. Similar attempts by [36] confronted the static nature of the standard cost-benefit analysis and claim its incapability to tell when would be preferable to build the road. The research used both stochastic and Monte Carlo simulation and showed the optimal timing for building a road within a cost-benefit framework. More advanced application with the help of urban information system (UIS) and GIS used in combination with CBA. However, according to [37] its result distorted although it was efficient at the beginning. It was because it needs sensitivity analysis besides to apply proper discount rate, CBA and mobile GIS. According to [36], CBA also used for public disaster risk reduction intervention. The research demonstrates risk and cost effectiveness of mitigation strategies. This is because about 60,000 people worldwide die annually mostly due to collapse of buildings in earthquake and lost several properties [38]. Regardless of different approaches and methods used, one important
point that every construction managers and decision makers should keep in mind is that, exaggerating the economic benefits and under estimating, the negative effects can result in over allocation of public resources.

4. Framework development and case implication: The Norwegian E39 ferry-free highway construction.

[6, 7] claims that CBA’s incapability to handle complex projects. The review summaries also support this claim by considering the hypothesis on the existence of complex activities and processes in mega projects that affects the cost-benefit development. Obviously, large/mega projects need huge investment and usually take long project completion time. To extend the hypothesis into practical discussions, we consider one complex project in Norway. The Norwegian Public Roads Administration (NPRA) is responsible to investigate all possibilities to eliminate all ferries along the western corridor (E39) between the city Kristiansand and Trondheim. NPRA expected to make sound decisions and propose best managerial solutions and technological alternatives. Norway’s coastal highway E39 is part of the European trunk road system. The route runs along the western coast of Norway and almost covers a distance of almost 1100 km. The preliminary plan shows E39 will have eight wide and deep fjords ferry connections. Indeed this project needs massive investments and longer spanning structures. When the construction completed, the current travel time of 21 hours expected to reduce in to 12 to 13 hours. According to NPRA, one of the objectives of the study is to substantiate the costs of construction, operations and maintenance, and the benefits for the society in a life cycle perspective of e.g. 50 years.

To main concern is, how can NPRA construct such complex project effectively and efficiently to provide optimal societal benefits? The literature summaries (from 3.1 to 3.6) showed the involvement of several attributes, methods related CBA, market changes, uncertainties, risks, proposals of different approaches for CBA, etc.

As a part of this megaproject, this research would like to study the state of arts, expected challenges, explore methodological advancements in analysing the cost benefits developments. Based on our structured reviews as explained in the research methodology, we identified potential future research areas which could support the decision making process. We found that, CBA is robust enough and applied in several construction projects. Nevertheless, it could be embedded to the emerging advanced frameworks, such as system thinking (system dynamic modelling). This provides to incorporate several factors and look the holistic effects of any change in the process of the construction. However, it seems some important concepts ignored in construction literature that are susceptible to expected and unexpected changes. This research poses questions, such as how our construction system use resilience concept as a setback mechanism for future uncertainties and risk? How can the society start getting the benefits in parallel with the investment? Does the re-emerging frameworks of concurrency and set-based approach be a possible solution to use CBA in such mega projects? (See fig. 1).

![Fig. 1 A framework for organizing resilient CBA.](image-url)
5. Conclusion.

Large construction projects require advanced decision support systems. However, in a situation of managing megaprojects like E39 ferry-free coastal highway with longer project span, several activities and challenges, one method cannot stand-alone to make sound critical decisions. Therefore, it is evident that combining more than one method and need a holistic, integrated multi-criteria decision-making process. As a contribution and from the result of our in-depth literature review, the system approach seems an untapped method to make integrated decisions in construction. In addition, combining concepts like resilience and uncertainty to cope up with expected and/or unexpected changes in the project’s life cycle can help to fill the shortcomings of the ordinary cost-benefit analysis. This apparently maximizes resource utilization and supports the holistic (multi-attribute) system approach decision-making. In line with our framework, [39] claims maximizing the value of the construction facilities projects, focusing on life-cycle costs will benefit the organization and the society in the long term.

The main takeaway and identified research gaps of CBA after referring to the construction projects are:

- Much of the literature focused more on cost and time. The benefit part and its attributes discussed less.
- CBA is one decision-making method at front-end but most benefits realized at later stages of the projects. So, how projects can analyze or involve the post implementation benefits in CBA?
- Large/mega projects have long span, involve several factors with different activities at different stages of the project. Therefore, time is one important factor perhaps equally with the cost. In this connection, how projects evaluate/analyze performances over time and check different scenarios and policies made.

We believe system thinking fills some of these gaps. Regardless of some efforts to use system thinking (apply dynamics models) on complex project, planning and controlling [41], there are limited research on applying system thinking to CBA. Typically, the change management (resilience and uncertainty) and benefit part not studied in the literature. However, literature prevails the capability of system thinking in complex construction projects [43, 44].

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