A COMPREHENSIVE EVALUATION PROCESS FOR TRANSPORT PROJECTS

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

A Comprehensive Evaluation Process for Transport Projects

Transport projects underpin the economic development of a country and thus attract substantial demand imposing immense pressure on many governments primarily due to scarcity of the public resources required to implement them. This particular context demands the governments and other related agencies to allocate public resources efficiently when investing in transport projects. Thus, the evaluation of transport projects becomes an important feature as it indicates how efficiently resources can be or were allocated to a given project. Nonetheless, the literature does not reveal a collectively agreed-upon process for evaluating transport projects despite its rationalization being accepted from the mid 19th century.

The processes predominantly using to evaluate transport projects range from the single-criteria cost-benefit analysis (CBA) to the multi-criteria analysis (MCA) methods and their different combinations. CBA is often criticized for its input- incompleteness raised due to inability to cope with non-monetizable impacts while MCA for its result-incompleteness raised due to those results not being able to demonstrate the implementation feasibility of projects and comparable absolutely. Thus, the most recent trend, combining CBA and MCA, is becoming more popular globally as it is capable of negating each other's disadvantages to a certain extent. However, even these combined models have failed to sort result-incompleteness effectively, primarily due to using MCA methods as their platforms. In view of solving the said input and result-incompleteness issues in existing processes, this research aimed to develop a new evaluation process for transport projects capable of ensuring (i) input-completeness by taking both monetizable and non-monetizable impacts into account and (ii) result-completeness by producing results enabling to test the implementation feasibility of each evaluated project and their performance-based prioritization.

This new evaluation process, termed as comprehensive evaluation process (CEP), was formulated by first establishing a Theoretical Comprehensive Evaluation Process (TCEP) using an inductive approach and then functionalizing it through an approach of deductive reasoning. The TCEP was developed on a MCA platform, ensuring input and result-completeness, and minimizing MCA method related issues such as subjectivity, arbitrariness, and double counting, and common issues of transparency, robustness, simplicity, and accountability. The functionalization improved the practicality issues associated with the TCEP in solving transport project evaluation problems and eventually established the Functionalized Comprehensive Evaluation Process (FCEP). Such formulated FCEP was incorporated with a methodological adjustment to test the implementation feasibility of each evaluated project and thereby established the CEP.

The CEP ascertains both input and result-completeness in its practical application to solve transport project evaluation problems and hence achieves originally set features for the new evaluation process in the research aim. This new process was demonstrated by applying it to an evaluation problem targeted to improve public transportation on the Galle Corridor in Sri Lanka. The results of the same demonstration were compared with their originals estimated using the CBA to validate the CEP justifying deviations through rational reasoning.

Keywords: input-completeness, result-completeness, multi-criteria analysis, functionalization

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BCA	Benefit-Cost Analysis
BCR, B/C	Benefit-Cost Ratio
BPL	Bus Priority Lane
BRT	Bus Rapid Transit
BVM	Benefit Valuation Module
CBA	Cost-Benefit Analysis
CEP	Comprehensive Evaluation Process
COSIMA	Composite model for assessment
CVM	Cost Valuation Module
DAP	Dummy Alternative Project
DOT	Department of Transport
EFFECT	Evaluation Framework of Environmental Impacts and Costs of Transport
ELECTRE	ELimination Et Choix Traduisant la Realité
EU	European Union
EUNET	European Network for Education and Training
FCEP	Functionalized Comprehensive Evaluation Process
FVM	Final Valuation Module
GDP	Gross Domestic Product
GPV	Global Priority Value
HEATCO	Harmonized European Approaches for Transport Costing
ICM	Impact Categorization Module
IRR	Internal Rate of Return
IS	Isolated Score
LPV	Local Priority Value
MAMCA	Multi-Actor Multi-Criteria Analysis
MAUT	Multi-Attribute Utility Theory
MCA	Multi-Criteria Analysis
NATA	New Approach for Transport Project Appraisal
NIS	Negative Ideal Solution
NPV	Net Present Value
OECD	Organization for Economic Cooperation and Development
PIS	Positive Ideal Solution
RO	Research Objective
RQ	Research Question
RWM	Railway Modernization
TCEP	Theoretical Comprehensive Evaluation Process
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UK	United Kingdom
US	Universal Score
USA	United States of America
WEIs	Wider Economic Impacts
w.r.t	with respect to

CHAPTER 1

RESEARCH BACKGROUND

1.1 Introduction

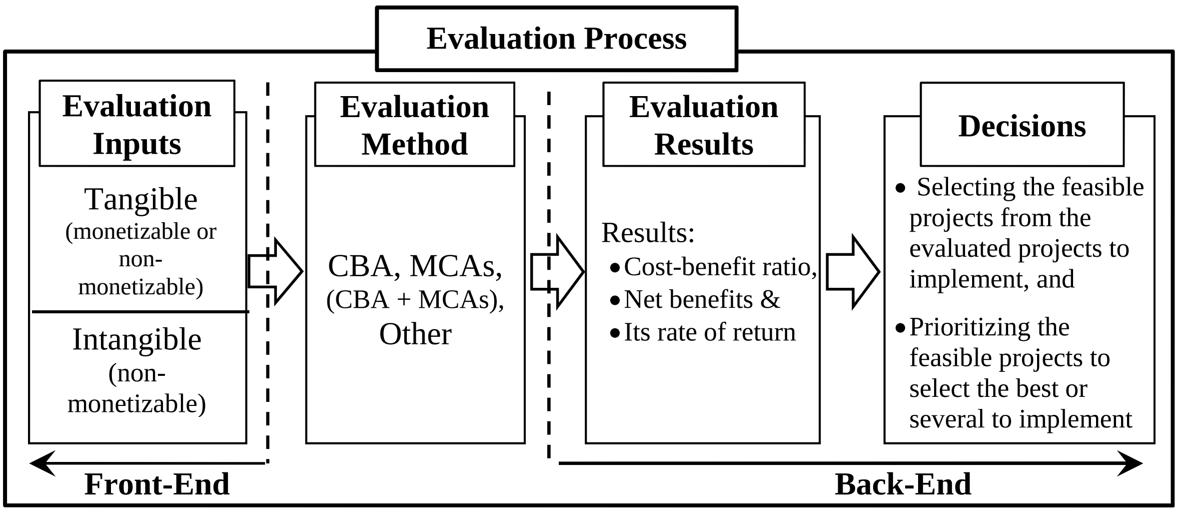
This chapter primarily provides the background of transport project evaluation, setting up of the research problem, aim, significance, scope, limitations, questions, and objectives of the research. Further, the chapter also provides clear definitions and appropriate classifications for key terms related to transport project evaluation in line with available literature to ensure consistency in their meaning and usage throughout the thesis. Lastly, the chapter introduces the structure of the thesis and a brief description of each chapter.

1.2 Introduction to Transport Project Evaluation

A transport project is an activity or series of activities executed to generate or improve a transport function by investing capital funds on new construction, improvement, or rehabilitation and recurrent funds on the associated operation and maintenance activities during its life. It has a definite scope, cost, and time-frame to deliver and has a set of intended benefits to achieve. The evaluation of a transport project refers to how effectively and efficiently funds have been utilized in delivery of the intended benefits of the project. This research targets a new process for evaluating transport projects eliminating identified drawbacks in existing processes. It should be noted that this new process is also applicable for evaluating programs, which may be defined as a collection of multiple projects managed in a coordinated way to achieve intended benefits that are not achievable by managing the included projects individually.

Transport projects underpin the economic development of a country (Nguyen, Cook, & Gunawan, 2018). Therefore, they always attract a substantial demand under public sector investments, particularly for building new infrastructures. Organization for Economic Co-operation and Development (OECD, 2019) shows that in 2017, China invested 5.8% of its Gross Domestic Product (GDP) in building up of new transport infrastructures whereas Australia invested 1.5%, India 1.1%, United Kingdom 1.0%, Japan 1.0%, the Russian Federation 0.8%, France 0.8%, and the USA 0.5%. Sri Lanka invested only about 0.8% of its GDP in new transport infrastructure in 2017 (Ministry of Finance, 2018), given its many other priorities as a developing country. Such a substantial demand for transport projects has imposed immense pressure on many governments, mainly because of the scarcity of public funds for investment (Asensio & Roca, 2001). This context has forced governments to allocate their public funds most effectively and efficiently when investing in transport projects (Jones, Domingos, & Moura, 2014). At this juncture, the evaluation of transport projects essentially becomes a vital process as it indicates how effectively and efficiently funds can be or were allocated in a given project (Hickman & Dean, 2017; Schutte & Brits, 2012).

The evaluation of a transport project is a process of weighing benefits (positive impacts) and costs (negative impacts) generated during and after implementation of a project compared to a base-case and thereby producing the final results as a score, ratio of costs and benefits, net benefits, and its rate of return, etc. (Asian Development Bank [ADB], 2017; Belli, Anderson, Barnum, Dixon, & Tan, 1998; European Commission [EC], 2014). These results need to support to make the decisions of (i) which projects are feasible for implementation among the evaluated, and (ii) which project(s) is (are) to be prioritized in implementation among those that are feasible. The overall framework of a conventional transport project evaluation process detailing key elements and their placements is presented in Figure 1.1.



Note: CBA = Cost-Benefit Analysis, MCAs = Multi-Criteria Analyses

Figure 1.1: Overall framework of a conventional transport project evaluation process
Source: Author

As shown in Figure 1.1, an evaluation process for transport projects consists of four elements: (i) evaluation inputs, (ii) evaluation method, (iii) evaluation results, and (iv) decisions. The evaluation inputs are at the front-end of the process, whereas the evaluation results and decisions are at the back-end. The evaluation method is in-between the evaluation inputs and results, converting the former to the latter.

The inputs of an evaluation process (referred to as the evaluation inputs) are the impacts generated by implementing a project and are in the form of costs and benefits. Some of these impacts are tangible, while others are intangible. Out of tangible impacts, some can be expressed in monetary terms while others cannot be. The former impacts are called monetizable, while the latter is called non-monetizable. All intangible impacts are non-monetizable. The above breakdown allows impacts to be classified as monetizable and non-monetizable over and above being tangible or intangible.

The evaluation method, placed as the intermediate component between the inputs and the results in the evaluation process, is a technique used to derive the results synthesizing the inputs fed in. The processes currently in practice for the evaluation of transport projects use methods ranging from single-criteria cost-benefit analysis (CBA) to multiple criteria analysis (MCA) methods and their different combinations (Shang, Tjader, & Ding, 2004). The competency of this method to absorb inputs and synthesize them to produce results supporting required decision making is a crucial factor in determining the ‘completeness’ of its parent process.

The CBA is largely a unified method, while MCA is less unified, probably with more than a hundred types of methods (Basbas & Makridakis, 2007; Jensen, 2012; Macharis & Bernardini, 2015; Tsamboulas et al., 1999). The above statement suggests a single unified process using CBA as the evaluation method (hereafter referred to as CBA process or CBA). In contrast, the same statement indicates the existence of multiple types of evaluation processes using different MCA methods (hereafter referred to as MCA processes or MCAs). Further, the multiplicity of MCA methods also lead to having different types of CBA and MCA combined processes (hereafter referred to as CBA-MCA combined processes).

The results derived by an evaluation process (referred to as the evaluation results) for each evaluated project indicate their individual performances[1] in achieving intended benefits by utilizing allocated funds. The CBA process provides results in three forms: cost-benefit ratio, net benefits, and its rate of return. On the other hand, MCA processes and CBA-MCA combined processes provide results as a score pertaining to each evaluated project. Any project having an excess of generated benefits over its invested cost is treated as being feasible for implementation. Thus, in the CBA process, a given project in order to be feasible for implementation, its evaluation results should be equal or exceed the thresholds of one in benefit over cost ratio, zero in net benefits, or favorable opportunity cost assessed through the rate of return. In the MCA processes and CBA-MCA combined processes, a threshold value for the scores should be established to determine the implementation feasibility of a project being evaluated. This threshold value is specific to the evaluation problem and hence it cannot be generalized like in the CBA process.

Projects with the higher numerical values in results are stronger in implementation feasibility thus are more preferred to implement. In overall, the results of an evaluation process are used to take two crucial evaluation decisions of (i) selecting the feasible project(s) for implementation by comparing their results with the relevant threshold value mentioned above and (ii) prioritization (or ranking) of evaluated projects comparing their performances demonstrated by the results. Usually, the prioritization is carried out only for the feasible project to select the best project or even a combination of projects to implement.

When analyzing the nature of inputs and the decisions to be made using such inputs, an evaluation process can be treated as 'complete' if it can (i) take all identified impacts, including both monetizable and non-monetizable, into account as inputs, and (ii) produce the results usable for testing the implementation feasibility of evaluated projects and enabling their prioritization. The former feature relates to incorporating

[1] The performance is referred to how effectively and efficiently funds have been utilized in achieving the intended benefits of the project. In CBA, cost benefit ratio and net benefits are measures of the effectiveness while rate of return of the efficiency.

inputs to the evaluation process and is referred to as the 'input-completeness' whereas the latter relates to the results in supporting the decisions and is referred to as the 'result-completeness' of the evaluation process. A failure of excluding at least a single identified input is termed in this research as the 'input-incompleteness', whereas the inability of results to use for the evaluation decisions of either testing the implementation feasibility of evaluated projects or prioritizing (ranking) of them or both treated as the 'result-incompleteness'.

The input-completeness primarily depends on (i) the ability to quantify (in monetary terms or otherwise) **all identified impacts** (inputs) to feed into the evaluation method; and (ii) the competency of the evaluation method (inbuilt in a process) to synthesize **all quantified impacts** in (i) above. On the other hand, the result-completeness depends on (i) the ability of the evaluation method to produce results demonstrating the performance of evaluated projects, and (ii) having a threshold value for the results in (i) above to determine the implementation feasibility of the evaluated projects. Any evaluation process that ensures both 'input and result-completeness' is treated as a 'complete' evaluation process, as indicated above.

1.3 Research Problem

The literature reviewed in Chapter 2 shows that the most widely accepted best practices in transport project evaluation currently are the CBA process, MCA processes, and CBA-MCA combined processes. The review further reveals that none of the above processes are 'complete' in transport project evaluation as all of them fail to ensure either input-completeness or result-completeness or both. The performances of the existing best practices against the afore-mentioned incompleteness issues are summarized in Table 1.1.

Table 1.1: Input and result-completeness of existing best practices

Evaluation Processes	**Input-completeness** (Inclusion of all identified impacts)		**Result-completeness** (Usability of Results to take evaluation decisions)	
	Monetizable	**Non-Monetizable**	**Usable for testing implementation feasibility**	**Usable for prioritization**
CBA	Included	Not Included	Usable	Usable
MCA	Included	Included	Not Usable	Usable[1]
CBA-MCA Combined	Included	Included	'Usable' but with limitations in some instances	Usable[1]

Note: [1]Usable only if all projects are evaluated in a single evaluation domain; CBA= Cost-Benefit Analysis, MCAs = Multi-Criteria-Analysis.

Source: Author

As demonstrated in Table 1.1, the most popular and widely used CBA process counts only monetizable impacts, ignoring all non-monetizable impacts despite them being identified as clear impacts of the transport projects under evaluation. Even the monetizable benefits only represent a part of the tangible impacts and often subject to criticism for the accuracy of their valuation methods. Thus, it is very clear that the CBA process suffers from the input-incompleteness in transport project evaluation. In contrast, the MCA processes are regarded as ensured with the input-completeness as their inbuilt evaluation methods are capable of counting both tangible as well as intangible impacts despite debatable techniques in quantifying the intangible impacts and limitations in techniques in quantifying some tangible impacts. However, it was revealed that most MCA methods inbuilt to these processes, except a few such as TOPSIS method, demonstrate deficiencies and complexities in counting opposing impacts (or criteria) such as costs and benefits, degrading the comprehensiveness of the input-completeness of the overall MCA processes. All in all, it can be concluded that the MCA processes demonstrate the input-completeness when compared to the CBA despite (i) quantification issues pertaining to some impacts and (ii) difficulties in handling opposing impacts in some MCA methods.

In contrast to the input-incompleteness, the CBA process shows perfect completeness in its results since those results support both the evaluation decision of testing implementation feasibility of the evaluated projects and their prioritization. This is because CBA results are performance indicative of each evaluated project and are coupled with a feasibility threshold value (e.g., unity in cost-benefit ratio, positive net benefits, and favorable opportunity cost in the rate of return). Meanwhile, the MCA processes show incompleteness in their results, which are in the form of 'scores', since those results are being only usable for prioritization of the evaluated projects but not for testing their implementation feasibility. This is due to these results not being coupled with 'feasibility threshold value' despite only being performance indicative. Even in the prioritization, results of the MCA processes can only be usable to compare the performances of projects only if those projects are evaluated with respect to a same set of criteria (or project impacts) weighted to represent a pre-set goal. In other words, the results of projects evaluated with respect to different sets of criteria in the MCA processes cannot be comparable and thus are unusable for prioritizing respective projects. This is due to MCA results being specific to an evaluation domain[2] considered. In contrast, the results of the CBA process, which are in the form of a cost-benefit ratio, net benefits, or rate of returns, do not depend on the evaluation criteria (or project impacts) used and hence are usable for comparing the performances of all kinds of projects even included in different evaluation domains. In this thesis, this phenomenon in the CBA process is termed as that its results facilitate 'absolute comparability' while in the MCA processes, that their results facilitate only 'relative comparability'.

In recent years, different combinations of CBA and MCA (referred to as combined, hybrid, or integrated processes) have been tested as transport project evaluation processes to apprehend one's incompleteness from other's completeness in inputs and results. However, such processes have not solved the problem of 'incompleteness' appreciably, particularly in relation to the result-incompleteness. In-fact, those processes are relevant and applicable to specific evaluation problems considered, thus

[2] An evaluation domain is a collection of three components: (i) set goal for the investment, (ii) selected projects to achieve the above set goal, and (iii) criteria set for evaluating projects' performance in achieving the set goal. Rationally selected projects derive more or less same and relevant impacts to achieve the set goal, and in turn those becomes the evaluation criteria. This indicates that rationally defined evaluation domain comprises firmly inter-connected components.

requires further generalization to make them usable for all kinds of transport project evaluation problems. These unsorted incompleteness issues related to the inputs and results in existing combined processes are detailed in Chapter 2, together with many other related issues.

In conclusion, none of the existing evaluation processes for transport projects have ensured the completeness of both inputs and results. They either suffer from input-incompleteness or result-incompleteness or both. Thus, 'incompleteness either in inputs or in results' of existing evaluation processes remains as a problem to resolve and is identified as the problem to be resolved under this research.

1.4 Research Aim and Significance

In order to address the aforementioned research problem - the incompleteness of inputs and results of the existing best evaluation practices - the aim of this research is set to develop a new evaluation process for transport projects strengthening both input and result-completeness to ensure the completeness of the overall process. Thus, theoretically, this new process should be capable to

(i) take all identified impacts, including both tangible and intangible (or monetizable and non-monetizable) impacts, into account as inputs, and

(ii) produce results usable for testing the implementation feasibility of each individual project evaluated and enable their performance-based prioritization.

Thus, the aim of this research can be concisely presented as;

> *"developing a new process for the evaluation of transport projects which is capable to (i) take all identified impacts, including both tangible and intangible (or monetizable and non-monetizable) impacts, into account and (ii) produce results usable for testing implementation feasibility of each individual project evaluated and enable their performance-based prioritization."*

Moreover, while building up this new process, all possible efforts are made to eliminate or minimize other conceptual, theoretical, and procedural flaws associated with the existing best practices. Consequently, the new process should be characterized with transparency, simplicity, robustness, and accountability to be exemplary for transport project evaluation as demanded by Banister (1997) and Mintzberg (1979) (as cited in Tsamboulas, Yiotis, & Panou, 1999). Here transparency refers to the ability to understand and interpret the process, simplicity to emphasis and clarity of pivotal point of the process, robustness to capability to consider all inputs in the process and provide a result unchallengeable, and accountability to process being explainable by tracking back through the different stages (Tsamboulas et al., 1999).

The proposed new evaluation process ensuring the above features in its real-life application to solve transport project evaluation problems is termed as the comprehensive evaluation process (CEP). In other words, the CEP is an evaluation process that can be practically applicable to evaluate transport projects ensuring both input and result-completeness. In this research, the CEP is developed in three stages.

(i) Initially, a process ensuring both input and result-completeness is established theoretically without considering its practicality in applying to evaluate transport projects. This formation is termed as the theoretical comprehensive evaluation process (TCEP).

(ii) Thereafter the TCEP is improved to make it practically applicable to evaluate transport projects. This particular improvement is termed as functionalization while its outcome is termed as the functionalized comprehensive evaluation process (FCEP). Such developed FCEP ascertains the input-completeness in its practical application, but not the result-completeness.

(iii) Thus, the FCEP is further improved to ascertain its result-completeness and thereby establish the CEP which is ensured with both input and result-completeness in its practical application to evaluate transport projects. The methodology adopted for developing the CEP is detailed in Chapter 3 while its developmental stages are briefed in Figure 1.2.

	TCEP		FCEP		CEP
A. Input-completeness	✓	Functionalization	✓	Identified Improvements	✓
B. Result-completeness	✓	→	**?**	→	✓
C. Practicality in application	**?**	*(ascertains A & C, but not B)*	✓	*(ascertains A, B & C)*	✓

Figure 1.2: Stages of the new evaluation process development
Source: Author

The significance of this research depends on the enhanced features inbuilt to the CEP compared to the existing evaluation processes for transport projects. As stipulated in the research aim, the CEP becomes significant since it is strengthened for both input and result-completeness, in contrast to the existing ones of which only one aspect, either the input-completeness or the result-completeness, is stronger. A detailed demonstration of the significance of this research is given in Chapter 8 after explaining the development and application of the CEP in subsequent chapters.

1.5 Research Scope and Limitations

The research scope is the set boundaries for the research in terms of its study area. For this research, it aligns with the set boundaries for the proposed CEP for the transport projects. Those set boundaries are described below.

(i) The CEP is to build as an extended version of the most recent best practices, and hence it is primarily based on available theories, concepts, and methods with minor adjustments. Such includes CBA and MCA techniques etc.

(ii) The CEP is applicable for evaluating any kind of transport project, including road projects, public transport improvement projects, and multi-purpose transport projects. Moreover, it is also applicable to transport projects in both local and global contexts as well as in both urban and rural sectors. Its applicability to non-transport projects is not tested herein.

Research limitations are the uncontrollable influences and factors that limit the research scope and its quality. Such limitations associated with this research are described below.

(i) Since the CEP uses available theories, concepts, and methods, such as CBA and MCA, in its development, their in-built fundamental conceptual and theoretical flaws are reflected in this new process also.

(ii) Identifying project impacts completely and assessing their influences precisely ensure the input-completeness of any evaluation process and thereby make its results comprehensive. But practically, the above two tasks are constrained by (a) the lack of information available on project impacts and their influences and (b) the generality of those available information. This is a common limitation for the existing evaluation processes and it remains unsorted for this new evaluation process too.

(iii) Since the CEP is developed on a MCA platform, its results are not absolute comparable but only relative comparable (refer Sub-section 6.5). Thus, those results are only usable for the prioritization of projects evaluated with respect to a same set of criteria. In other words, results obtained for the projects evaluated with respect to different sets of criteria are not comparable. This is considered as another limitation of this new process.

The above limitations do not significantly degrade the value of this new evaluation process. A more detailed illustration of the limitations of this research is given in Chapter 8 after comprehensively demonstrating the development and application of the CEP in subsequent chapters.

1.6 Research Questions

The research problem, together with its aim, directed to formulate four Research Questions (RQs) presented below.

RQ1: What are the currently available best practices for transport project evaluation and their strengths and weaknesses?

RQ2: What are (i) the selected weaknesses (from RQ1) to be addressed and (ii) proposed further improvements to be incorporated in the proposed new evaluation process?

RQ3: What are the sequential tasks to be followed in developing the proposed new evaluation process? These tasks should ensure the strengths of the existing best practices in the proposed process while addressing the above-selected weaknesses and incorporating further improvements.

RQ4: How to apply and validate the new evaluation process?

1.7 Research Objectives

The following research objectives (ROs) are developed to respond to the aforementioned research questions.

RO1: Critically review currently available transport project evaluation practices and identify the best practices and their weaknesses requiring improvements (Response to RQ1).

RO2: Identify the weaknesses to be addressed and further improvements to be incorporated in the proposed new evaluation process in line with the research aim and its significance (Response to RQ2).

RO3: Develop the proposed new evaluation process, which eliminates the identified drawbacks in current best practices and complies with the research aim and its significance (Response to RQ3).

RO4: Demonstrate the application and validation of the new evaluation process through a case study (Response to RQ4).

1.8 Chapter Breakdown

Chapter 1	**Research Background:** This chapter provides an overview of the research work, demonstrating transport project evaluation concisely and designing it by setting up the research problem, aim, significance, scope, limitations, questions, and objectives. Moreover, the chapter extends to provide clear definitions for key technical terms intended to use in this thesis, ensuring their clarity and consistency in the meaning.

Chapter 2	**Practices in Transport Project Evaluation**: The chapter explores the development of worldwide practices in transport project evaluation to date and concludes after critically reviewing the current best practices in terms of their theoretical frameworks, application procedures, and strengths and weaknesses. It eventually underpins the identified research gaps to be treated under this research and justifies the motive to develop a new evaluation process for the transport projects, in addition to providing necessary recommendations and guidance for its development.
Chapter 3	**Research Methodology:** This chapter first demonstrates the features that should be inbuilt into the proposed new evaluation process for eliminating the major weaknesses of the existing evaluation processes for transport projects. Thereafter it presents research approaches to ensure such features on a MCA platform. Eventually, the chapter describes the methodologies for developing the proposed new evaluation process and its validation aligned with the research approaches.
Chapter 4	**Formulation of Theoretical Comprehensive Evaluation Process:** The chapter describes (i) formulating the theoretical comprehensive evaluation process (TCEP), (ii) analyzing it for understanding the fine-tunings required for its functionalization and thereby identifying the additional knowledge to be gathered, and (iii) gathering such identified additional knowledge required through further literature reviews. Eventually, the chapter provides the necessary recommendations and substances for establishing the functionalized comprehensive evaluation process (FCEP).

Chapter 5	**Functionalization of Theoretical Comprehensive Evaluation Process:** This chapter details the functionalizing TCEP by incorporating the recommendations and knowledge gathered in the previous chapter. The said functionalization targets to improve the practicality of the TCEP in applying to evaluate transport projects. Eventually, the chapter analyses the FCEP to identify necessary improvements to upgrade it to the CEP.
Chapter 6	**Testing Implementation Feasibility of Evaluated Project:** The FCEP presented in the previous chapter ultimately derives scores indicating the performances of each evaluated project in achieving the set goal for the investment. However, those scores are not self-indicators of the implementation feasibility of respective projects. Thus, the chapter introduces a 'threshold score' for the evaluated projects to declare them feasible. This chapter completes the formulation of the proposed new evaluation process (CEP) for transport projects. Eventually, the chapter discusses the CEP's application in different evaluation contexts.
Chapter 7	**Demonstration & Validation:** This chapter demonstrates the application of formulated CEP by applying it to a transport project evaluation problem targeted to improve public transportation in Galle Corridor in Sri Lanka. The results of this demonstration are compared with their original results estimated with CBA to validate the CEP justifying the deviations through rational reasoning.
Chapter 8	**Conclusions & Recommendations:** This chapter provides conclusions in relation to (i) the achievement of research aim and objectives and (ii) contribution to the knowledge detailing the significance and limitations of the CEP. In addition, the chapter provides recommendations for effective handling of this new process while highlighting requiring future research to improve its application.

1.9 Summary

This chapter provides an overview of transport project evaluation first and then sets up the research problem, aim, significance, scope, limitations, questions, and objectives. In brief, the research aim was set to sort out the problem of the inability to ensure ‘completeness of inputs and results’ in existing evaluation processes for transport projects by introducing a new evaluation process. The chapter further extended to define key terms associated with this research in line with available literature to ensure their consistency in the meaning and usage throughout the thesis. Eventually, it outlines the structure of the thesis providing a brief introduction to the content in each chapter.

CHAPTER 2

PRACTICES IN TRANSPORT PROJECT EVALUATION

2.1 Introduction

This chapter reviews the related literature, primarily to ascertain two arguments used to establish the research problem and aim in the previous chapter. Those two arguments are: (i) current best practices in transport project evaluation have narrowed down to CBA, MCA, and their combination and (ii) those best practices still have unresolved weaknesses including ‘inability to ensure completeness in inputs and results’ which are identified to be treated under this thesis. Moreover, the chapter extends its review to justify the motive to develop a new evaluation process for the transport projects, as intended in the research aim and provides necessary recommendations and guidance for its development.

2.2 Structure of Literature Review

This review is carried out in two stages, as shown in Figure 2.1.

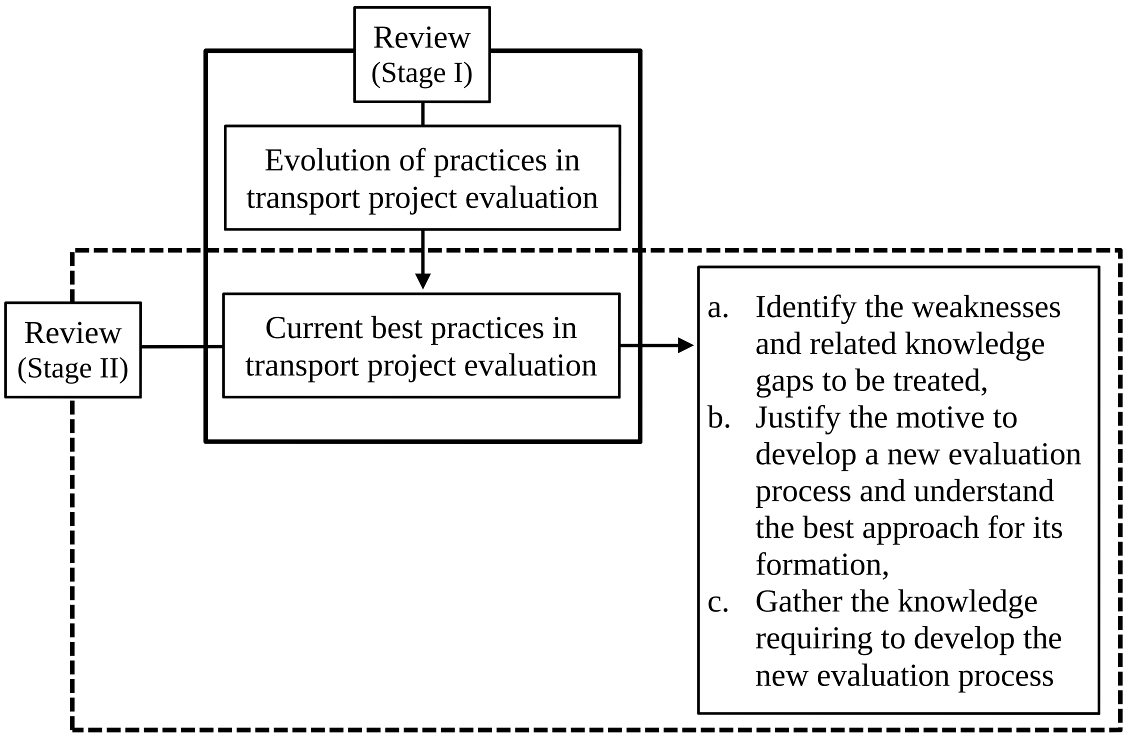


Figure 2.1: Structure of the literature review
Source: Author

Under Stage I, current best practices in transport project evaluation are ascertained as CBA, MCA, and their combinations, primarily on the credibility basis. For this purpose, the evolution of worldwide practices adopted for the evaluation of transport projects is examined, particularly in the land transport sector, from its origin in the mid-19th century to date. Under Stage II, each of those current best practices is reviewed in terms of theoretical frameworks and their soundness; application procedures and their limitations; and strengths and weaknesses. It allows to (i) identify the weaknesses and related gaps in 'the best practices' nailing down the ones intended to treat under this research, and (ii) justify the motive to develop a new evaluation process and understand the most appropriate approach to follow in this research for building up the said new evaluation process, and (iii) partially gather the conceptual and theoretical knowledge required to develop the new evaluation process.

2.3 Stage I: Evolution of Practices in Transport Project Evaluation

The literature shows that the evolution of practices in transport project evaluation can be divided into two distinct time frames primarily based on their developments in conceptual and theoretical frameworks. They are (i) early developments (from origin to beginning of 21st century), and (ii) recent developments (after the 2000s to date). Two sub-sections below, separated for afore-said time frames, outline the gradual, systematic development of underlying concepts, theories, and methods in the evaluation processes over the years and concludes presenting current best practices to be further assessed in relation to gap identification and new process formulation.

2.3.1 Early Developments

Early developments of evaluation processes in the global context can be segregated into four key topics: (i) origin of transport project evaluation, (ii) establishment of CBA as a standard practice, (iii) moving towards alternative approaches, and (iv) emergence of MCA as a standalone practice. These topics are discussed in the following sub-sections to find out the best practices leading to the year 2000s.

2.3.1.1 Origin of transport project evaluation

The evaluation of transport projects has an extended history, even though approaches used in such evaluations have not been confined to a single method that can be collectively agreed upon universally (Bristow & Nellthorp, 2000; Hayashi & Morisugi, 2000; Joint Transport Research Centre, 2008; Korytárová & Papežíková, 2015; Mackie, Worsley, & Eliasson, 2014; Wanle, Ming, & John, 2019). Nakamura (2000) has indicated that an attempt made by the French Civil Engineers in the mid-19th century, when the emergence of the railway led to question the requirement of conventional projects such as roads and canals, as the first scientific approach followed in the evaluation of transport projects. However, it is quite evident that the evaluation of transport projects was rationalized with the use of cost-benefit analysis in the evaluation of infrastructure projects since mid 20th century (Coombs, Hobbs, & Jenkins, 2005; Grant-Muller, Mackie, Nellthorp, & Pearman, 2001; Organisation for Economic Co-operation and Development [OECD], 2006). Grant-Muller et al. supported this argument making a strong statement of:

The major upsurge in the development of appraisal techniques for transport projects came in the late 1960s and early 1970s. During this period, principles of cost-benefit analysis of transport projects were practically detailed through programs based on theoretical and empirical work, for example, the relevant monetary values for time and safety benefits (pp. 237-238).

In favor of the second half of Grant-Muller et al. (2001) statement given above, the subsequent sub-section provides clear evidence on the establishment of CBA as a standard practice in project evaluation.

2.3.1.2 Establishment of CBA as a standard practice

The practice of cost-benefit analysis prominently appeared in the Flood Control Act 1936 in the United States of America (USA) while its concept first appeared in an article written by Jules Dupuit in the mid-19th century and subsequently formalized by Alfred Marshall by the end of the same century (Damart & Roy, 2009; Michael & Revesz, 2013; OECD, 2006; Pearce, 1983; Posner & Adler, 1999). However, Pearce

(1983) stated that the conceptual framework of CBA was firmly established based on the welfare economic theory after the said Act was introduced and with certain key theoretical contributions made in the late 1930s. Organization for Economic Co-operation and Development (OECD, 2006) asserts this argument: “The body of modern-day welfare economics which underlies CBA was established by Hicks (1939, 1943), Kaldor (1939) and others in the 1930s and 1940s” (p.32).

As stated at the beginning of this sub-section, even though there is no single method universally agreed, it is evident that CBA had earned worldwide popularity as a standard practice to evaluate infrastructure projects, including transport projects. OECD (2006) believed that pressure mounted on European governments to utilize public funds rationally and efficiently after ending World War II in 1945 provided the initial momentum for CBA to popularize. Backing their own belief, the OECD, founded with 18 European countries in 1948 to rebuild the war-affected economies and expanded to include the USA and Canada in 1961, sponsored to develop early manuals for standardizing CBA in project evaluation. These manuals were authored by Ian Little and James Mirrlees in the late 1960s and compiled into a single document in 1974 with necessary revisions to the previous and known as the OECD Manual (Little & Mirrlees, 1974; OECD, 2006; Weiss, 1978). Weiss (1978) expressed that this manual caused to revive the discussions on project evaluations, which seemed almost over at the beginning of the 1970s and motivated the World Bank to introduce a new methodology for the project evaluation. However, Weiss, in his comparative assessment of (i) theoretical approaches presented in the OECD manual, (ii) new World Bank methodology (Bruce, 1975; Tak & Squire, 1975) and (iii) another prominent methodology practiced by the United Nations Industrial Development Organization (UNIDO) at that time (Dasgupta, Marglin, & Sen, 1972), demanded further improvements in project evaluation methodologies, highlighting the failures of all three approaches to (i) deal with multi-dimensional nature of evaluation problems (only economic efficiency is considered leaving out social and environmental impacts, etc.), and (ii) model future aspects influencing the project. It is noted that underlying theories of all these three approaches have been developed based on CBA.

Being specific to transport projects, Grant-Muller et al. (2001) stated that the series of Round Table meetings held by the European Conference of Ministers of Transport (ECMT) in Paris since the late 1960s were immensely contributed to establishing specific norms for project appraisal in the transport sector. In this regard, Grant-Muller et al. highlight the contribution of Round Table reports done by Beesley and Evans (1970), Frost (1977), and Harrison and Quarmbly (1969) to emulate the practical development of CBA at that time. The authors also believed the outcome of these meetings provided the foundation for current appraisal practices in transport projects and the baseline for measuring progress in later developments.

2.3.1.3 Further standardization and customization of CBA

OECD (2006, p.34) indicated that the conceptual and theoretical framework of CBA was seemed well-establish by the end of the 1980s, as a general practice of project evaluation, including transport projects, with the publication of its own manual and subsequent publication of the World Bank. However, methods of (i) estimating inputs such as discount rates, conversion factors, and residual values, etc., and (ii) monetizing of project costs and benefits were left to discuss through the country or agency-specific manuals, guidelines, and researches. Such key early manuals developed at country or agency level for transport project evaluation includes;

- **COst Benefit Analysis (COBA):** This is a procedural approach based on conventional CBA compiled into a computer program to evaluate transport projects in the United Kingdom since 1973 (Price, 1999). The original version was upgraded based on the recommendations of the Standing Advisory Committee on Trunk Road Assessment to deal with certain identified issues of urban roads (1986), environmental impacts (1992), induced traffic (1994) and, the impacts of transport on economic growth and competitiveness (1999) and thereby improved its quality in the application (Vickerman, 2000).

- **Guide to Practical Project Appraisal: Social Benefit-Cost Analysis in Developing Countries** (Hansen, 1986)**:** The guide was prepared in 1986 to improve the applicability and practicability of the previous publication by UNIDO, Guidelines for Project Evaluation (Dasgupta, Marglin, & Sen, 1972) which had been developed based on a theoretical flat-form of CBA. This guide also retained CBA as its basic framework and improved methods in treating market price distortions incurring in the economies of developing countries and certain parameters to be used in CBA. However, there was no emphasis on incorporating indirect and external costs or benefits.

- **Guide to Benefit-Cost Analysis in Transport Canada** (Economic Evaluation Branch of Transport Canada, 1994)**:** Transport Canada, the department responsible for developing regulations, policies, and services of transport functions, sanctioned CBA to carry out for major transport investments by publishing dedicated guidelines in 1994. It has encouraged decision-makers to evaluate projects based on direct costs and benefits with the appropriate qualitative assessment on indirect and external benefits.

- **World Bank Handbook on Economic Analysis of Investment Operations** (Belli et al., 1998)**:** The World Bank published this handbook in 1998 as a practical guide to (i) provide its staff with analytical tools that are firmly established with economic theories, but yet simple and practical in application, and (ii) provide a more transparent approach to the economic evaluation of projects. The handbook offered a set of usable tools to conduct financial, economic, and fiscal analysis for the projects, particularly in the health, education, and transport sectors. The approach recommended for evaluating transport projects using CBA primarily relying on monetizable direct benefits while suggesting methods to internalize environmental externalities by monetizing them.

- **Guides in the United States of America for Transport Project Evaluations** (Lee, 2000; Weisbrod, 2013)**:** CBA was not mandatory for federal transportation decision-making until 1994, although federal regulations demanded it for all other proposed projects with effect of the Federal Navigation Act of 1936 and the Flood Control Act of 1939. President Clinton's Executive Order (EO) 12893 of January

26, 1994, made it compulsory for all federal agencies to adopt CBA for quantifying and monetizing all benefits and costs to the maximum extent possible. This development led federal government's administrations, including United States Federation Highway Administration, Federal Aviation Administration, and Federation Transit Administration, to issue transport sector evaluation guides from time to time in the 1990s based on CBA theories. At the same time, state governments also produced their own guidelines based on CBA and supported with appropriate tools (Eg, BCA.net for highway projects in Arkansas, Michigan, Connecticut; Cal-B/C tool for California; NetBC for Indiana). However, in prioritization of projects, MCA was widely used, taking into account the non-monetizable impacts and considering the output of CBA as another criterion.

2.3.1.4 Moving towards alternative methods

In addition to the afore-mentioned published guides and manuals, there are many other publications recommending methods for monetizing costs and benefits and estimating relevant parameters in the evaluation of transport projects. Those include: Vickerman (2000) for the United Kingdom, Rothengatter (2000) for Germany, Quinet (2000) for France, Morisugi (2000) for Japan, Talvitie (2000) for developing countries, and Bristow and Nellthorp (2000) for the European Union countries. It is noted that none of these publications, except a few, have been able to provide explicit methods either to (i) monetize all identified indirect and external impacts (costs and benefits) associated with transport projects, or (ii) internalize them in an alternative way to decision making process. However, the overall analysis of all these publications reveals the gradual tendency to use CBA with some form of qualitative assessment of indirect and external impacts or together with MCA to incorporate those elements accepting their difficulty to express in monetary terms. Such an approach eliminates the one-dimensional nature of CBA in the decision-making process.

The late development by the end of the 20th century of moving towards alternative evaluation forms is evident in a study conducted by the European Network for Education and Training (EUNET) in 1998 for its 14 member states of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Poland, Spain, Sweden, and United Kingdom. Based on the finding of the above study Bristow and Nellthorp (2000) showed that nine member states, namely Finland, France, Germany, Ireland, Italy, Poland, Spain, Sweden, and the United Kingdom, had stepped to use CBA together with some form of quantitative and/or qualitative appraisal to include non-monetizable environmental and social impacts while another four countries, namely Austria, Belgium, Greece, and Netherland had already switched to use MCA as the primary form of evaluation, incorporating outputs of CBA and qualitative assessment as independent criteria. Authors also highlighted that some ambitious member states of Belgium, Denmark, Finland, Germany, France, Poland, Spain, and Sweden had developed methods to monetize some of the environmental effects of transport projects, and even in a minority of cases (notably Germany and Spain) had further widened monetizable impact coverage of CBA by including the external socio-economic effects too. This study revealed that only one country, i.e., Denmark, was using CBA in standalone out of all 14 member states by 1998.

There are few studies demonstrating transport project evaluation practices outside Europe when leading to the 21st century. Such includes Hayashi and Morisugi (2000) for Japan and the USA, Douglas and Brooker (2013) for Australia, and Douglas, Wallis, Lawrence, and Wignall (2013) for New Zealand. The findings of each of these studies are summarized below.

Hayashi and Morisugi (2000), in their international comparison of transport project evaluation practices, revealed that by the year 2000, Japan was using a kind of MCA supplemented by CBA while the USA was using CBA expanded to include equity impacts for large projects and MCA variations and other informal methods for the projects at the regional level. Furthermore, the authors were in agreement with the findings of Bristow and Nellthorp (2000), discussed above in relation to the United Kingdom, Germany, and France, which were the other countries they studied.

In contrast to all countries studied so-far in different continents, evaluation practices in Australia and New Zealand still heavily relied on CBA by the year 2000. Douglas and Brooker (2013) stated that in 1998, Australia standardized using CBA for all infrastructure projects, including transport projects by publishing "Guidelines on Economic Appraisal of Assets". Similarly, New Zealand, which was using CBA as the primary tool since the 1970s, sometimes together with MCA, eventually recommended using CBA as the most appropriate tool for evaluating transport projects under Transfunds in 1997 with detailed procedural publication as stated by Douglas et al. (2013).

In brief, it is evident that by the end of the 20th century, there was a clear tendency in international transport project appraisal practices to enhance CBA as a standalone tool or together with MCA or some other form of qualitative assessment. In fact, few countries such as Austria, Belgium, Greece, and the Netherlands had switched to use MCA as the primary evaluation form. However, it is noted that most advanced developments in MCA, usable in transport project evaluation, were incurred after the 1990s. The combination of CBA and MCA had not appeared as an effective and sophisticated tool by this time around.

2.3.1.5 Emergence of MCA as a standalone practice in transport project evaluation

MCA, as a standalone practice for transport project evaluation, is prominently appeared with the introduction of New Approach for Transport Project Appraisal (NATA) by Department for Transport, Environment, and the Regions in the United Kingdom in 1998. This approach was introduced replacing the Department's previous practice of COBA and was first used for national road schemes in the 1998 Roads Review, and subsequently to all transport modes (Price, 1999).

Price (1999) indicated that NATA has rested on five main criteria of environmental impact, safety, economy, accessibility, and integration, each of which has several subcriteria that can be measured qualitatively or quantitatively. Vickerman (2000) in his demonstration of using NATA, explains that the core of the COBA method is incorporated in the assessment of safety criterion and journey time-related sub-criteria, while the remaining new sub-criteria are evaluated separately by direct measurement for quantitative sub-criteria and scaled measurement (1-7) for qualitative sub-criteria. Vickerman further indicates that the final results of NATA do not integrate into a single figure by assigning criteria weights but instead present an analysis summary table (AST), including conventional COBA benefit-cost ratio, for characterizing the project. Thus, Odgaard, Kelly, and Laird (2005) argued that this approach is not MCA in its purest form. NATA has left decision-makers to determine the level at which net negative environmental impacts are traded off against positive COBA score based on public inquiries (Vickerman, 2000). However, Tavasszy, Jonkhoff, Burgess, Rustenburg, and Hunt (2005) believed that harmonization of evaluation criteria in this method had contributed to transparency, in addition to foster the role of CBA in decision-making.

The continuity of NATA in the 2000s is further discussed in the next sub-section on Recent Developments.

2.3.1.6 Transport project evaluation trends in developing countries

Evaluation practices and their evolution discussed thus-far are mostly related to the developed countries. All of those countries were practicing or attempting to practice rationalized formal procedures for transport project evaluation. But such rationalized procedures were not noticeable in developing countries, mainly due to most of the projects in those countries were driven by political interest and/or marginalized with limited domestic fund availability. However, when foreign or donor funding was received, these countries were demanded to adopt evaluation practices recommended by those funding sources. As the World Bank and UNIDO were the key funding sources before the year 2000, most of these developing countries followed guidelines based on CBA in such engagements. Talvitie (2000) supported this argument presenting the procedure adopted by the World Bank in the economic evaluation of road projects in developing countries in the 1990s.

2.3.1.7 Key driving forces in the evolution of transport project evaluation practices

So far, this review has demonstrated the evolution of transport project evaluation practices without adequately examining the causes for such evolution. Hence, before moving forward, it is important to answer the question, *“what were the key driving forces influenced to evolve practices in the transport project evaluation?”*

Scrutiny of the evolution of evaluation practices discussed thus far shows that it is primarily driven by the intention of incorporating indirect and external benefits such as social and environmental benefits. Grant-Muller et al. (2001) explained this as "focus has broadened" (p.238). In their review, Grant-Muller et al. further mentioned that "change in the appraisal context" also caused to evolve the practices. This argument was well supported by Bristow and Nellthorp (2000) in their concluding remarks. In their generalization, Grant-Muller et al. explained this context change incurred from the appraisal paradigm of project level, single-mode (roads, rail, air, water) and government-funded in 1970 to the paradigm of spatial or corridor level, multi-modal integration and variety of funding sources by the end of the 19^{th} century respectively. Grant-Muller et al. further added one more reason to the evolution of practices: "the balance of power between governments and the public has shifted". His supportive argument for this reason was that the modern-day public highly demand rational justification for the project compared to the public in the old days during which relatively minimal public consultation was adequate. The validity of the above-said three reasons remains unchanged in relation to the evolution of project appraisal practices even for modern days.

In summary, this sub-section shows that three distinguished best practices in transport project evaluation had emerged by the end of the 20^{th} century. They are (i) CBA as a standalone practice, (ii) MCA as a standalone practice, (iii) combination of CBA and MCA. In addition, it is noted that sometimes CBA had been used with a qualitative assessment on non-monetizable benefits or costs. However, those approaches cannot be promoted as best practices since they don't have a standard procedure to follow, and more often, their final decisions are based on CBA results. Thus, it is reasonable to consider them as a part of CBA standalone practice.

2.3.2 Recent Developments

This sub-section covers the evolution of transport project evaluation practices from 2000 to date. It demonstrates the progression of the afore-mentioned three best practices emerged by the end of 20^{th} century as well as new practices emerged under different socio-economic-political contexts in developed and developing countries at the levels of respective governments, international organization, and multilateral funding agencies.

2.3.2.1 Evaluation practices in European Developed Countries

The study carried out by Odgaard, Kelly, and Laird (2006) as a part of Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO) for the European Commission[3] provides a better cross-section of transport project evaluation processes practiced in Europe by 2005 and its progression. This study was a repetition of the previous work done by EUNET in 1998 and conducted due to (i) expansion of European Union (EU) up to 25 countries by 2004 from 14 countries in 1998, and (ii) evolution of evaluation practices in many countries since the last survey in 1998 (Odgaard, Kelly, & Laird, 2006). Table 2.1 summarizes the practices adopted by different member countries for the appraisal of transport projects by mode, as appeared in the Odgaard et al. (2005).

Table 2.1: Transport project appraisal methods used by EU countries (2005)

SN	Country	Road	Rail	Air	Inland Water	Sea
1	Austria	C,M,Q	C,M	A	C	N
2	Belgium	C,Q	C,M	A	A	A
3	Denmark	C	C	A	A	A
4	Finland	C,Q	C,Q	N	C,Q	C,Q
5	France	C	C	N	C	N
6	Germany	C,A	C,A	N	C,A	N
7	Ireland	C,Q,A	C,Q,A	C,Q,A	C,Q,A	C,Q,A
8	Netherlands	C,Q	C,Q	C,Q	C,Q	C,Q
9	Sweden	C	C	C	C	C
10	Switzerland	C,M	C	A	A	A
11	UK	C,M,Q,A	C,M,Q,A	C,M,Q,A	C,M,Q,A	C,M,Q,A
12	Czech Republic	C,M	C,M	A	C,M,Q,A	A
13	Estonia	C	C	A	A	A
14	Hungary	C,M	A	A	A	A

[3] European Commission is the executive branch of the European Union

SN	Country	Road	Rail	Air	Inland Water	Sea
15	Latvia	C	A	A	A	A
16	Lithuania	C	C	C,Q	A	C,Q
17	Poland	C,M	C	A	A	A
18	Slovak Republic	C,M	C	A	A	A
19	Slovenia	C	C	A	A	A
20	Cyprus	C,M,A	N	N	N	N
21	Greece	C,A	C,A	C,A	N	C,A
22	Italy	C	C	C	C	C
23	Malta	C	N	N	N	N
24	Portugal	C	C	C,A	N	C
25	Spain	C,M	C,M	C,M	N	C

Key:
C = Cost-benefit Analysis (CBA); M = Multi-Criteria Analysis (MCA); Q = Quantitative Measurements (QM); A = Qualitative Assessment (QA) and N = No information/not relevant

Definitions:
C = Cost-benefit analysis (CBA): The effects are assigned a monetary value and included in an overall economic appraisal of the total value of the project in monetary terms.

M = Multi-Criteria Analysis (MCA): The effects are not assigned a monetary value but are included in an overall project appraisal by assigning non-monetary weights to the individual effects.

Q = Quantitative Measurements (QM): The effects are estimated in physical units or numbers (cardinal scale), but in contrast to the multi-criteria analysis (MCA), no specific weights are assigned to allow aggregation of the effects to a single criterion.

A = Qualitative Assessment (QA): The effects are classified into one of several ranked categories (ordinal scale) based on well-defined standard criteria for each of the categories, which are invariant from project to project; No systematic appraisal methods are used. It also includes a free format verbal description of effects.

Note. This assessment has been done for all EU Member States excluding Luxembourg for which data had not been received and for Switzerland as a non-EU country. Reprinted from *Current Practice Project Appraisal in the European Countries* (p.74), by T. Odgaard, C. Kelly and J. Laird, 2005, European Commission.

The analysis of Table 2.1 leads to the following conclusions:

- All 25 EU member states, including few developing states, have been using CBA to appraise transport projects, particularly in the land transport sector, in addition to using MCA and other quantitative measurement and qualitative assessment.
- CBA has hardly been used as a standalone tool in appraisals but more often been used together with MCA or quantitative measurement.

- There are no instances of MCA or Quantitative measurements having been used as standalone tools. However, this interpretation seems unfair in relation to MCA, especially when UK continued appraising transport projects using MCA led NATA, of which CBA forms independent criteria. This indicates whenever MCA is used together with CBA or any other method, treating those as separate criteria inbuilt to MCA, the practices have been generalized to call as 'combined approach' rather than calling it a MCA led method. Hence it is fair to say some of the combined approaches involving MCA are led by MCA.

- In contrast to the appraisal of land transport projects, air and water projects have been mostly appraised by using quantitative measurement and qualitative assessment techniques in these countries.

- The UK, notably, has used all four techniques to assess transport projects, reflecting its extensive use of NATA.

The findings of the above-mentioned HEATCO studies, carried out from 2004 to 2006, led to standardizing the transport project appraisal practices largely within the framework of CBA for the European Union (Bickel et al., 2006). These standardized practices for transport projects were incorporated in the *Guide to Cost-Benefit Analysis of Investment Projects,* a comprehensive guideline for appraising infrastructure investment projects for the period of 2008-2013, which updated and expanded the previous edition in 2002, which in turn was the follow up of a first brief document in 1997 and of a subsequent substantially revised and augmented text in 1999 (European Commission [EC], 2008). European Commission used this guide in appraising projects financed through its Structural Funds (SF), Cohesion Fund (CF), and Instrument for Pre-Accession Assistance (IPA) in its member countries since 2002 (Rudolph et al., 2014).

The afore-mentioned guide was again updated for the same purpose in 2014 for the programming period of 2014-2020, incorporating (i) the latest developments in EU policies and methodologies for CBA and international best practices, and (ii) considerable experience gained in project preparation and appraisal during the previous programming periods of the cohesion policy (EC, 2014). EC (2014) stated that the main change of this edition compared to the previous was its concerns over a reinforced operational approach and a stronger focus on the investment priorities of the cohesion policy. It is further noted that this guide (2014) has not seriously considered the Wider Economic Impacts (WEIs) which was an emerging topic in transport project appraisal from the beginning of the 21st century, especially after 2005 (Kanemoto, 2013; Wanle et al., 2019). WEIs (costs or benefits) refers to economic impacts which are additional to transport user benefits counted in conventional CBA and risen due to failures in secondary markets (non-transport markets), such commonly includes (i) agglomeration impacts, (ii) labor market and tax impacts and (iii) output change in imperfectly competitive markets (ATAP Steering Committee, 2016; Douglas & O'Keeffe, 2016; Wangsness, Rodseth, & Hansen, 2016). These WEIs were also recommended to internalize the decision-making process through CBA when monetized or MCA when quantified but not monetized (Wangsness et al., 2016).

It was not mandatory for the member countries to follow the European Commission's guidelines when projects were financed through domestic sources though many opted to follow them. Hence it is also important to have an assessment of how domestically funded projects were appraised in Europe. Tavasszy et al. (2005), who took part in HEATCO, expressed that most of the countries in North and West regions of the EU had their own comprehensive guidelines for project appraisal, especially for road transport, whereas the South and East regions had less developed guidelines. The UK, the Netherlands, and Germany had well-developed guidelines by 2005.

United Kingdom: As indicated in the previous sub-section, since 1998, UK continued to use NATA, which was based on MCA, and supported with partial CBA in decision making (Tavasszy et al., 2005). NATA remained as the mandatory toolbox whenever national funding or a national value for money perspective was required in the UK (Mackie, 2010). In 2003, the Department for Transport (UK) advanced the NATA launching a web-based Transport Analysis Guidance (WebTAG) as a requirement for all projects/studies demanding government approval (Geurs, Boon, & Van Wee, 2009). In 2007, the Department of Transport (UK) launched a review of NATA to address the issues that emerged after its ten-year usage and to synchronize with the department's new policy goals. In 2009, NATA was refreshed to (i) incorporate valuation methods for some of previously non-monetized direct and indirect impacts, (ii) update parameters related to user cost estimation and forecasting, and more importantly, (iii) incorporate wider economic impacts and climate changes impacts. Even though NATA appears as a sophisticated and complete tool, it is still criticized for 'not including real and wider economic impacts fully and being whole process too technical to understand (UK Parliament, 2011). Nevertheless, it remains as a MCA led transport project evaluation process supported by CBA.

The Netherlands: CBA was standardized in the year 2000 by introducing OEI (Onderzoeksprogramma Economische Effecten Infrastructuur; formerly OEEI) guidelines to evaluate of all domestically funded major projects in the Netherlands (Annema, Koopmans, & Wee, 2007; Tavasszy et al., 2005). An assessment carried on the OEI guidelines in 2002 demanded certain improvements in relation to monetizing external effects including socio-economic effects and standardizing more issues (e.g., risk valuation, rest value) (De Jong, 2013; Tavasszy et al., 2005). Such identified improvements were researched and incorporated as appendices to the OEI guidelines in December 2004 (De Jong, 2013). As stated by Tavasszy et al. (2005), non-monetizable costs and benefits were ignored in decision making as per OEI guidelines, but De Jong (2013) stated that such non-monetized impacts were presented in a table, without processing further. However, De Jong (2013) further added that MCA was continued to use every now and then for project evaluations for private sector organizations and local governments and for Environmental Impact Reports. The author expressed that OEI guidelines were improved on many fronts by 2012, especially in monetizing indirect and external impacts.

Germany: Germany, in its federal administration system, practices different appraisal procedures and methods at national, federal state, and local authority levels. Those include (i) economic appraisal for the federal infrastructure plan including federal roads, railways, and inland waterways ('Bundesverkehrswegeplan,' in short, BVWP), (ii) Recommendations for economic appraisal for roads ('Empfehlungen für

Wirtschaftlichkeitsuntersuchungen an Straßen, in short, EWS) for state and local roads, and (iii) Standardised appraisal method for regional and local public transport investments ('Standardisierte Bewertung von Verkehrswegeinvestitionen des öffentlichen Personennahverkehrs,' in short, Standardisierte Bewertung) (Gühnemann, 2013). The BVWP, which was standardized with CBA in 1985 for project appraisal, last updated in 2003 and anticipating further updates in 2015 (Gühnemann, 2013). It counts external effects like air pollution, noise, climate change in monetary terms while other environmental damages and effects on urban development are incorporated through MCA (Tavasszy et al., 2005). The core appraisal methodologies in-built to EWS, and Standardisierte Bewertung is also CBA, but in practice, those often combine with MCA and qualitative assessments (Gühnemann, 2013).

2.3.2.2 Evaluation practices in Non-European developed countries

Many developed countries outside Europe, such as the United States, Australia and Asian countries like Japan and Taiwan, had guidelines for CBA by the year 2000 and used it as a standalone tool or took part in a broader appraisal framework like MCA in prioritizing or selecting projects (Tavasszy et al., 2005).

USA: The recent transport project evaluation practice in the USA is a continuation of what was introduced in the 1990s. The review done by Weisbrod (2013) demonstrates the evolution of USA practices for about a decade since the year 2000. US DOT comprises separate modal agencies, and thus each agency controls its own discretionary grant programs, developing its own guidance on the benefit-cost analysis (BCA; USA often refers to cost-benefit analysis as benefit-cost analysis). This includes BCA guidance on highway asset management (Federal Highway Administration, 2003), rail transit new starts (Federal Transit Administration, 2008), freight intermodal project investment (FHWA, 2008), and aviation improvement (Federal Aviation Administration, 1999).

State and local transportation agencies can use US DOT guidance on BCA methods, but not mandatory unless a federal discretionary grant supports the project. Since most state and local transportation projects are funded jointly with state and federal formula funds to the states, they are evaluated, prioritized, and funded following the state DOT regulations. The "Red Book" – The Manual for User Benefit Analysis for Highways published by AASHTO in 1977 and updated in 2003 and 2010, is widely accepted and used by most state DOTs. Many but not all state DOTs conduct BCA to support their evaluation and prioritization of proposed projects. Alternatively, the multi-criteria rating is widely used by states for prioritizing and selecting projects since it enables considering broader definitions of social benefits. Even those states conducting BCA regularly, use its results together with MCA, including non-monetized benefits and costs. The Metropolitan Planning Organizations set up for the urbanized area, with over 50,000 residents, typically use some form of MCA to assess regional transport projects in terms of their impact on broad social, environmental, and economic goals.

Japan: Tavasszy et al. (2005) stated that Japan used CBA differently for transport project appraisal compared to other countries. Authors demonstrated that they carried out the appraisal in two stages: first, a CBA with basic cost-benefit elements leading its failure to meet the minimum CB-Ratio criteria to the second round of CBA in which extra effects grouped in the categories of (i) evaluation in a wider scope (extension of cost-benefit items), (ii) evaluation of interregional equity (overview of how the effects are distributed to different groups of stakeholders), and (iii) evaluation in non-monetary terms (qualitative assessment) were considered.

2.3.2.3 Most recent transport project evaluation practices (after 2014)

So-far discussed practices are mostly fallen in the first decade of the 21st century. The review done by Mackie, Worsley, and Eliasson (2014) in 2014 for seven countries representing three different continents is the latest detailed literature available to summarize the most recent appraisal practices around the world. This review is based on a study for the UK Government in 2013 (Mackie & Worsley, 2013), and it shows the positions of transport project appraisal practices of seven countries: England, the Netherlands, Germany, Sweden, the United States, Australia, and New Zealand.

In this review, Mackie et al. (2014) show that CBA is the core of transport project appraisal for all seven countries, being it results the main criteria for decision making. Further, the authors reveal that all these seven countries have introduced their own methodologies to monetize most of the indirect and external impacts such as safety, noise, pollution, and climate changes, etc. Mackie et al. further state that some of these countries also have highly standardized modeling and forecasting methods, ensuring that the travel costs and traffic volume inputs to the appraisal are comparable across schemes. This indicates that over the last two or three decades, several countries have committed to using CBA standardizing its framework and broadening valuation technique to capture indirect and external impacts. However, such improvements are not consistent across the countries. This review also shows that the latest concepts, such as WEIs and regeneration impacts, have also been adequately treated by all seven countries in their own ways, while some have even used appropriate modeling tools to quantify them. However, it should be noted that MCA and qualitative assessments still have a vital role to play for taking non-monetizable components, mostly indirect and external impacts, into account in the decision-making process.

2.3.2.4 Transport project evaluation practices in developing countries

There is no acceptable publication on transport project appraisal in developing countries, either at present or in the recent past. However, when considering most of these countries' social, economic, and political context, it is evident that domestically funded projects, ranging from small-scale to medium-scale, are mostly chosen on political interest primarily assisted with the micro-level qualitative assessment on social needs. In foreign-funded projects, often ranging from medium scale to large scale, these countries are bound to follow the guidelines stipulated by respective funding sources. Those funding sources primarily include multilateral funding agencies such as the World Bank, Asian Development Bank, African Development Bank, Inter-American Development Bank, and JICA, etc. They often recommend CBA together with stipulated guidelines to the borrowers for appraising selected projects during its preparatory stage (ADB, 2017; Belli et al., 1998; Japan International Cooperation Agency, 2010; World Bank, 2005). However, these funding agencies do not expect the borrower to carry out high-end CBA, including extensive analysis of social impacts, environmental impacts, and wider economic impacts, etc. mainly due to the extensive time required and scarcity of relevant data and information.

In summary, from 2000 to date, three prominent global trends in transport project evaluation practices are noticeable: (i) using CBA widely as a standalone practice standardizing with published guidelines and broadening monetizable capacity at country level and different agency level, (ii) using combinations of CBA and MCA with gaining popularity though they are not standardized yet, and (iii) using MCA as a standalone practice (Eg. NATA) despite its popularity to likely decline against the above two practices.

2.3.3 Stage I: Conclusions

Over the years, researchers, practitioners, and agencies have developed various techniques to evaluate transportation projects. During the second half of the 20th century, CBA prominently came forward as a common practice in transport project appraisal, although it was not fully standardized. By the start of the 21st century, three different approaches were clearly noticeable in transport project appraisal: (i) strengthening CBA by monetizing more and more impacts such as social and environmental impacts and (ii) using MCA together with CBA to internalize non-monetizable impacts, and (iii) using MCA as a standalone tool. These three approaches, particularly the first two, gained popularity globally during the last decade due to the continuously improved methodological framework and standardization.

2.4 Stage II: Critical Review of Current Best Practices

The literature review conducted so-far shows that current best practices in transport project evaluation narrow down to (i) CBA as a standalone practice, (ii) MCA as a standalone practice, and (iii) CBA and MCA combined approaches, primarily based on the global acceptance and credibility. As such, heron the literature review is confined to scrutinize each of the above three practices to:

(i) Identify their weaknesses and related knowledge gaps allowing to arrest the weaknesses (or gaps) to be treated in this research,

(ii) Justify the motive to develop a new evaluation process and understand the most appropriate approach to follow in building up the said new evaluation process, and

(iii) Gather the conceptual and theoretical knowledge required to develop the new evaluation process.

This scrutiny is carried out in terms of theoretical frameworks and their soundness, application procedures and their limitations, strengths and weaknesses for two standalone practices of CBA and MCA first and then for its combination. The scrutiny of the combined approaches is made after CBA and MCA standalone practices for a better understanding of their effectiveness in resolving issues associated with the parent methods.

2.4.1 Theoretical Frameworks of CBA and MCA and their Soundness

2.4.1.1 Cost-Benefit Analysis (CBA)

The CBA is the widely and commonly used process to evaluate transport investments across the globe (Beria, Maltese, & Mariotti, 2012; Browne & Ryan, 2011; Grimaldi & Beria, 2013; Naess, 2006). It assesses annual costs and benefits associated with a given project, compared to a base-case in monetary terms over a pre-determined evaluation period, to develop an annual net benefit stream and thereby express the project's implementation feasibility in terms of an internal rate of return, a net present value or a benefit-cost ratio (ADB, 2017; Belli et al., 1998; EC, 2014; International Transport Forum, 2010; Pearce, Mourato, & Atkinson, 2006; Sassone & Schaffer, 1978). As such, CBA simply measures the efficiency (or sometimes referred to as effectiveness) of an investment in two forms: financial efficiency for private investment and economic (or social) efficiency for public investments. When it is applied to public investments, CBA is more precisely known as 'social' cost-benefit analysis since costs and benefits are assessed from a whole-of-a-society perspective in such instances (Buncle, et al., 2013; Hickman & Dean, 2017; Van Wee & Roesera, 2013). In principle, though CBA is equally applicable to private and public projects, the method is most frequently used for public decision-making because of its focus on assessing social welfare instead of financial profitability (Hickman & Dean, 2017). Nevertheless, in transport project evaluation, social cost-benefit analysis sometimes supported with financial cost-benefit analysis when implementing agency targets to earn revenue (such as toll collected highways). The literature review presented herein focuses only on social cost-benefit analysis though referred to as CBA in general terms.

The CBA lays its foundation on (i) theoretical framework of microeconomics, (ii) theory of social welfare in economics[4], and (iii) notion of the rational individual, where a person makes decisions to maximize net benefits in relation to known costs and benefits (Economic Commission for Europe [ECU], 2003; Hickman & Dean, 2017). It functions as a tool designed for the application of these theories to the practical problems of public sector decision-making, not just in transport, but also in health, power generation, and environmental protection, amongst the others (ECU, 2003).

In Social CBA, the valuation of costs and benefits should be done in economic terms by using the concepts of opportunity costs and shadow pricing while ignoring transfers (ADB, 2017; EC, 2008). These costs and benefits are assessed in monetary terms compared to a base-case and forecasted over the project life using an acceptable method. In CBA, if a project to be declared economically feasible, its net aggregated benefits to society should outweigh the net aggregated costs (Nickel, Ross, & Rhodes, 2009). For this decision to be taken, CBA offers three forms of indicators, often called the decision criteria: net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR) (Shang et al., 2004; Wee, 2012).

The NPV is used to assess the total present value of net benefits incurred over the lifetime of the investment at a given discount rate (Hüging, Glensor, & Oliver, 2013). In other words, the NPV of a project is the total difference between the annual

[4] The body of modern-day welfare economics which underlies CBA was established by Hicks (1939, 1943), Kaldor (1939) and others in the 1930s and 1940s (OECD, 2006).

discounted stream of benefits and the annual discounted stream of costs over the project life (Nickel et al., 2009). If the NPV is greater than zero, the project is declared as being economically feasible for implementation. In accordance with the economic theories, NPV of the total net benefit stream over a period of N years under a discount rate of *r* can be expressed as below (ECU, 2003);

$$NPV\ (r, N) = \sum_{n=1}^{N} \frac{(\Delta TB_n)}{(1+r)^n}$$

Where,

ΔTB_n - Net benefit of investment over 'no investment' scenario, mathematically represented for the n^th year as follows

$$\Delta TB_n = \Delta B_{n,with\ investment} - \Delta B_{n,no\ investment}$$

The second decision criterion, IRR, calculates the discount rate, which makes NPV zero (Hüging et al., 2013). Under this criterion, a project is declared as being economically feasible when the IRR is greater than the minimum acceptable discount rate. The IRR can be illustrated mathematically as follows;

$$IRR_{n+1} = IRR_n + NPV_n \left(\frac{r_n - r_{n-1}}{NPV_n - NPV_{n-1}} \right)$$

Where,

r - discount rate

IRR_n - n^{th} approximation of IRR

NPV_n - NPV value with the discount rate selected as n^{th} approximation of IRR

The third decision criterion, BCR, is the ratio of the present value (PV) of total economic benefits to the present value of the total economic costs [BCR= PV (Benefits) / PV (Costs)] (Hüging et al., 2013). By definition, BCR acts as a measure of effectiveness in fund utilization and hence can be used to prioritize a long list of independent projects, giving priority to those with the higher BCRs and cutting off the list when the available fund is exhausted (Jensen, 2012). The mathematical representation of the BCR is given below (Schulz, 2011):

$$BCR = \frac{\sum_{t=1}^{N} B_t (1+r)^{-t}}{\sum_{t=1}^{N} C_t (1+r)^{-t}}$$

Where,

t	- time period in years
N	- project life
r	- discount rate
B_t	- Aggregated project benefits in year *t*
C_t	- Aggregated project costs in year *t*

In brief, an investment (or a project), providing a positive NPV and, in turn, an IRR higher than the minimum rate of return expected on capital (minimum acceptable discount rate) and a BCR higher than unity, produces adequate benefits to justify the economic return on its investment, thus feasible for implementation.

2.4.1.2 Multi-Criteria Analysis

Multi-Criteria Analysis (MCA), formally referred as Multi-Criteria Decision Analysis (MCDA), emerged as a methodological approach since the 18th century after Condorcet published the book about decision-making by a plurality of voices while its fundamental theoretical framework was noticeably improved after the study of 'Cours d'Economie Politique' in 1896 by the Pareto (Basbas & Makridakis, 2007). MCA is less of a unified technique than CBA (Jensen, 2012). At present, there are many different types of MCA techniques, probably more than a hundred, available to support decision-makers in different capacities, particularly when they need to make judgments depending on more than one criterion (Basbas & Makridakis, 2007; Jensen, 2012; Macharis & Bernardini, 2015; Tsamboulas et al., 1999). These MCA techniques are primarily designed to rank alternatives from the most preferred to the least preferred based on their achievements of a predefined objective, which are measured in the form of set criteria (Department for Communities and Local Government (UK), 2009; Farahani, Steadie Seifi, & Asgari, 2010).

In common practice, MCA techniques are classified into three categories (Schutte & Brits, 2012; Stewart, 1992; Stewart & Losa, 2003). They are: (i) Goal programming and reference point approaches, (ii) Descriptive methods and outranking methods, and (iii) Value function approaches.

The first category, goal programming and reference point approaches, are suitable to narrow down the search for the best solution in the presence of many alternative solutions (Jensen, 2012; Stewart, 1992). The second category, descriptive and outranking methods, is useful in cases (i) where there are a small number of alternatives, (ii) when compensation among performance areas is difficult, and (iii) when it is doubtful whether a 'true' order of alternatives exists corresponding with the preferences of the decision-makers (Jensen, 2012; Sijtsma, 2006). The third category, the value function approaches, is highly judgment oriented and is useful when a full ranking of alternatives is required (Jensen, 2012; Sijtsma, 2006). According to Jensen (2012), Sijtsma (2006), and Stewart (1992), the value function approaches are the ones mostly used in the transport project evaluation, particularly its subset of additive scoring methods which determine the performance of an alternative by adding the scores (standardized and weighted) of different criteria to present the preferred alternative as the one with the highest overall score.

2.4.1.2.1 MCAs in Transport Project Evaluation

Amongst numerous multi-criteria analysis methods, Tsamboulas et al. (1999) identified five most suitable methods for transport project evaluation after reviewing the widely used methods in terms of (i) their track records of applications and user acceptance in the appraisal practices, and (ii) their applicability, data requirements, ease of use, and usability of results in different problem situations. Those five methods comprise analytical hierarchy process (AHP), multiple attribute utility approach (MAUT), ideal point approach (ADAM method), REGIME, and ELECTRE family. The first three methods (AHP, MAUT, and ADAM) are in the category of additive methods, while the last two methods in the category of outranking methods. Aldian and Taylor (2005) also believed that the above five methods are the most important ones for transport project evaluation, while Tudela, Akiki, and Cisternas (2006) additionally recommended PROMETHEE outranking procedure also as a better method to evaluate transport projects. It should be noted that Analytic Network Process (ANP), which is the generalized form of AHP, was not popular as other methods in this time around since it was introduced only in the mid-90s.

The most recent research work done by Macharis and Bernardini (2015) in 2015, retrieving 276 publications since 1983, presents a cross-section of different MCA methods mostly used over the years in transport project evaluation. According to this study, the method mostly used in the retrieved articles is the Analytic Hierarchy/Network Process (AHP & ANP) or its variants developed by Saaty (1988) (33%). It is followed by the techniques of Fuzzy set (14%), Multi-Actor Multi-Criteria Analysis (MAMCA) (12%), ELECTRE (7%), PROMETHEE (6%), and TOPSIS/VIKOR (5%) in preference order.

The afore-mentioned researches and other related literature revealed that although there are numerous MCA methods, only a few are widely used for transport project evaluation. In this thesis, several of those, namely (i) Analytic Hierarchy Process (AHP), (ii) Analytic Network Process (ANP), (iii) REGIME, (iv) ELECTRE family, (v) Fuzzy Set, (vi) PROMETHEE, (vii) Multi-Actor Multi-Criteria Analysis (MAMCA) are chosen to study their theoretical framework concisely.

1. Analytic Hierarchy Process: The AHP, developed by Saaty in 1977 (Saaty, 1977) is an additive method (Stewart, 1992) . It is capable of decomposing a complex decision-making process into a hierarchical structure, of which top-most occupied by the main goal while bottom-most level by discrete alternatives under consideration and intermediary levels by criteria and sub-criteria with appropriate links established between the attributes of adjacent levels (Beria et al., 2012; Tudela et al., 2006). Many researchers believe that AHP paved the way for MCA to be used in transport project evaluation (Basbas & Makridakis, 2007). Figure 2.2 graphically illustrates a simple AHP hierarchical model with one layer of criteria.

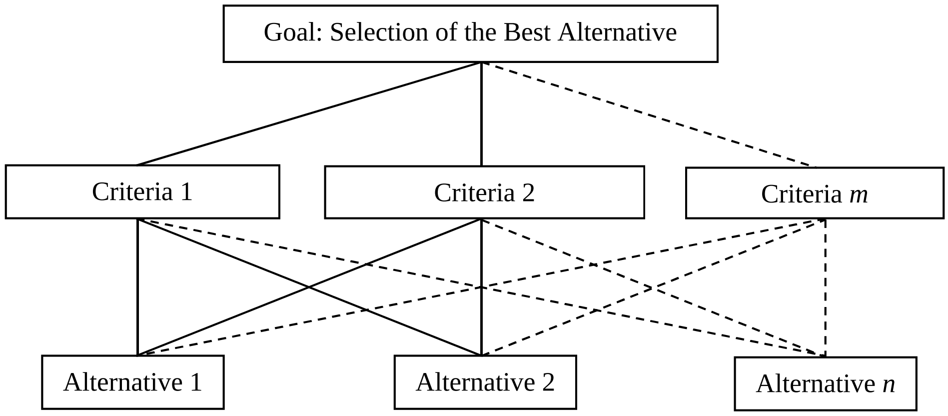


Figure 2.2: Hierarchy of goal, criteria, and alternatives
Source: Tudela, Akiki, and Cisternas (2006)

During its decision-making process, AHP has to go through three key sequential stages of (i) constructing the hierarchy; (ii) weighting criteria, sub-criteria, and alternatives by adopting pairwise comparisons as required, and (iii) calculating the final score for the alternatives (Basbas & Makridakis, 2007; Beria et al., 2012). When construction of the said hierarchy, setting up the goal, alternatives, criteria, sub-criteria, and their inter-dependencies should be done avoiding the double-counting of attributes and with the involvement of experts, decision-makers, decision-takers, and, if necessary, the general public (Tudela et al., 2006). Once the hierarchy is constructed, weights for criteria, sub-criteria, and alternatives should be established, assessing their relative importance with respect to the attributes in the immediate upper level by using the pairwise comparison (Saaty, 2008a). As Saaty (1977) suggested, the final score for each alternative is determined by aggregating respective weight contributions transferred by the attributes in the penultimate level (i.e., criteria or sub-criteria). These final scores are used to prioritize (or rank) the alternatives. The AHP is further detailed in Chapter 4.

2. Analytic Network Process: Another MCA adopted in transport project evaluation is the ANP, which is a generalization of AHP (Velasque & Hester, 2013). The ANP technique was also developed by TL Saaty in 1996 (Saaty, 1996a). Unlike AHP, ANP offers a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower-level elements and about the independence of the elements within the same levels (Saaty, 1999). Instead of a hierarchy structure of AHP, ANP functions in a network structure replacing uni-directional relationships of AHP with bi-directional relationships, which are often called dependencies and feedbacks or forward and backward dependencies (Saaty, 1996a). With the above-improved features, ANP becomes more powerful than AHP in the decision-making environment (Taslicali & Ercan, 2006). A detailed assessment of ANP is given in Chapter 4.

3. ELimination and Choice Expressing Reality (ELimination Et Choix Traduisant la REalité; ELECTRE) Family: The outranking concept was first introduced by Roy in 1968 (Roy, 1968) with the presentation of the ELECTRE method (Figueira, Salvatore, & Matthias, 2005; Tsamboulas et al., 1999). All methods based on the outranking concepts require to perform a pairwise comparison between every pair of alternatives under the basic principle of choice A outranks choice B if there is enough evidence to prove that A is at least as good as B, while there is no overwhelming reason to refute the statement (Basbas & Makridakis, 2007). ELECTRE evolved into ELECTRE I and then continued with ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS, and ELECTRE TRI (Electre tree), to mention a few (Figueira et al., 2005).

In ELECTRE I, the decision-maker primarily determines the Concordance and Discordance limits (Tsamboulas et al., 1999; Żaka & Kruszyńskib, 2015). After determining the limits, all pairs of alternatives are tested for valid outranking relations, and thereby positive and negative flows are computed. Final rankings are decided based on the intersection of those flows (ELECTRE I). Tsamboulas et al. (1999) described differences of subsequent versions: ELECTRE II follows more or less the same process of implementation in its first version, with a small variation in the computation of the Concordance index; ELECTRE III had been improved to address the weak preference issue in previous versions; and ELECTRE IV used some proportionality functions to denote the outranking relations between pairs of alternatives instead of Concordance and Discordance limits of other versions.

4. REGIME method: This method was introduced as an outranking method in 1983 (Hinloopen, Nijkamp, & Rietveld, 1983). It uses pairwise comparison based on which a synthetic index is calculated to proceed with the analysis (Beria et al., 2012; Tsamboulas et al., 1999). The synthetic index reveals the extent of the performance of various selected alternatives in relation to the criterion referring to each analyzed experience (Beria et al., 2012). The higher the index, the more preferable is the alternative. In the REGIME analysis, the focus is the sign of differences between the impacts of alternatives (Hinloopen et al., 1983). Beria et al. (2012) pointed out that the primary concern with the REGIME method is its lack of relevant condition of independence from irrelevant alternatives, i.e., an irrelevant alternative can alter the rank of the relevant ones. This limitation badly influences when assessing public policies.

5. Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) family: These are another form of outranking methods developed and presented for the first time in 1982, including the PROMETHEE I for partial ranking of the alternatives and the PROMETHEE II for the complete ranking of the alternatives (Velasque & Hester, 2013). A few years later, several types of the PROMETHEE methods such as PROMETHEE III for ranking based on intervals, PROMETHEE IV for complete or partial ranking of the alternatives when the set of viable solutions is continuous, PROMETHEE V for problems with segmentation limitations, PROMETHEE VI for the human brain representation and, PROMETHEE GDSS for group decision-making were developed (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010). Behzadian et al. (2010) has demonstrated execution of PROMETHEE II, used for the complete ranking of alternatives, in sequential steps of (i) determination of deviations based on the pairwise comparison, (ii) application of relevant preference function for each criterion, (iii) calculation of global preference index, (iv) calculation of positive and negative outranking flows for each alternative and partial ranking, and (v) calculation of net outranking flow for each alternative and complete ranking.

6. Fuzzy Set Theory: The concept of fuzzy sets was introduced by L. A. Zadeh in his paper Zadesh (1965) published in1965 (Basbas & Makridakis, 2007; Massad, Ortega, de Barros, & Struchiner, 2008; Stewart, 1992). Fuzzy set theory is an extension of classical set theory that is used to resolve numerous problems with imprecise and uncertain data (Balmat, Lafont, Maifret, & Pessel, 2011). In fuzzy set terms, each alternative would have some degree of membership in the fuzzy set of good (or acceptable or satisfactory) solutions with respect to each criterion taken into consideration, and those individual membership contributions are taken into account to determine the overall alternative's membership in the fuzzy sets as an indicator of the strength of its claim to being good (or acceptable, or satisfactory) in overall (Stewart, 1992). Based on the degree of their membership in the fuzzy intersection, alternatives are ranked accordingly. Fuzzy sets have a greater ability to handle insufficient information, imprecise inputs, the evolution of available knowledge, and complex decision-making problems though it is sometimes difficult to model a real-world problem (Velasque & Hester, 2013).

7. Multi-Actor Multi-Criteria Analysis (MAMCA): The concept of Multi-Actor Multi-Criteria Analysis (MAMCA) appeared in 2009 for the evaluation of infrastructure projects, particularly transport projects (Macharis, Witte, & Ampe, 2009). Though this method is not popular, it becomes prominent compared to conventional MCA approaches, due to its improved features to count different stakeholder opinions (Macharis, Turcksin, & Lebeau, 2012; Macharis et al., 2009). Different stakeholders in the transport sector project include users, investors, operators, society, and the government. Many authors recommend counting different stakeholder opinions in the decision-making process as it creates ownership of the final decision among the stakeholders enabling successful implementation of the project (Banville, Landry, Marte, & Boulaire, 1998; Hickman & Dean, 2017; Macharis et al., 2009). Macharis et al. (2012) demonstrated the methodological approach of MAMCA in seven sequential steps of (i) defining the problem and the alternatives, (ii) identifying stakeholders, (iii) defining criteria and weights, (iv) operationalizing criteria by constructing indicators and measurement methods, (v) constructing the evaluation matrix, (vi) ranking the alternatives and conducting a sensitivity analysis to assess the stability of the ranking and (vii) implementation.

It should be noted that the results of all the above MCA processes are used to assess the performances of the evaluated alternatives comparatively and thereby enabling prioritization (or ranking). But, in the case of transport projects, it is required to know the economic feasibility or the social profitability (in terms of having excess benefits over the invested cost) to decide whether the particular project is implementable or not. Such an indication of implementation feasibility is not enabled with the results of the above MCA processes. Thus, it is a major setback for using MCA based processes in the transport project evaluation.

2.4.1.2.2 Comparison of Different MCA Methods

Basbas and Makridakis (2007) and Velasque and Hester (2013) compared different MCA methods in various aspects. Table 2.2 summarizes their findings in terms of strengths and weaknesses of different methods in using transport project evaluation. This comparison has included all MCA methods discussed in the previous sub-section, except MAMCA and ANP, but with few more additional techniques used in transport project evaluation.

Table 2.2: Comparative evaluation of multi-criteria analysis techniques

Method	Strengths (or advantages)	Weaknesses (or disadvantages)
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data-intensive; provide a complete ranking of the alternatives; availability in user-friendly software; compatible with other techniques; flexible, transparent and user-friendly; possibility to include views of many decision-makers	Problems due to the interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal phenomenon; absence of threshold values; the 1–9 scale is often internally inconsistent; the link between the 1–9 scale and the decision-makers’ preferences do not have a sound theoretical foundation

Method	Strengths (or advantages)	Weaknesses (or disadvantages)
ELECTRE	Takes uncertainty and vagueness into account; threshold values are given; available in Software	Its process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and weaknesses of the alternatives to not be directly identified; arbitrary definition of the outranking relations and the threshold values; incomplete ranking of the alternatives
REGIME	Provides complete ranking; available in the software	Absence of threshold values
PROMETHEE	Easy to use; does not require the assumption that criteria are proportionate; six alternative types of preference functions to model the decision-makers' views; geometric representation of the results; available in Software	Does not provide a clear method by which to assign weights; selection of the preference function cannot be fully justified; not fully explicit process
Fuzzy Set Theory	Allows for imprecise input; takes insufficient information into account.	Difficult to model the problem; requires numerous simulations before use.
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences; provides complete ranking; model the personal views of the decision-makers.	Increased data requirements, analytical endeavor and total cost, especially when many decision-makers participate in the process; The decision-makers do not feel comfortable to fully reveal their personal system of preferences; preferences need to be precise
Simple Multi-Attribute Rating Technique (SMART)	Simple; allows for any type of weight assignment technique; less effort by decision-makers.	Procedure may not be convenient considering the framework.
Simple Additive Weighting (SAW)	Ability to compensate among criteria; intuitive to decision-makers; calculation is simple thus does not require complex computer programs.	Estimates revealed do not always reflect the real situation; results obtained may not be logical.

Method	Strengths (or advantages)	Weaknesses (or disadvantages)
Technique for Order of Preferences by Similarity to Ideal Solution (TOPSIS)	Has a simple application process; easy to use and program; the number of steps remains the same regardless of the number of attributes; can handle opposing impacts, provides a complete ranking	Its use of Euclidean Distance does not consider the correlation of attributes; difficult to weight and keep the consistency of judgment. The result of the analysis is very prone to change at criteria weights

Note: ANP has not been considered in the original source, although it is accepted as a better method for transport project evaluation.

Source: Basbas and Makridakis (2007), and Velasque and Hester (2013)

Though Basbas and Makridakis (2007) and Velasque and Hester (2013) presented a comparison of different MCA methods, in terms of their strengths and weaknesses, authors neither ranked them nor in favor of any as the best suited for the evaluation of transport projects. However, when analyzing their comparison of different MCA methods given in Table 2.2, AHP likely holds an edge over other methods to accept as the best-fitted method for transport project evaluation. However, it is noted that ANP has not been considered by the authors in their comparison, probably because it was a new method by then and hence not popular among the researchers and practitioners at that time.

The work done by Tsamboulas et al. (1999) provides a rating for several identified MCA methods based on their performance in transport projects evaluation with respect to several related criteria. This work provides a better understanding of the most suited methods for transport project evaluation. Table 2.3 presents the assessment of Tsamboulas et al. (1999).

Table 2.3: Summary of performances of the identified five multi-criteria methods

No.	Criteria	REGIME	ELECTRE	MAUT	AHP	ADAM
1	coping better with real-world situations	***	**	**	***	**
2	offering decision analysis closest to the rational human	*	**	***	***	***

No.	Criteria	REGIME	ELECTRE	MAUT	AHP	ADAM
3	Better structuring and ease to follow	*	**	**	***	**
4	Using straightforward mathematical approximations to represent reality	*	**	***	***	*
5	Simplicity	**	*	**	***	**
6	Treatment of any number of projects	**	**	***	***	***
7	Treatment of any number of	*	***	***	***	***
8	Treatment of uncertainty	*	*	***	**	**
9	Encouragement of special interest group	**	*	*	***	*
10	Sensitivity	*	**	***	***	***
11	Accountability	*	**	**	**	**

Note: *** very good; ** good; * not good; ADAM = Ideal point approach, AHP = Analytic hierarchy process, ELECTRE = Elimination and (Et) choice translating reality, MAUT = Multi-attribute utility theory; Reprinted from "Use of multicriteria methods for assessment of transport projects" by D. Tsamboulas, G. Yiotis, K. Panou, 1999, *Transportation Engineering*, 125(5), p.414.

Tsamboulas et al. (1999) state that the assessment with respect to criteria 1 to 4 in Table 2.3 was based on the experts' responses to a well-structured questionnaire while the rest was based on the authors' extensive analysis of each method. Table 2.3 indicates that AHP is the best performer in overall, claiming "very good" for nine criteria out of eleven. None of the other MCA methods shows such a high overall performance. Again, this assessment also has not taken ANP into account even though it has proven as a better tool for the transport project evaluation in the recent past. However, ANP being the generalization of AHP, its performance in the transport project evaluation should be undoubtedly rated at the level of AHP or above that. This aspect will be further reviewed as a comparison of AHP and ANP in Chapter 4 when selecting an appropriate MCA method for the proposed new evaluation process herein.

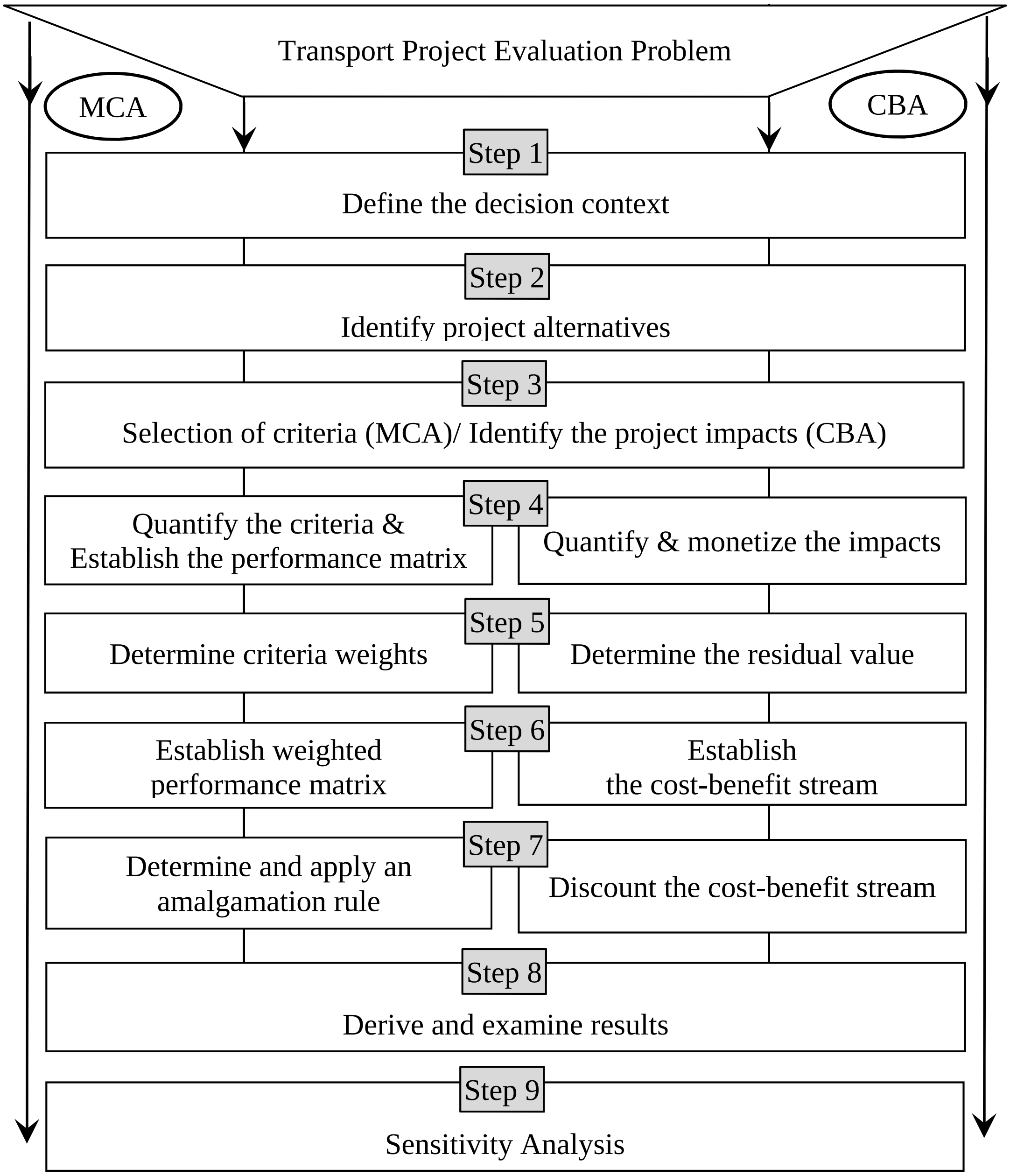
In brief, findings of this sub-section reveal that out of all MCA methods used in transport project evaluation, AHP becomes the prominent performer. However, it is noted that ANP, which is the generalized form of AHP, has not received due credits in available literature mainly because of its recent introduction has not offered adequate time to be popular. Thus, ANP requires a fundamental review based on its conceptual and theoretical framework later on.

2.4.1.3 Key Similarities & differences in Theoretical Frameworks of CBA & MCA

CBA, which reduces all criteria to a single criterion by monetizing impacts as much as possible and leaving out the rest, is also one extreme case of MCA (Beria et al., 2012; Gamper, Thoni, & Weck-Hannemann, 2006; Tudela et al., 2006). But MCA is less of a unified technique than CBA (Jensen, 2012). There are two major differences of CBA and formal MCA: (i) the former generates results for testing implementation feasibility of project alternatives and their prioritization, whereas the latter's results only being usable for the prioritization of project alternatives, and (ii) the latter, being multi-criteria enabled, can incorporate both monetizable and non-monetizable impacts in the evaluation process whereas the former is only limited for monetizable impact (Tudela et al., 2006). In brief, CBA is weak in incorporating inputs (completeness in inputs) but stronger in producing results enabling key evaluation decisions (completeness in results) while MCA demonstrates other way round.

2.4.2 Application Procedures of CBA and MCA and their Limitations

The related literature shows that the application procedure of CBA is largely unified, whereas of MCA is less unified, varying across different methods. However, the MCA methods categorized under value function approaches, which are the ones widely used in transport project evaluation, are largely confinable to a generalized procedure. Basbas and Makridakis (2007), Beria et al. (2012), Gamper et al. (2006), Jensen (2012), and Sijtsma (2006) have generalized the application procedure of such MCA methods. Figure 2.3 presents a generalized application procedure for MCA in sequential nine steps aligned to the afore-mentioned sources and compares the same with the generalized application procedure of CBA derived in consistent with the demonstrations of Buncle et al. (2013), ECU (2003), Hüging et al. (2013), Jensen (2012), Mackie (2010), Pearce et al. (2006), and World Bank (2005).



Note: CBA = Cost-Benefit Analysis, MCA = Multi-Criteria Analysis

Figure 2.3: Comparison of application procedures of CBA and MCA
Source: Author

Figure 2.3 demonstrates that both methods are similar in tasks to be performed under the first three steps and the last two steps. However, there are minor deviations in their executions. Intermediary four steps to be performed in CBA and MCA are completely different from each other. In line with the literature mentioned above, all nine steps given in Figure 2.3 are detailed below for both CBA and MCA, highlighting their similarities, differences, and limitations.

The first step, defining the decision context, is common for both CBA and MCA. This step first defines (i) the goal for the investment, and (ii) limitations for the evaluation in terms of geographical and time scales for both MCA and CBA. Thereafter (i) decision criteria (NPV, IRR, or BCR) are identified for CBA based on the expected outcome of the evaluation, and (ii) decision-makers and stakeholders are identified for MCA to carry out the analysis. In identifying the decision-makers for MCA, the required expertise and experience are to consider in addition to when and how they are involved in the analysis.

The second step, which is also in common for both CBA and MCA, is to identify project alternatives that can satisfy the set goal for the investment. The selection of alternatives is highly influenced by the expertise and experience of the decision-makers. However, it is not mandatory to always choose alternatives that are likely to be feasible and sustainable, though they should be in accordance with the prevailing legal and other restrictions. But, in the case of MCA, it is stressed to define all alternatives at the very beginning to avoid the 'rank reversal issue' associated with many MCA methods (Kong, Wei, & Gong, 2016). Since such an issue is not associated with CBA, adding or removing alternatives can be done even at a later stage.

The third step in the procedural line-up is again similar for both CBA and MCA though it is termed differently: identifying project impacts for CBA and selecting evaluation criteria for MCA. Both intended to identify all impacts as much as possible (costs and benefits) resulting from the implementation of project alternatives. Typical impacts (or the evaluation criteria) consider in transport project evaluation include: construction costs, operating costs, periodic and routine maintenance costs as infrastructure costs; user time savings, vehicle operating cost savings, and accident cost savings as user benefits; savings due to the reduction in air and noise pollutions, network congestion and climate change as externalities. In defining these impacts (or criteria), their completeness, relevance, mutual independence, concurrence with geographical and time scales defined at the beginning are considered. In the selection of impacts (or evaluation criteria), only the monetizables are relevant for CBA, while such limitation is not with MCA. This indicates MCA's ability and CBA's inability to ensure the input-completeness in respective evaluation processes in terms of incorporating impacts.

In the fourth step, both CBA and MCA quantify the impacts (or the criteria) in relation to each selected project alternative. In CBA, quantification of impacts is done by using acceptable methods in a manner that those can be monetized later. In MCA, criteria are quantified to reflect the performances of each alternative as scores. These scores are often established by comparing project alternatives in pairwise with respect to each criterion. When conducting this pairwise comparison, consistency should be ensured to have better results. In CBA, the quantified impacts should be monetized, ignoring the impacts that cannot be monetized. In MCA, the quantified impacts should be assembled in a performance matrix. The performance matrix assembles alternatives on columns, criteria on rows, and the scores in the cells. The scores in the cells represent the performance of each alternative against the chosen criteria. When quantifying impacts, Damart and Roy (2009) highlighted to count future trends of the impacts over the project's design life. Further, such quantification should be done referring to a 'base-scenario' commonly known as 'do nothing' or 'do minimum' scenario.

Under the fifth step, in CBA, a residual value is determined for each project alternative to establish the infrastructure value at the end of its projected lifetime or, in other words, the non-depreciated value of assets at the end of the project life (Jones et al., 2014). The determination of the residual value for infrastructure projects is still a debatable topic, though the straight-line depreciation method is still commonly used (Campos, Rus, & Barrón, 2007). In MCA, weights are determined in this step to establish the relative importance of chosen criteria in terms of achieving the set goal. These weights express the decision-makers' preferences in most cases; thus, they may involve subjectivity. The pairwise comparison is commonly used for this weight determination.

In the sixth step, CBA establishes the annual cost-benefit stream for each project alternative by using forecasted impacts over project design life and residual value.

Meanwhile, MCA establishes the weighted performance matrix by multiplying weights determined for each criterion in the previous step with related scores in the performance matrix.

In the seventh step, CBA discounts annual costs and benefits associated with each project alternative to their present values by using a pre-defined discount rate. This allows comparing costs and benefits that occur at different times. However, discount rates vary considerably across countries, significantly affecting the results' comparability (Naess, 2006; Odgaard et al., 2005). In the same step, MCA applies a suitable amalgamation rule to translate the scores in the weighted performance matrix into a single overall score for each project alternative considered. This amalgamation rule is specific to the MCA method used for the evaluation.

In the eighth step, both CBA and MCA derive and examine the results. In CBA, the discounted cost-benefit stream (seventh step) is used to derive NPV, BCR, while the undiscounted cost-benefit stream (sixth step) to derive IRR. NPV and IRR indicate the economic feasibility (or social profitability) of the project alternatives, thus used to decide acceptance or rejection of the alternative. The BCR is often used to rank project alternatives. Thus, the results of CBA can be used for testing the implementation feasibility of project alternatives as well as for their prioritization. In MCA, the overall scores derived for each alternative in the previous step are the results. Unlike in CBA, those results in MCA are only usable for prioritization of the project alternatives considered. MCA's results cannot be used for determining the implementation feasibility of projects as MCA based evaluation processes do not explicitly derive a minimum feasibility threshold score, similar to the discount rate in CBA. Further, MCA's results (overall scores) only specific to the evaluation problem that they are derived for. Thus, these results are only relatively comparable, whereas CBA's results are absolutely comparable. This usability of these results demonstrates the MCA's inability and CBA's ability to ensure the result-completeness.

The last step of the application procedure is the sensitivity analysis, which is in common for both CBA and MCA. This analysis examines how vulnerable the results of CBA and MCA against the changes of parameters or variables which involve a certain degree of uncertainty in their estimation. Such parameters and variables include discount rate, residual value, project start delay, estimated costs, and benefits, etc.

In brief, the above demonstration reveals several issues associated with the application procedures of CBA and MCA. The most important issue identified in support of this research is that both evaluation processes show incompleteness either in terms of inputs or results: CBA in terms of inputs while MCA in terms of results. This identified issue ascertains the research problem to treat under this research in relation to MCA and CBA.

2.4.3 Strengths and Weaknesses of CBA and MCA

In this sub-section, strengths (or advantages) and weaknesses (or disadvantages) are assessed comparatively for CBA and MCA processes in their use for the transport project evaluation. Table 2.4 provides a comparison of strengths and weaknesses of CBA and MCA as largely identified by Annema, Mouter, and Razaei (2015), Beria et al. (2012), Browne and Ryan (2011), Jensen (2012), Korytárová and Papežíková (2015), and Nguyen et al. (2018) and further extended with other related literature cited below.

Table 2.4: Comparison of major strengths and weaknesses of CBA and MCA

	CBA	**MCA**
Strengths	• Theoretical unambiguity and higher explanatory power • Largely formalized, rigorous and rationalized method, • Results can be easily communicated and comparable across different projects, • Independent from subjective judgments, and	• Potentially all the impacts, including both quantitative and qualitative, can be incorporated, • Promote public participation, provide insight of conflicts, and allow compromise, • Results can only be used for comparing alternatives included in a single evaluation domain, but not for projects included in different evaluation domains,

	CBA	MCA
Strengths	• Potentially participative (The modern applications of CBA allow participation through the definition of shadow values and taking into account the distributive aspects through the use of Kaldor-Hicks matrixes)	• Assure the democracy in the application process, • Applicable to soft effects (such as beauty, personal beliefs, attitudes, etc.), • Equity issues are adequately treated, and • Transparency – fairly acceptable since multiple facets are presented
Weaknesses	• Difficult technique, expensive, requires many data sometimes hardly available, • Only take the monetizable impacts into account. Such impacts limited to time value saving, vehicle operating cost-saving and safety benefits, often leaving out many social and environmental impacts due to difficulty in monetization, • Monetization of impacts are not well-formulated and often controversial, • Practically impossible to assess "soft" effects (beauty, personal beliefs, attitudes, etc.), • equity issues are not directly assessed but left to the decision-makers, • Transparency – not clear as assumptions are hidden behind a single figure, and • Non-democratic – participation of stakeholders in the evaluation process is not adequately promoted.	• Largely informal methods, • Potential ambiguity, subjectivity, arbitrariness in some components especially in the perception of public costs versus private benefits • Risk of double counting • Lack of clarity, consistency, and accountability, and • Participation process is too detailed sometimes

Note: CBA = Cost-Benefit Analysis, MCA = Multi-Criteria Analysis

Source: Author

According to its proponents, the CBA is a powerful, relatively easy, widely used (Naess, 2006) and firmly embedded tool to the project appraisal process (Browne & Ryan, 2011). Thus, it has become a 'common language' used in worldwide project evaluation (Beria et al., 2012). As presented in Table 2.4, afore-said superiority and popularity has gained through its theoretical unambiguity (Nguyen et al., 2018; Annema et al., 2015) and higher explanatory power (Korytárová & Papežíková, 2015) alongside rigorous, transparent, formal, and rational framework (Damart & Roy, 2002; Farrow & Toman, 1998). This rational framework provides clear results which are easy to be communicated and hence shared and engaged despite it comprises much more complex (Damart & Roy, 2002), and expensive (Lee, Kang, & Kim, 2009) technical application procedure and questionable monetization process for some intangible aspects (Aldian & Taylor, 2005; Bristow & Nellthorp, 2000; Tsamboulas et al., 1999; Tsamboulas & Mikroudis, 2000; Walker, 2000). On the other hand, MCA becomes more prominent over CBA, as it allows to count both monetizable and non-monetizable impacts. It is a more informal process, providing access to every stakeholder to be involved and known about the action to be realized (Walker, 2000), ensuring "democracy" by allowing for public debate (Damart & Roy, 2002). Moreover, it is a better method to settle possible arguments (Walker, 2000), and to get preferences and priorities revealed (Lee et al., 2009). In this respect, MCA-based processes also allow to raise thoughtful questions about the way of weighting different opinions (Aldian & Taylor, 2005), and thus resulting accountability, transparency, and coherence in its application (Sayers, Jessop, & Hills, 2003).

The above concisely demonstrates the strengths associated with CBA and MCA processes. The rest of this sub-section details the weaknesses associated with two processes to nail the knowledge gaps and thereby to ascertain the research problem demonstrated in Section 1.3. For comparability purposes, these weaknesses are classified and detailed as (i) Weaknesses in CBA Process as Strengths in MCA Processes, (ii) Weaknesses in MCA Processes as Strengths in CBA Process, (iii) Weaknesses in Common for CBA and MCA Processes, (iv) Weaknesses in CBA Process only and (v) Weaknesses in MCA Process only.

2.4.3.1 Weaknesses in CBA Process as Strengths in MCA Processes

While demonstrating the theoretical frameworks (refer Sub-section 2.4.1) and application procedures (refer Sub-section 2.4.2) of CBA and MCA, CBA's inability and MCA's ability to incorporate all identified impacts in their evaluation processes were elaborated accordingly. This particular weakness in CBA or the strength in MCA is further detailed and supported here with the reviewed literature.

CBA’s complete or partial ignorance of some impacts, particularly socio-environmental impact, mainly due to difficulties in quantification and monetization them is the main criticism against CBA (Barford & Salling, 2015; Mackie & Preston, 1998; Vickerman, 2017). This indicates the inability of the evaluation method to embodying non-monetizable impacts into the evaluation process. Monetization of some impacts, such as equity impacts, is highly unlikely while other effects (e.g., intangible impacts included in wider economic benefits or environmental impacts such as nature and landscape deterioration due to new infrastructure) is highly questionable (Barford, Salling, & Leleur, 2011; Beria et al., 2012; Beukers, Bertolini, & Te Brömmelstroet, 2012; Browne & Ryan, 2011; Guhnemann, Laird, & Pearman, 2012; Macharis & Bernardini, 2015; Niemeyer & Spash, 2001; Shang et al., 2004; Wee, 2007). Moreover, frequently monetized impacts such as travel time savings, vehicle operating cost savings, accident cost savings, and emission cost savings are yet to be formalized in estimation. The incompetency of the method to embodying non-monetizable impacts into the evaluation process, and questionable approaches in monetizing some impacts concisely explained by Hickman and Dean (2017) labeling CBA as ‘Incomplete cost – Incomplete benefit analysis’ (p.4). However, Ackerman and Heinzerling (2004) had been optimistic to label it as ‘complete cost- incomplete benefits analysis’ (p.207), acknowledging the ability to monetize project cost elements though they are questionable at times. All in all, the above arguments/statements reaffirm that the CBA process suffers from the **input-incompleteness.**

In contrast to CBA, MCA based evaluation processes are **capable of incorporating impacts/criteria which cannot be easily converted to monetary terms**, or the impacts/criteria which are intrinsically qualitative and unquantifiable like environmental impacts (Annema et al., 2015). This highlights the fact that MCA methods inbuilt to the processes are having the freedom of potentially including every possible impact, unlike CBA, which only takes monetizable impacts into account (Barford et al., 2011; Barford & Salling, 2015; Beria et al., 2012; Macharis &

Bernardini, 2015). This feature in the MCA methods demonstrates the ability of the MCA processes to ensure the **input-completeness**. However, this input-completeness is hindered by a method-related issue of **questionable and vague approaches of many MCA methods in synthesizing opposing influenced impacts of costs and benefits** in transport project evaluation. This concern is raised due to the absence of inbuilt techniques in those methods to handle the said impacts having opposing influences on the project performance (negative weights are not allowed in MCA methods). Thus, these MCA methods are often supported with some other techniques and strategies to realize the afore-said synthesis. Such indirect approaches more often end up with less clarity. However, it is noted that TOPSIS method is one of the methods having an inbuilt mechanism to synthesize opposing influences. But it is not heavily used in transport project evaluation at present. This method is further detailed in Chapter 4 as it makes a part of the new evaluation process developed herein.

In addition to the above-said method-related issue, there are two input processing-related issues hindering the input-incompleteness of MCA based evaluation processes. They are (a) quantification issues pertaining to some impacts and (b) lack of clarity in separating costs and benefits. The quantification methods of intangible impacts, such as frequently used pairwise comparison, are often subjected to criticisms, as those involve subjectivity and judgmental errors. Even the quantification methods of tangible impacts (including monetizable impacts) also create debatable topics due to their theoretical shortcomings. Moreover, segregation of costs and benefits is required to be precise, particularly when using a MCA method demanding costs and benefits as separate inputs. It is noted that some of the literature refers to negative benefits (such as congestion, emission, and accidents) are also as ‘costs’. Such inconsistencies in segregating costs and benefits lead to produce weak results.

Thus, even though the MCA based processes have the competency to embody all kinds of impacts ensuring the input-completeness compared to CBA, strengthening them against (i) input processing related issues of (a) quantification issues pertaining to some impacts, and (b) lack of clarity in separating costs and benefits, and (ii) method related issues in synthesizing opposing influenced impacts in some MCA methods would enhance the effectiveness of input-completeness.

Many authors have praised MCA based processes, over CBA process, for their **ability to incorporate the opinions of multiple stakeholders into the decision-making process** also (Annema et al., 2015; Beria et al., 2012; Macharis & Bernardini, 2015; Thomopoulos, Grant-Muller, & Tight, 2009). In fact, this is the second most important feature of MCAs over CBA other than its ability to take multiple impacts, including the non-monetizables, into account. Beria et al. (2012) highlighted that counting opinions of multiple stakeholders in the evaluation process is immensely helpful for the successful implementation of transport projects as it builds up ownership for the evaluation recommendations among the stakeholders. Similarly, Haezendonck (2007) stressed the importance of involving stakeholders in the CBA process also, despite such does not seem to be a regular feature in its current practices. However, incorporating stakeholders' opinions in the CBA process could be difficult because the CBA is based on welfare theory and compensation criteria, in which each stakeholder has its own set of costs and benefits (Macharis & Bernardini, 2015). Being incorporating multiple stakeholders' opinions is an input-related feature of the evaluation process, the above assessment rates CBA as a comparatively weak tool in relation to the input-completeness. However, this aspect is not significant and not a 'must include feature' to ensure the completeness of an evaluation process.

2.4.3.2 Weaknesses in MCA Processes as Strengths in CBA Process

The demonstration of theoretical frameworks (refer Sub-section 2.4.1) and application procedures (refer Sub-section 2.4.2) of CBA and MCA elaborated the results of CBA are usable for testing implementation feasibility of the evaluated projects and their prioritization, while the results of MCA, is only usable for the latter. This particular weakness in MCA or the strength in CBA is further detailed and supported here with the reviewed literature.

One of the common advantages in both CBA and MCA processes recognized by Annema et al. (2015) is that both methods give results in a single number for each evaluated project. CBA uses the concepts of willingness to pay (WTP) for positive effects (or willingness to accept monetary compensation, WTA, for negative impacts) and discounting to correct time preferences to aggregate while MCA uses the perceptions of experts/decision-makers/stakeholders for weighting, and subsequently aggregating project impacts into one single number (Annema et al., 2015). As stressed earlier, the results of CBA clearly indicate the implementation feasibility (or social profitability) of an evaluated project and thus usable to take the decision of whether a particular project should be implemented or not, in addition, to use them for comparing performances of different projects for prioritization or ranking (Jensen, 2012). OECD (2006) further elaborated this argument to express that unlike other methods such as cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA), CBA's results have (i) ability to demonstrate the implementation feasibility of a project standalone compared to an acceptable value of decision criteria (IRR above discount rate; Positive NPV; BCR over the unity), (ii) ability to use for comparing performances of projects absolutely enabling ranking projects regardless of their evaluation domains (same or different domains), and (iii) capacity to determine the optimal point where net benefits are maximized for a given project or policy intervention. These results-oriented positive features demonstrate **the result-completeness of the CBA process**.

In contrast to the CBA's results, MCA's results show limited usability. Schutte and Brits (2012) stress that, unlike in CBA, the MCA results cannot be used to judge the social profitability or implementation feasibility of a project due to the absence of a minimum feasibility threshold score. Moreover, these results are only relative comparable instead of being absolutely comparable as in CBA (Gamper et al., 2006). Thus these results are only usable for ranking or prioritization of projects included in a single evaluation domain (Schutte & Brits, 2012). In other words, the results of MCA methods cannot be used to (i) test the implementation feasibility of each evaluated project and (ii) prioritize them when included in different evaluation domains. These limitations indicate that MCA is far behind what is offered by CBA results, which simply facilitate all kinds of result-oriented decision makings. The above ascertain the **result- incompleteness associated with MCA processes** highlighted while demonstrating its theoretical framework and application procedure in the previous sub-sections.

In addition to 'input and result-incompleteness issues', there are various other weaknesses associated with CBA and MCA processes. A few of those appearing as critical are detailed below.

2.4.3.3 Weaknesses in Common for CBA & MCA Processes

Many raise **ethical concerns** over CBA and MCA methods primarily because of (i) individual preference being the main determinant of impact valuation, and (ii) disregarding equity and distributional effects to indicate gainers and losers of the investment (Annema et al., 2007; Gamper et al., 2006; Hickman & Dean, 2017; Hyard, 2012; OECD, 2006; Sen, 2000; Van Wee & Roesera, 2013; Wee, 2012). In case of the latter, there are instances CBA results are supported with a separate distribution analysis to understand who incurs the costs and who enjoys the benefits to secure the social priorities (Buncle et al., 2013; Grimaldi & Beria, 2013). Buncle et al. (2013) show that there are some cases, projects were given up due to the inappropriate distribution of costs and benefits despite their positive CBA results.

The other main criticisms in common for both CBA and MCA are related to their weaknesses in transparency, robustness, and simplicity. Beria et al. (2012), Browne and Heinzerling and Ackerman (2002), and Ryan (2011) questioned the transparency related to both methods on many fronts while Annema et al. (2015) raised concerns over the robustness of both methods, particularly citing heavy dependence on the transportation model involving considerable uncertainties on parameters used, and future forecasting of assumed scenario. Moreover, Basbas and Makridakis (2007) criticized MCA for the uncertainties as it not being explicit in transforming qualitative data into quantitative data. In terms of simplicity, Beria et al. (2012) and Heinzerling and Ackerman (2002) argued that CBA is extremely difficult for the public to understand and participate in the process due to its highly complex, resource-intensive, and expert-driven nature. Beukers et al. (2012; De Jong (2000), and Jensen (2012) supported this argument, labeling CBA as an unreliable and unpredictable 'black box'.

However, there is no considerable concern over the simplicity of MCA despite occasional criticisms raised against the extensive elicitation required in transferring qualitative data to quantitative data.

2.4.3.4 Weaknesses Specific to CBA Process Only

In addition to the afore-mentioned, CBA in isolation has been often criticized for its (i) debatable theoretical platform rested on the social welfare theory (Hyard, 2012; OECD, 2006; Wee, 2012), (ii) key assumption to maximize or optimize social welfare for not clearly indicating which indicator should be targeted (Wee, 2012), (iii) poorly constructed reference cases (Annema et al., 2007; De Jong & Geerlings, 2003; Naess, 2006; Wee, 2007); (iv) poor incorporation of uncertainties (Salling & Banister, 2009; Ševcíková, Raftery, & Waddell, 2011); (v) limitted opportunities for learning and optimizing plans as it being the final assessment (Beukers et al., 2012), (vi) too much focus on travel time saving without showcasing its influence towards spatial economic developments (European Conference of Ministers of Transport, 2004); (vii) perceiving unbalanced attention between monetized effects and non-monetized effects (Beukers et al., 2012), (viii) debatable discounting of future impacts, particularly environmental and social impacts which gain negligible present value compared to user benefits (Hickman & Dean, 2017; Jones et al., 2014; Ludwig, Brock, & Carpenter, 2005) and (ix) determination of discount rate, (Mackie et al., 2014) alongside with project life and residual value (Jones et al., 2014).

2.4.3.5 Weaknesses Specific to MCA Processes Only

Many authors have raised concerns over **subjectivity, arbitrariness, and double-counting effects** in MCA methods (Annema et al., 2015; Beria et al., 2012; Thomopoulos et al., 2009; Macharis & Bernardini, 2015). These concerns are mainly raised against the additive scoring methods, which are extensively used in transport project evaluation. Subjectivity and arbitrariness concerns are mainly raised due to judgmental decisions in assigning weights to criteria and quantifying intangible impacts, while double counting is due to the inability of methods to simulate inter-influences of criteria. However, it is found that ANP method, one of the recent addition to the MCA family, is improved to minimize (i) subjectivity and arbitrariness issues through its inbuilt techniques for determining weights for criteria and (ii) double-counting effect by facilitating to simulate inter-influences among criteria. This ANP method is further detailed in Chapter 4 as it is used in the new evaluation process developed herein.

Moreover, the **possibility of cycles or the rank reversal phenomenon** is another criticism of MCA (Kong et al., 2016). This is a case where introducing a new alternative or removing an existing alternative modifies the ranking of the other alternatives (Belton & Gear, 1983). This is a common issue for many multi-criteria techniques, including AHP, ANP, and TOPSIS, and first highlighted by Belton and Gear (1983) for AHP (Kong et al., 2016).

In addition, Basbas and Makridakis (2007), based on their extensive literature review, criticized the MCA for the drawbacks of (i) its diverse techniques do not always converge to the same results, (ii) under-estimation of different types of uncertainties (data, parameter, and model related), (iii) losing important information of the problem when simplifying it to apply a MCA technique, and (iv) being its outcome highly depends on the selected weights of the criteria used. Moreover, the authors criticized the MCA for providing indistinguishable results when comparing or ranking the different alternatives for certain evaluation problems. Montibeller and Belton (2009) supported this argument indicating that an alternative with a single strong performance in a selected criterion and weak performances in other criteria would score the same as another alternative, which has all partial effects in a medium performance.

2.4.4 Integration of CBA and MCA: Is it an Effective Alternative to Standalone CBA and MCA?

The CBA and MCA combined processes are the third and the last best practice in transport project evaluation identified under Review I to scrutinize further. The literature shows that there is no widely used and globally accepted unified formal combined process at the moment. Thus, they are still available as ‘rough models’ at the development stage. This sub-section first demonstrates the motive to develop such combined processes. After that, their theoretical frameworks, strengths, and weaknesses are assessed in relation to their effectiveness in eliminating or minimizing the drawbacks associated with its parent processes of MCA and CBA.

2.4.4.1 Motive to Develop Combined Processes

As discussed in the previous sections, both CBA and MCA show various weaknesses when they use for the transport project evaluation in isolation. But the fact that one’s weakness becomes the other’s strength (refer Sub-section 2.4.3.1 and 2.4.3.2), particularly related to the incompleteness of inputs and results, motivated researchers and practitioners to test the performance of the combined processes. This motivation led many authors to recommend using both methods in combination as a good practice to negate each other’s shortcomings to a certain extend (Annema et al., 2015; Sijtsma, 2006; Tsamboulas & Mikroudis, 2000; Tudela et al., 2006; Van Wee & Roesera, 2013).

When analyzing the weaknesses of each method, CBA has its major issue related to the inputs while MCAs have them related to the results: CBA struggles to incorporate multiple impacts (economic, social, and environmental) and multiple stakeholder opinions in the evaluation process while MCA struggles to provide results which demonstrate the implementation feasibility of a project and comparable across different evaluation domains. These are the weaknesses that are primarily targeted to address when combining the two methods, but how effectively they were treated depends on the theoretical soundness of the combined processes (Barford & Salling, 2015; Sijtsma, 2006). Apart from those, when combining two methods, transparency, ethical issues, and distributional effects are also improved from the perspective of CBA to a certain extend (Sijtsma, 2006). All in all, it appears that CBA is more benefitted when integrated with MCA, and hence this approach can be promoted as an improvement of CBA rather than other-wise.

2.4.4.2 Theoretical Frameworks of Combined Approaches

As stated above, the combined processes are still available as ‘rough models’ at the development stage. Beria et al. (2012) discuss several ‘rough’ combined processes adopted by EU member states providing the initial momentum to the trend. Authors stated that in most of such cases (i.e., in Sweden, Netherlands, United Kingdom), CBA was used as the primary method supported with a MCA method to incorporate non-monetizable impacts, whereas in some other cases (i.e., Belgium, Austria, and Greece), MCA was used as the primary method incorporating CBA results as one of the criteria. Moreover, somewhere in 2007/8, France, which was practicing CBA in standalone, commenced using MCA tools, particularly in the view of incorporating different stakeholder opinions (Damart & Roy, 2009). Besides these rough combinations, there are several theoretically sound models developed by combining CBA and MCA. Among those, Evaluation Framework of Environmental impacts and Costs of Transport (EFECT), EUNET and COSSIMA are prominent in the literature.

EFECT is a generalized methodological framework developed on MCA platform using an additive function for evaluating transport projects with a specific orientation to count environmental impacts (Beria et al., 2012; Tsamboulas & Mikroudis, 2000). This framework was developed by Tsamboulas and Mikroudis (2000), and it is noticeably one of the early rationalized attempts to combine CBA and MCA for evaluating transport projects. This framework is capable of assessing a transport project extensively, covering both spatial and time impacts for all modes in a network. It executes in four steps of structuring, weighting, rating, and exploring; and provides a simple and intuitive understanding of results while treating uncertainty explicitly through fuzzy sets or, implicitly, through sensitivity analysis. Moreover, the framework allows to use it with either the core model with a basic set of criteria or the full model with a comprehensive set of criteria when needed (Tsamboulas & Mikroudis, 2000).

EUNET, the approach developed for the evaluation of transport projects under the European Commission's fourth framework project, considers MCA as the base method and has incorporated the CBA results in terms of a BCR or NPV as an additional criterion, and thereby presents the composite result as relative weight scores (Barford & Salling, 2015). While the overall approach is based on CBA and MCA, the weighting of criteria is carried out using the REMBRANDT method (Marcial

Echenique and Partners [MEP], 2001). This approach has formed into a software sophisticating its application in the evaluation of transport projects. For each impact, a detailed approach had been in-built for assessment, together with monetary values or recommendations on scoring for non-monetary impacts (MEP, 2001). In addition, several variants and supplementary procedures have been developed, particularly to represent the effects of uncertainty (MEP, 2001).

COSIMA – DSS (Composite model for assessment – decision support system) was introduced in 2005 by Salling, Jensen, and Leleur (2005) to extend conventional CBA into a more comprehensive type of analysis, as often demanded by decision-makers, by including "missing" decision criteria of relevance for the actual assessment task (Salling, Steer, & Jensen, 2007). In this model set-up, the well-established MCA technique of analytical hierarchy process (AHP) has been adopted with two criteria sets of monetary and non-monetary impacts enabling the non-monetary part to be monetized comparing with the total benefit over cost rate from the CBA (Salling et al., 2005). In other words, this model set-up of COSIMA consists of both CBA part and MCA part and that MCA part is truly additive to the CBA part to provide a total value representing the evaluated project's performance (Barford et al., 2011; Salling et al., 2007). In brief, COSIMA – DSS approach seeks to 'translate' the MCA result into CBA 'language' by assigning shadow prices to the criteria, and thereby present the composite result as total rates of attractiveness (Barford et al., 2011; Barford & Salling, 2015). The major difference of COSIMA is that MCA is being embodied to CBA rather than CBA is being another criterion in MCA as the case of many other previous attempts. However, Barford and Salling (2015) pointed out that the COSIMA approach has later proven as a difficult practice to apply mainly due to the trade-off considerations that need to be executed between the CBA and MCA parts to estimate the shadow prices. Further, this trade-off between CBA and MCA parts is not justified with accepted scientific methods, and hence its validity is technically questionable.

Recently, two applications in close similarities to the EUNET approach, including the CBA as an additional criterion in the MCA, have been introduced: (i) Guhnemann et al. (2012) have presented a composite model to support the effective implementation of a transport policy when prioritizing national road infrastructure programs, and (ii) Barford and Salling (2015) have produced EM-DSS (EcoMobility-Decision Support System) to evaluate transport projects and policies, embodying the risk and uncertainty assessments to the core of the model as a new feature compared to the other models in the same caliber. Besides those, Annema et al. (2015) also have suggested a rough composite model for evaluating transport projects and policies, based on trade-offs between the outcomes of CBA and MCA, in line with the views of twenty one (21) Dutch politicians interviewed.

2.4.4.3 Strengths and Weaknesses in Combined Approaches

It was noted that all prominent CBA-MCA combined processes discussed herein have considered CBA as another criterion in MCA, except in the case of COSIMA. This is the widely spread general trend in building up CBA and MCA combined processes, even in the case of rough models. However, when CBA becomes another criterion in MCA, the issue of results not being an indicator of project's implementation feasibility (social profitability) remains largely unresolved unless any specific treatment been made in the process development or set a threshold value for the final result. Further, these results also restrict to compare alternatives relatively but not absolutely. In such instances, the result-incompleteness issue still remains unresolved even in the combined processes, like in MCA standalone practice, despite ensuring the input-completeness by incorporating multiple impacts and stakeholder opinions. However, the COSIMA, which uses additive formulae instead of treating CBA as another criterion in MCA, has eliminated the afore-said result-oriented drawback (result-incompleteness) as it provides the final results as present values for each evaluated project. But, as mentioned before, its theoretical soundness, particularly the valuation of the non-monetizable part comparing with the monetizable part, is debatable.

Moreover, there are several other inherited drawbacks of CBA – MCA combined processes, especially when they used as classic MCA techniques (separate criteria assigned with weights), such as AHP or ANP, taking CBA results as another criterion of MCA. These approaches count a set of impacts, included in the CBA component both in the form of benefits and costs, under a single weight, while other impacts, not included in the CBA component, are assigned with different weights individually. Such a strategy leads to poor reflection of the significance of individual impacts included in the CBA part. Further, it leads to double counting as there is no clarity between the impacts included in CBA and Non-CBA parts. Even if the CBA part is disintegrated to assign different weights for individual impacts, it is still debatable how to treat benefits and costs (or disbenefits) on a common platform as they are having a completely opposing influence on the project's feasibility (negative weights are not allowed in MCA).

Although many combined processes have not been able to resolve the result-incompleteness issue appreciably, they minimize several other issues associated with CBA and MCA standalone practices. Such minimized issues include: subjectivity, arbitrariness, and accountability issues associated with MCA; and input-incompleteness, non-democratic nature, transparency, and ethical issues associated with CBA. Thus, these combined processes are arguably better than CBA and MCA standalone practices, regardless of their result-incompleteness issue. The degree of improvement largely depends on the MCA technique used in the combined process.

2.4.5 Stage II: Conclusions

The critical review in Stage II shows that each of the three best practices of CBA as a standalone practice, MCA as a standalone practice, and CBA-MCA combined approaches has in-built theoretical and process-related strengths and weaknesses in their use for transport project evaluation. CBA's superiority, mainly due to: its firmly established theoretical and conceptual framework, completeness of results, and supportiveness to make rational decisions. However, its inability to ensure the input-completeness (incorporate all identified impacts) together with ethical issues, debatable theoretical platform, controversial discounting of future impacts, failure to secure objectivity and transparency, and process-related issues have forced the decision-makers to search for alternative approaches.

MCA methods are promoted as an alternative approach to CBA, particularly due to its ability to (i) incorporate all identified impacts, including non-monetizable (input-completeness) and (ii) count multiple stakeholder opinions. However, the review shows that there is no unified, firmly established MCA based approach to evaluate transport projects to date, particularly as an effective alternative to CBA. Regardless of many issues, the major failure in MCA to surpass CBA as a better evaluation method is its incompleteness in results, i.e., inability to generate results enabling testing implementation feasibility of independent projects and prioritizing them when included in different evaluation domains.

The most recent trend in the transport project evaluation process, combining CBA and MCA, sought to negate each other's negatives with opposing positives. These types of processes effectively improve CBA's inability to ensure the input-completeness in addition to counting multiple stakeholder opinions but show weakness to resolve the MCA's incompleteness issue in the results as they are not indicative on the implementation feasibility of evaluated projects and comparable absolutely. Thus, it can be concluded that even combined processes have not been able to resolve the 'incompleteness issue' associated with evaluation processes appreciably, and hence it has been left for future researchers to resolve. However, these combined processes have shown supremacy in relation to other drawbacks associated with their parent methods. Thus, this combined approach can be promoted as the 'best' to carry forward for further improvements.

2.5 Knowledge Gaps

The literature review clearly shows that the evolution of transport project evaluation processes is primarily driven by the attempts made to improve its input-completeness and result-completeness. The earliest process in transport project evaluation, CBA, was failed in its evaluation process to count all identified impacts, precisely the non-monetizables (input-incompleteness), though it was succeeded in generating results usable in testing implementation feasibility of the evaluated projects and their prioritization (result-completeness). This failure in CBA led researchers and practitioners to use MCA methods in transport project evaluation, considering its ability to count all identified impacts, including both monetizable and non-monetizable impacts (input-completeness). But MCA processes were failed to ensure completeness in results as they were only usable for prioritization of projects included in a single evaluation domain. The latest development, combining CBA and MCA, was intended to trade-off one's failure from other's success, thereby ensuring both the input-completeness and the result-completeness. However, though these processes were also able to ensure the input-completeness, none of them was managed to ensure the result-completeness as almost all of these processes had been developed on MCA platforms, not on CBA platforms. The obvious reason for less use of CBA platforms to develop these processes is the inability to monetize all identified impacts.

The above briefing ascertains that thus far, researchers and practitioners have not been able to develop a 'complete' evaluation process for the transport project evaluation, and hence the opportunity to develop a new evaluation process still widely open. This argument justifies the motive to develop a new evaluation process in this research. Moreover, the evolutionary attempts to move away from the CBA process undoubtedly prove the fact that all identified impacts are not monetizable. Thus, if counting all identified impacts (or ensuring the input-completeness) is **mandatory**, it is a **must** to develop the evaluation processes on a MCA platform, as a MCA standalone process, or in combination with CBA. This argument is justified by the fact that the latest development in transport project evaluation practices of MCA standalone practices and combined practices were being based on the MCA platforms. Thus, it was decided to develop the new evaluation process herein also on a MCA platform. Then it leaves to address the knowledge gaps causing the **result-incompleteness** and other weaknesses on MCA platforms. Those weaknesses associated with the processes built on MCA platforms are detailed in Sub-section 2.4.3 and 2.4.4 and summarized in Table 2.5, classifying as major and other weaknesses together with related knowledge gaps, and recommended intervention to be adopted for filling those knowledge gaps.

Table 2.5: Weaknesses, knowledge gaps, and recommended interventions for MCA platforms

Weaknesses	Related knowledge gaps resulting the weakness	Interventions to be taken for filling the Knowledge Gaps
Major Weaknesses		
Input-incompleteness: The ability to incorporate all identified impacts is automatically ensured by using a MCA platform. Thus, the major input-incompleteness issue is already sorted out by selecting a MCA platform.	*No related knowledge gap to be treated*	*Interventions are not required*
But following minor issues degrade the effectiveness of the input-completeness on MCA platforms, (i) Method related issue in synthesizing opposing influenced impacts.	(i) Inability in many available MCA methods to synthesize two opposing influenced impacts effectively.	(i) There are MCA methods already strengthened with the ability to synthesize two opposing influenced impacts effectively (Such as TOPSIS). Thus, using such an improved method in developing the evaluation process is recommendable.
(ii) Input processing related issues: (a) lack of clarity in separating costs and benefits, and (b) quantification issues pertaining to some impacts, particularly for key impacts such as travel time savings, vehicle operating cost savings, accident cost savings, and emission cost savings.	ii(a). Non-availability of standardized definitions for costs and benefits. ii(b). Non-availability of standardized formula for quantifying key impacts such as travel time savings, vehicle operating cost savings, accident cost savings, and emission cost savings.	ii(a). Properly defining costs and benefits in relation to transport project evaluation problems ii(b). Formulating generalized equations for quantifying the key impacts generating when implementing typical transport projects.

Weaknesses	Related knowledge gaps resulting the weakness	Interventions to be taken for filling the Knowledge Gaps
Result-incompleteness: Results of MCA based evaluation processes, produced as 'scores', are performance indicative of the evaluated projects. But they are not self-indicators of implementation feasibility and hence not usable for comparing performances of evaluated projects included in different evaluation domains. Thus MCA results are only usable for the prioritization of evaluated projects included in a particular evaluation domain.	The absence of a feasibility threshold value for the scores prevents them from being indicators of the implementation feasibility of evaluated projects.	Introducing a threshold value for the scores derived.
	Scores are being specific to an evaluation domain, they do not allow to compare projects included in different evaluation domains and in turn, their prioritization.	No recommendable intervention. [the new evaluation process is limited to evaluate projects included in a single evaluation domain]
Other Weaknesses		
Ethical concerns: Two concerns in MCA based processes, (i) Being individuals' preferences the main determinants of impact valuation.	(i) Non-availability of theoretically sound tools in-built to MCA methods in assigning weights for the criteria and quantifying the intangible (qualitative) impacts has led to using personal judgments.	There are new MCA methods improved to minimize the influence of personal judgments in the final results (Such as ANP). Thus, using such an improved method in developing the evaluation process is recommendable.
	The degree of involvement of personal judgments and resultant subjectivity influence on the final results vary across different MCA methods.	Completely eliminating personal judgments in MCA methods is highly unlikely.
(ii) Disregarding equity and distributional effects to indicate gainers and losers of the investment. (This weakness is also noticeable in CBA)	(ii) The inability of results to indicate the distribution of benefits among project stakeholders has led to disregard equity and distributional effect in project evaluation.	No recommendable intervention. [This should be considered as one of the limitations in the new evaluation process too]

Weaknesses	Related knowledge gaps resulting the weakness	Interventions to be taken for filling the Knowledge Gaps
MCA methods related issues: These include subjectivity, arbitrariness, and double-counting effects and are mainly raised against the additive scoring methods largely used in transport project evaluation.	Non-availability of theoretically sound tools in-built to MCA methods in assigning weights for the criteria and quantifying the intangible (qualitative) impacts has led to using personal judgments. This causes to raise subjectivity and arbitrariness concerns. Inability in MCA methods to simulate inter-influences of criteria has also caused to double count some impacts if they are not defined as mutually exclusive.	There are new MCA methods improved to minimize subjectivity and arbitrariness issues through their inbuilt techniques and double-counting effect by facilitating to simulate inter-influences among criteria (Such as ANP). Thus, using such an improved method in developing the evaluation process is recommended. Further, double counting can also be minimized by defining criteria ensuring their mutual exclusiveness. Completely eliminating personal judgments in MCA methods is highly unlikely.
Common issues: weaknesses in transparency, robustness, simplicity, and accountability	Knowledge gaps for these common weaknesses cannot be specifically elaborated. But these are the common issues raised due to theoretical and procedural approaches inbuilt to MCA methods. The degree of the influence of weakness depends on the MCA method used in the evaluation process.	There is no recommendable intervention in common for all methods. But when formulating a new evaluation process, necessary adjustments can be made as appropriate to minimize these issues.
Rank reversal issue: Adding or removing an alternative (or a project) to the evaluation domain often leads to reverse the ranking of original alternatives fully or partially.	This is a common theoretical flaw in many MCA methods, particularly in additive scoring methods used in transport project evaluation. Many methods, including AHP, ANP, and TOPSIS, have now been strengthened with rank preservation adjustments.	Introducing rank preservation adjustments to the MCA methods used in evaluation processes or using MCA methods already strengthened with the rank preservation adjustments is recommended.

Note: ANP = Analytic Network Process, CBA = Cost-Benefit Analysis, MCA = Multi-Criteria Analysis, TOPSIS = Technique of Order Preference by Similarity to Ideal Solution.

Source: Author

Attending to all the above gaps in developing the new evaluation process is beyond the scope of this research, whereas the focus is primarily to sort out major weaknesses related to the incompleteness of inputs and results. But when developing the new evaluation process, all possible attempts are to make for minimizing or eliminating all other weaknesses listed in Table 2.5 to ensure the comprehensiveness of the overall process.

In brief, this section justified the motive to develop a new evaluation process in this research and supported to select its platform as MCA. Thus, in the development of the new evaluation process, weaknesses of the MCA platform should be sorted out as much as possible, securing its already inbuilt strengths.

2.6 Summary

The literature review presented in this chapter first reviewed the worldwide evolution of transport project evaluation practices and identified the current best practices. Secondly, such identified practices, namely the CBA, MCA, and combination of both, were critically reviewed in terms of their theoretical framework, application procedures, and strengths and weaknesses. Based on the findings of the critical review on each of the three best practices, (i) ascertained the research problem related to 'incompleteness issue' of existing evaluation processes by demonstrating their strengths and weaknesses, (ii) justified the motive to develop a new evaluation process for transport projects by proving non-availability of a complete process at present, and (iii) recommended developing that new process on a MCA platform sorting out its associated weaknesses.

This chapter satisfies Research Objective 1 (RO1) and responds to Research Question 1 (RQ1) set up in Chapter 1.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The previous chapter justified the need for an improved evaluation process for the transport projects and stressed to develop it on a MCA platform after sorting out associated issues for such platforms. This chapter first demonstrates the demanded features for the new evaluation process and the research approaches to ensure such features on a MCA platform. Eventually, the chapter describes the methodologies for developing the new evaluation process and its validation aligned with the research approaches.

3.2 Overall Research Approach

The research aim, justified in the literature review, demands the following key features for the new evaluation process for transport projects,

(i) input-completeness by taking all identified impacts, including both tangible and intangible (or monetizable and non-monetizable) impacts, into account as inputs, and,

(ii) result-completeness by producing results usable for testing implementation feasibility of each evaluated project and enabling their performance-based prioritization.

This new process ensuring the above features in its practical or real-life application to evaluate transport projects was termed as the comprehensive evaluation process (CEP) and accomplished in **four sequential stages** listed below:

(i) **Stage one**: formulating an evaluation process theoretically, ensuring the key features in the research aim, i.e., input and result-completeness. In this formulation, the practicality in applying this process to evaluate transport projects was not considered. Such formulated process was termed as the theoretical comprehensive evaluation process (TCEP),

(ii) **Stage two**: functionalizing the above formulated TCEP improving its practicality in applying to evaluate transport projects. Such improved TCEP was termed as the functionalized comprehensive evaluation process (FCEP),

(iii) **Stage three:** Establishing the CEP by incorporating necessary improvements to the FCEP for ascertaining input and result-completeness, and

(iv) **Stage four**: validating the above formulated CEP.

In stage one, the TCEP was formulated on a MCA platform capable of synthesizing two opposing influences for ensuring the input-completeness as recommended in Table 2.5. In this formulation, it was assumed that implementing all other recommendations in Table 2.5 for ensuring input and result-completeness would also be possible. Those assumed as possible include (i) segregation of costs and benefits, and (ii) valuation of identified costs and benefits, (iii) finding out a MCA method for synthesizing two opposing influences (costs and benefits), and (iv) deriving a threshold value for testing implementation feasibility of the evaluated projects. These assumptions, together with unattended other weaknesses listed in Table 2.5 (i.e., ethical concerns, method-related issues, and common issues of MCA platforms), indicate that this theoretical formulation still requires improvements to resolve its practicality issues and flaws in its real-life application to evaluate transport projects. Enhancing the TCEP to make it practically applicable to evaluate transport projects was termed as functionalization in this thesis.

Stage two, functionalizing the CEP, simply designed for resolving the afore-said ‘practicality issues and flaws in application’ associated with the TCEP. Thus, this stage was for (i) understanding the fine-tunings required for the TCEP for improving its practicality in application to evaluate transport projects, and (ii) improving them accordingly in the TCEP when transforming it to the FCEP. In turn, the FCEP can be referred to as a process that customized the TCEP to enhance its practicality issues and flaws in the application. However, this functionalized form was only able to ascertain the input-completeness but not the result-completeness. The way that functionalization was performed did not ascertain the result-completeness in the FCEP explicitly. This failure, precisely the results' inability to test the implementation feasibility of evaluated projects, led to improving the FCEP further and establishing the CEP.

Stage three, establishing the CEP, was for ascertaining the result-completeness of the FCEP. At this stage, two tasks were carried out: (i) assessing necessary improvements to incorporate into the FCEP to ascertain the result-completeness, and (ii) accordingly incorporating those identified improvements to the FCEP. With these improvements, the FCEP was qualified to be the CEP as it was then practically applicable for evaluating transport projects ensuring the targeted features in the research aim, precisely the input and result-completeness.

Stage four, validating the CEP, was carried out by ascertaining the validity of CEP's results. This validation recommends CEP to use for evaluating transport projects.

3.3 Stage-wise Research Approaches

In the literature, it was found that there are two possible scientific approaches to handle stage one**,** which is in the nature of a new theory, concept, or model developments: the deductive approach and inductive approach (Saunder, Lewis, & Thornhill, 2009). The main difference between the deductive approach and the inductive approach is that whilst the former is aimed to test a theory and/or hypothesis, the latter is concerned to generate a new theory emerging from the data, information, and methods available. In stage one, the inductive approach was adopted whereby the TCEP was to develop immerging from available information and methods, enabling to incorporate the demanded features into it.

In stage two, where the FCEP was to establish by customizing the TCEP, rational reasoning was adopted. Primarily there are two forms of the rational reasoning techniques applicable for the above customization: deductive reasoning and inductive reasoning (Heit & Rotello, 2010). The deductive reasoning is a process moving from a common or all-inclusive form of a statement, theory, or concept to its specific or customized form by giving logical reasons, whereas inductive reasoning is moving from a specific form to a common form in the same way. This indicates that deductive reasoning is more like a top-down logic leading to a conclusion guaranteed to be true, while the inductive reasoning is a bottom-up logic leading to a conclusion that may be true. Since stage two was to convert the TCEP to the FCEP, i.e., moving from an all-inclusive (theoretical) form to a customized (functionalized) form, the deductive reasoning was selected as the appropriate rational reasoning technique for the stage. Figure 3.1 graphically illustrates the deductive nature associated with stage two.

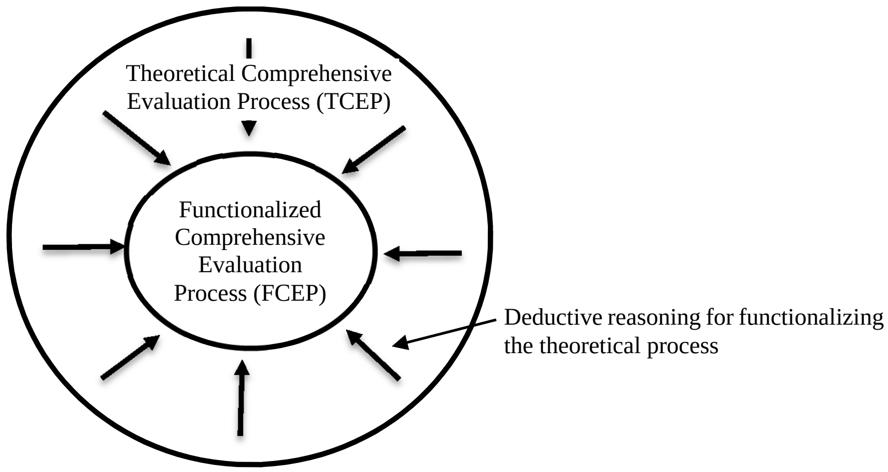


Figure 3.1: Deductive reasoning for functionalizing the theoretical process

Source: Author

In stage three, the inductive approach was adopted since the FCEP was to improve with available concepts and theories for ensuring its result-completeness ascertaining its ability to test the implementation feasibility of evaluated projects.

In brief, a combination of the inductive approach (for stages one and three) and the deductive reasoning (for stage two) was adopted as the most practical and less time-consuming approach for formulating the new evaluation process.

Meantime, stage four, validating the CEP, was designed in the form of a compatibility test that compares the new process's results with those of existing best practice of CBA after both applying to a same transport project evaluation problem.

3.4 Methodologies

In line with the research approach, methodologies were developed for (i) formulating a new evaluation process for transport projects and (ii) validating such formulated process. The first methodology attends to the first three stages in the research approach while the second methodology to the last stage.

3.4.1 Methodology for Formulating a New Evaluation Process

As mentioned above, this methodology jointly performs the first three stages mentioned in the overall research approach, i. e. in brief, formulating the TCEP, functionalizing the TCEP to establish the FCEP, and establishing the CEP. Those three stages were assembled into five tasks and demonstrated in Figure 3.2.

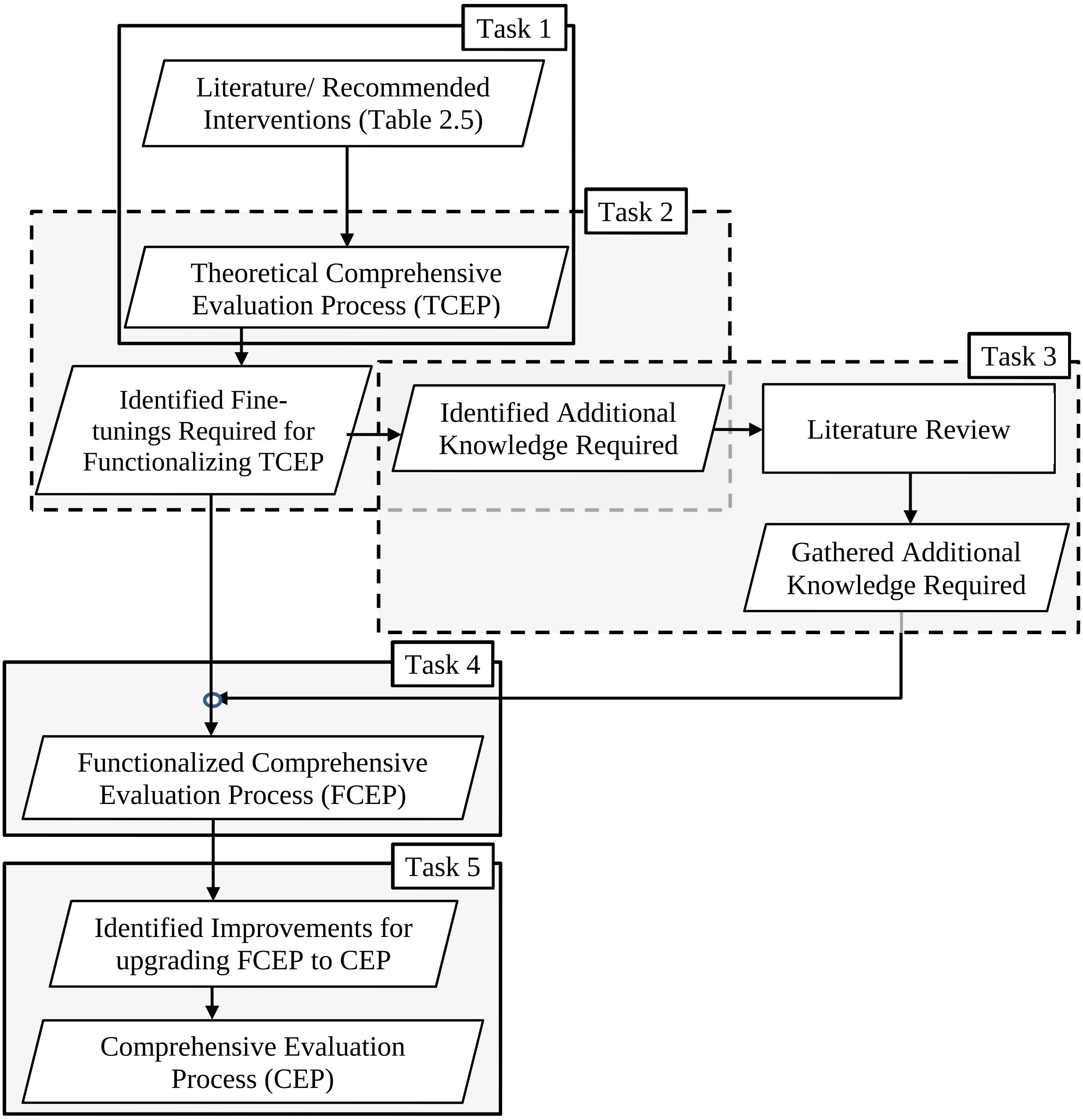


Figure 3.2: Methodology for formulating the new evaluation process

Source: Author

The methodology illustrated in Figure 3.2 is briefed in five sequential tasks below and detailed in subsequent chapters.

(i) **Task 1 – Formulating the theoretical comprehensive evaluation process**: As mentioned before, the technique adopted for this task is the inductive approach. In this task, the evaluation process was established theoretically on a MCA platform, (i) following the structure of a conventional transport project evaluation process (Figure 1.1) and (ii) implementing relevant recommended interventions for ensuring input and result completeness on a MCA platform (Table 2.5). In addition, several assumptions were also made to ensure completeness in this theoretical formation, as mentioned in Section 3.2. In formulating this TCEP, its practical applicability to evaluate transport projects was not assessed.

(ii) **Task 2 – Analyzing the theoretical comprehensive evaluation process:** This makes a part of functionalizing the TCEP and is for (i) understanding the fine-tunings required for the TCEP for improving its practicality in application to evaluate transport projects and thereby (ii) identifying additional knowledge required for such fine-tunings. The technique adopted in this analysis was deductive reasoning, as mentioned before. This task primarily attends to the assumptions made in formulating the TCEP, and common and method-related issues pertaining to the MCA processes.

(iii) **Task 3 - Gathering identified additional knowledge required through further literature reviews:** The identified additional knowledge required to functionalize the TCEP (or to convert the TCEP to the FCEP) in the previous task was in the areas of (i) multi-criteria analysis and (ii) quantification and monetization of impacts. Under this task, those were gathered by reviewing the available related literature.

(iv) **Task 4 – Functionalizing the theoretical comprehensive evaluation process:** The functionalization of the TCEP, commenced under Task 2, was carried forward and completed by incorporating the identified and gathered additional knowledge under Task 2 and Task 3, respectively. This task also followed the deductive reasoning similar to Task 2.

(v) **Task 5 – Establishing comprehensive evaluation process**: The formulated FCEP under Task 4 failed to ascertain the result-completeness explicitly, as its results are not usable for testing the implementation feasibility of the evaluated projects. Under this task, necessary improvements to ascertain the result-completeness were identified and incorporated into the FCEP and thereby upgraded it to the CEP. This task also followed the inductive approach similar to Task 1.

All the above tasks are related to achieving Research Objective 3. Tasks 1, 2, and 3 are demonstrated in Chapter 4, while Tasks 4 and 5 in Chapters 5 and 6.

3.4.2 Methodology for Validating the New Evaluation Process

This methodology is for validating the new evaluation process while demonstrating its application to an actual transport project evaluation problem. The selected evaluation problem for this purpose was the proposal to improve the passenger transportation on Galle Road Corridor in Sri Lanka presented in the Strategic Plan for Traffic Management in Colombo Metropolitan Region (University of Moratuwa, 2015). The Strategic Plan had tested several project alternatives through a CBA to find out the best performing one to implement for achieving the targeted goal of improving the mobility of the corridor. The same project alternatives were tested through the new evaluation process formulated herein and eventually compared its results with the results of the original CBA to investigate their compatibility. The deviations of the results were justified through rational reasoning. The above-mentioned compatibility test and rational reasoning for deviations provided an acceptable validation for the new evaluation process.

Tasks related to this methodology satisfy the last research objective and describes in Chapter 7.

3.5 Summary

This chapter first introduced the new evaluation process for transport projects, emphasizing required features to be inbuilt. Thereafter the chapter established a four-staged approach for formulating the said process and validating it. Following that staged approach, respective methodologies for formulating the new evaluation process and validating it were also established.

This chapter itself attends to Research Objective 2 (RO2) by identifying the weaknesses to be addressed and further improvements to be incorporated in the new evaluation process. It also demonstrates the approaches and methodologies for executing Objective 3 (RO3), developing the new evaluation process, and Objective 4 (RO4), validating the developed new evaluation process.

CHAPTER 4

FORMULATION OF THEORETICAL COMPREHENSIVE EVALUATION PROCESS

4.1 Introduction

This chapter describes the execution of the first three tasks of the methodology for formulating the new evaluation process for the transport projects, the CEP. Those tasks are in the sequential order of (i) formulating the TCEP, (ii) analyzing the TCEP for understanding the fine-tunings required for its functionalization and, in turn identifying the additional knowledge to be gathered, and (iii) gathering such identified additional knowledge through the literature reviews. Eventually, the chapter provides the necessary recommendations and substances for executing the next task, functionalizing the TCEP.

4.2 Task 1: Formulating Theoretical Comprehensive Evaluation Process

As mentioned in the methodology, the first task was to formulate the TCEP for transport projects on a MCA platform (i) following the structure of a conventional transport project evaluation process (Figure 1.1), and (ii) implementing relevant recommended interventions for ensuring input and result-completeness on a MCA platform (Table 2.5). The TCEP is referred to as an evaluation process (i) ensured with all positive features considered in the research aim, particularly the completeness in inputs and results, and (ii) developed not considering ‘its practicality’ when applying it to a transport project evaluation problem (refer Section 3.2).

When using MCA for the transport project evaluation, the literature stresses treating costs and benefits as separate input categories (input clusters) to make the process ‘well rationalized’ and thereby produce effective results. This feature of not mixing costs and benefits as inputs has contributed to the success of CBA, while their mixing in some MCA techniques has often led to criticisms (refer Sub-section 2.4.3). Thus, the TCEP was also designed to treat costs and benefits as separate input clusters.

In the evaluation processes treating costs and benefits separately, it is required to have a specific total cost and total benefit value for each project to feed into the evaluation method. Thus, the TCEP was designed firstly to classify both cost and benefit elements as monetizable and non-monetizable, secondly to valuate them separately, and finally to synthesize them to reach the afore-said specific total cost and benefit values for each project. Appropriate MCA methods for separately valuing and synthesizing costs and benefits were selected and built into the process.

The next step was to synthesize the above total cost and benefit values for deriving a final score for each project being evaluated. For this purpose, a MCA method capable of synthesizing two opposing influences (costs and benefits) was selected and built into the process. Those scores derived can be used to (i) test the implementation feasibility of evaluated projects in the presence of a threshold value, and (ii) their performance-based prioritization.

The above-adopted process can be summarized sequentially as follows;

(i) identification of project impacts,
(ii) segregation of impacts into costs and benefits,
(iii) grouping costs and benefits as monetizable and non-monetizable,
(iv) valuation of costs and benefits to have a specific cost and benefit value for each project under evaluation,
(v) synthesizing the total cost and benefit values of each evaluating project to derive a corresponding final score; at this step, a minimum cut-off value for the final score to test the implementation feasibility of projects was also established, and
(vi) determination of implementation feasibility of evaluated projects and their prioritization based on the final scores derived

The above steps can be formed into four formulation modules, namely (a) impact categorization module (ICM), (b) cost valuation module (CVM), (c) benefit valuation module (BVM), and (d) final valuation module (FVM) as represented graphically in Figure 4.1 while being aligned to the structure of a conventional transport project evaluation process, illustrated in Figure 1.1. Steps (i) and (ii) are included in the impact categorization module; step (iii) and (iv) in the cost valuation and the benefit valuation modules; and (v) and (vi) in the final valuation module.

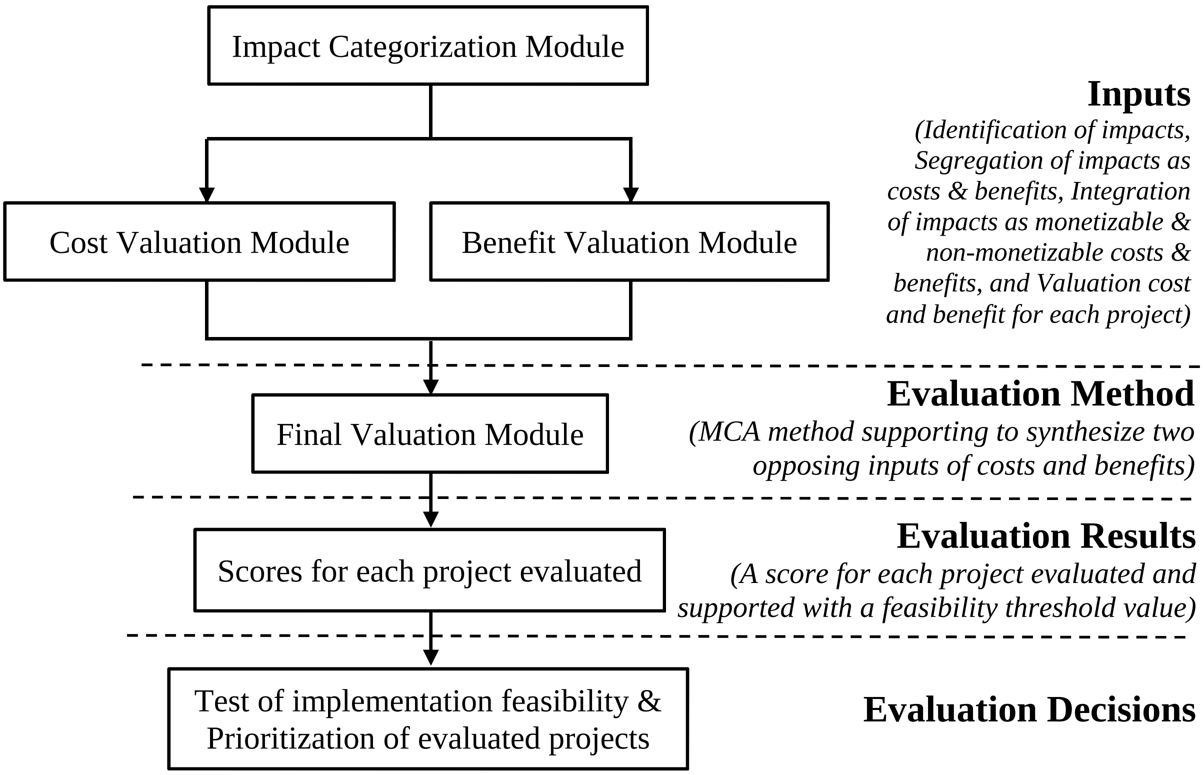


Figure 4.1: Theoretical comprehensive evaluation process (module-wise)

Source: Author

Figure 4.2 presents the TCEP as an activity flow chart detailing each of the modules given in Figure 4.1.

The above process was theoretically developed, ensuring completeness in both inputs and results, and thus, it is qualified as the theoretical comprehensive evaluation process defined for this research (refer Section 3.2). It should be noted that while building up this process, the practicality of executing each step was not tested and proven. Only the necessity of selecting several MCA methods to in-build into this process was highlighted. But they were also not identified. In addition, procedures for (i) segregation of costs and benefits, and (ii) valuation of identified costs and benefits, (iii) deriving a threshold value for testing implementation feasibility of the evaluated projects were not detailed. Thus, the next task analyses the TCEP and provides necessary recommendations to improve its practicality in applying to real transport project evaluation problems.

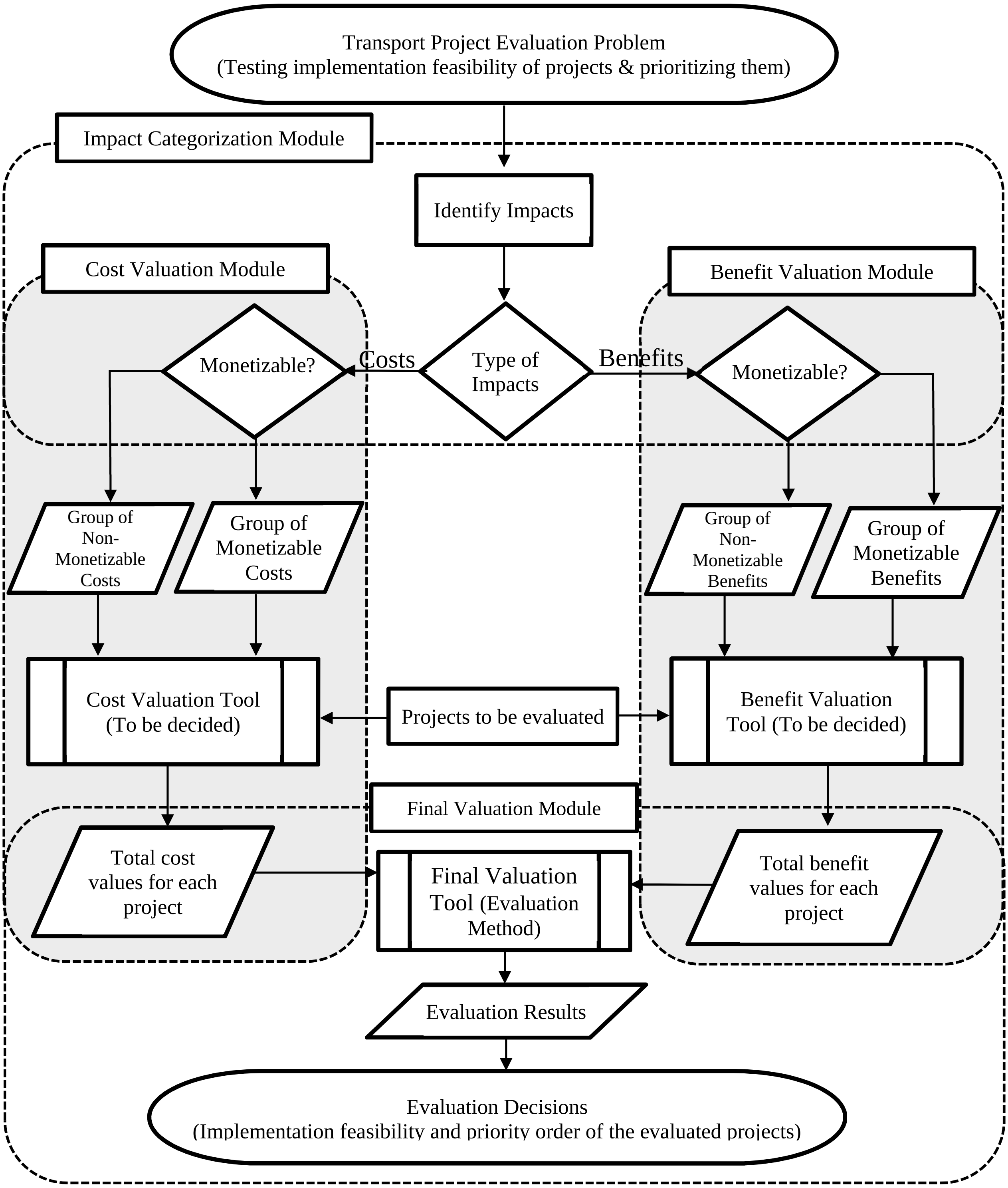


Figure 4.2: Theoretical comprehensive evaluation process
Source: Author

4.3 Task 2: Analysis of the Theoretical Comprehensive Evaluation Process

The task was focused on (i) understanding the fine-tuning required for the TCEP for improving its practicality in applying to evaluate transport projects and thereby (ii) identifying additional knowledge required for such fine-tuning. The analysis was carried out by the execution steps listed in the previous section.

Step 1: identifying project impacts is a common element in any form of a project evaluation process, and indeed, it becomes the first task to be executed in the ICM as well as in the overall process. In ex-ante project evaluation, impacts are identified based on previous experience in similar nature and hence largely depend on the expertise of the analyst (Beria et al., 2012). In ex-post project evaluation, impacts are clearly comprehensible, and hence those can be judged based on the detailed assessment of real-project experience (Beria et al., 2012). It should be noted that types of impacts do not vary by projects as they are included in a single evaluation domain.

Step 2: Segregation of impacts into costs and benefits is the second task included in the ICM as well as in the evaluation process. It is also a common in-built task in the CBA and also becomes regular for many MCA based processes.

Broadly the impacts are classified into costs and benefits and are defined in transport project evaluation as economic losses and gains respectively imposed on society as a whole (ADB, 2017; EC, 2008; World Bank, 2010). When considering the fact that transport projects are usually implemented with public funds, it is evident that the government or its relevant agency bears all the ‘costs’ of a project on behalf of the whole society. These costs include construction cost, operational cost, routine and periodic maintenance costs of infrastructure. On the other hand, the benefits of a transport project are the impacts imposed on individuals in the society as a result of project implementation. In contrast to the costs which are centralized to one institute, benefits influenced on many individuals or groups in society. Those benefits can be either positive or negative, depending on their net effect compared to a base case (without project case or any other alternative case). Usually, in the literature, ‘negative benefits’ are termed as costs in project evaluation, but in this research, those are still treated as ‘negative benefits’ without treating them as ‘costs’ to ensure the consistency in definitions.

In brief, costs in transport project evaluation denote the impacts imposed on government (or relevant agency) in the form of the spending resulted with the implementation of the project while benefits are those impacts imposed on society as a whole regardless of their positivity (gain) or negativity (loss) to the influenced individuals or groups. This classification was used to segregate impacts into costs and benefits in this research.

Step 3: Grouping costs and benefits as monetizable and non-monetizable is the next step in the process and becomes the first task under the CVM and the BVM. The arguments presented in Step 2 suggest that ‘costs’ in transport projects are always monetizable, while benefits are likely to remain as either monetizable or non-monetizable. This conclusion on costs helps to revise the CVM in the TCEP, discarding the input of ‘group of non-monetizable elements’ to the Cost Valuation Tool (refer Figure 4.2). The ability to monetize benefits depends on the availability of standard scientific methods or calculability from the fundamentals. It is better explainable in relation to a classification of benefits demonstrated below.

The benefits of transport projects are broadly classified into internal and external benefits based on their nature of influence. The internal benefits further can be classified into direct and indirect benefits based on their nature of generation. Figure 4.3 graphically illustrates the different types of benefits by their influence on different groups.

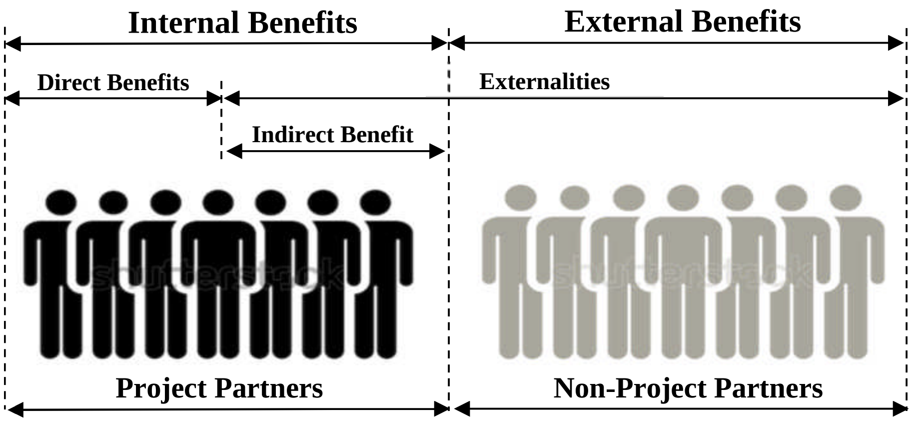


Figure 4.3: Project benefits by their influence on different social groups

Source: Author

The internal benefits are those influenced on targeted or known project partners[5] (targeted benefit gainers, anticipated losers, and cost payers such as government or related agency bearing the cost, etc.) while external benefits are the ones influenced on third-parties not targeted to be influenced through the project implementation. These internal benefits can be classified into direct benefits and indirect benefits. Direct benefits are those purposely aimed to generate by implementing a project and commonly include the savings in travel time cost, vehicle operating cost, and safety cost. On the other hand, indirect benefits are those not intended to generate but still generated as a by-product of project implementation. Benefits related to congestion and air pollution are examples of indirect benefits. Indirect benefits, together with external benefits, form externalities. The externalities are formally defined as costs or benefits that do not fall on those individuals or agencies targeted but on other individuals or on society as a whole (Department of Transport [UK], 2005).

Based on the above classification, typical monetizable and non-monetizable benefits are grouped in Figure 4.4, largely in relation to a public transport improvement project.

[5] The project partners are largely confined to transport sector and pre-defined geographical area during the project formulation.

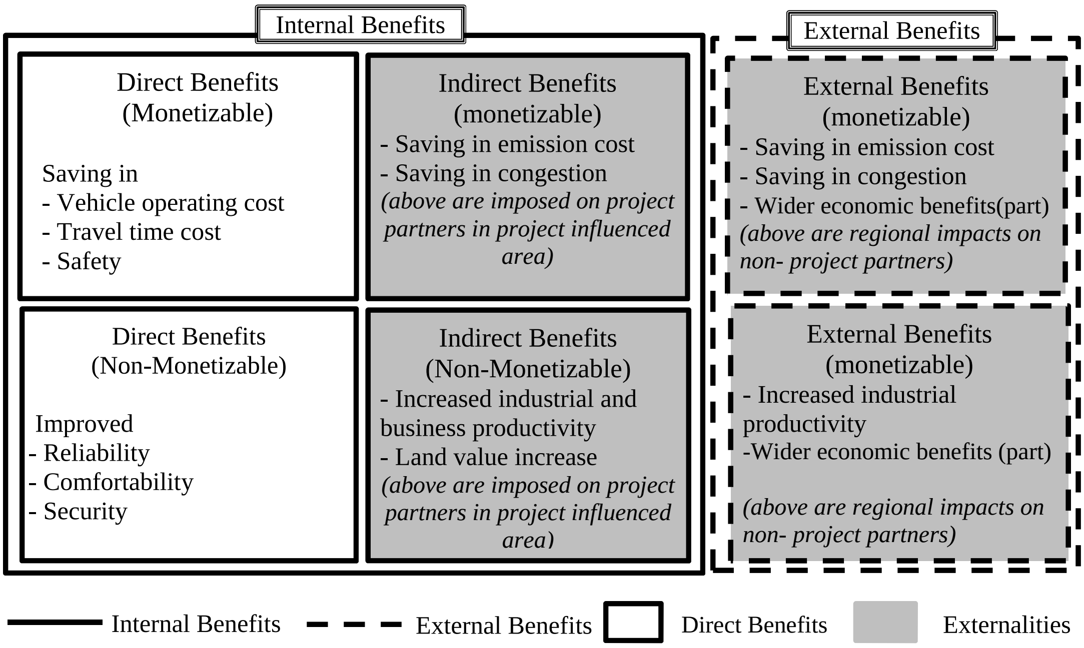


Figure 4.4: Grouping of typical benefit items

Source: Author

The direct benefits include the most common and vital benefit elements in transport project evaluation. Those direct benefits include monetizable benefits such as savings in vehicle operating cost, travel time cost, and safety cost and non-monetizable benefits such as improved service comfort, reliability, and security. The indirect benefits are the second most important category. They comprise typical monetizable elements such as savings in emission cost and congestion cost and non-monetizable elements such as increased land value, industrial and business productivity. It is evident that the indirect benefit elements are also imposed on non-project partners, and corresponding shares are counted under external benefits as per the benefit classification given above. Some of these benefit items shared across internal benefits and external benefits such as savings in emission cost and congestion cost are monetizable usually through fundamental theories, while others remain non-monetizable. The rest of the benefit elements included in external benefits are primarily the wider economic benefits, which remain largely non-monetizable (Douglas & O'Keeffe, 2016; Wangsness et al., 2016).

Step 4: Valuation of benefits and costs associated with each project under evaluation is the next step in the line-up. The valuation of costs is performed under the CVM, while the valuation of benefits is performed under the BVM. As mentioned in Step 2, costs associated with the transport projects are always monetizable, and hence their valuation can be done in monetary terms. The procedures adopted for the valuation of typical cost elements in transport projects are discussed in Sub-section 4.4.1 in detail. In contrast to the costs, benefits associated with the transport projects include both monetizable and non-monetizable elements demanding an advanced tool for valuating them individually and aggregating to a single measure.

In this new evaluation process, the monetizable benefits were valued in monetary terms, as in the case of costs. The methods recommended for monetization of typical benefit elements associated with the transport projects are demonstrated in Sub-section 4.4.1. For the non-monetizable benefits, a suitable tool was needed for (i) valuating both tangible and intangible elements first, and (ii) later enabling them to aggregate with valued monetizable benefits to reach a single benefit criteria value for each project. Fundamentally this particular tool should be a MCA technique as it is to handle multiple benefit elements (or criteria) to deliver a unified result. Therefore, selecting a suitable MCA technique from the numerous techniques available became a prerequisite. As detailed in Chapter 2, the most appropriate MCA method that best fits the above requirement is AHP or its generalization of ANP. Hence it was decided to choose one of these as the benefit valuation tool. Sub-section 4.4.2 presents the suitability assessment and an application demonstration of the selected method.

Step 5: Synthesizing the total cost and benefit values to derive a score for each project is the penultimate step in this evaluation process and includes in its FVM**.** This step is to derive a score for each project synthesizing its relevant total cost and benefit values from the CVM and the BVM, respectively. Such synthesis is achievable by adopting a MCA technique, as in the case of the BVM. However, AHP or ANP, demonstrated so far, is not suitable for synthesizing the two opposing groups of criteria such as costs and benefits considered herein. The literature such as Bianchini (2018), Chang, Liao, Tseng, and Liao (2015), Karim and Karmaker (2016), Percin (2009), Shahroudi and Rouydel (2012), Shelton and Medina (2010), and Wu, Lin, and Lee (2010) show that TOPSIS has been an effective tool to synthesize such two opposing groups of criteria. Interestingly, in most of those cases in the literature, TOPSIS has been used alongside AHP or ANP, similar to the case with this research. Based on the above facts, TOPSIS was selected as the valuation tool to use in the FVM. Sub-section 4.4.3 demonstrates the theoretical and application procedure of TOPSIS in detail.

At the same time, a threshold value for the above derived final scores was established to test the implementation feasibility of each alternative evaluated. This was established by introducing a 'dummy project' to the evaluation domain in which the cost-benefit ratio is kept at unity. The strategy adopted for this purpose is detailed in Chapter 6.

Step 6: Determination of implementation feasibility of evaluated projects and their prioritization based on the final scores derived is the last step of the evaluation process presented herein. Since the final scores are performance indicative, the evaluated projects are ranked in the descending order of their corresponding scores, giving the highest preference to the one that scored the most and the least preference to the one that scored the lowest in preparing their implementation schedule. In this schedule, only the evaluated projects having their scores equal to or above the feasibility threshold value are treated as feasible for implementation.

4.4 Task 3: Theories and Methods for Functionalizing the TCEP

The previous section identified the additional knowledge required for functionalizing the TCEP. Such identified additional knowledge required (refer Step 4 & 5 of Section 4.3) are summarized below and gathered accordingly in this section.

i. Monetization of impacts,
ii. Review on AHP and ANP to select one of them as the benefit valuation tool in the BVM, and
iii. Review of TOPSIS to apply it as the final valuation tool in the FVM.

4.4.1 Monetization of Impacts

This section presents the monetization methods for the most common cost and benefit elements associated with the evaluation of transport projects. In the literature, many sources are demonstrating how to estimate the benefits related to vehicle operating cost, travel time cost, accident cost, emission cost as well as costs related to construction/rehabilitation, operation, and maintenance (ADB, 2017; Belli et al., 1998; Department of Transport [UK], 2014). But none of those has attempted to form a set of equations to calculate the afore-mentioned cost items, probably because of their nature being inconsistent across different projects. However, since the monetization of costs and benefit elements is an essential feature in the CVM and BVM modules, equations were formulated for the most common cost and benefit elements considering a multi-modal transport network, aligning with the work presented in Kumarage and Weerawardana (2013) as a part of this research.

In the evaluation of transport projects, terms of benefit and cost are referred to relative values and indeed to the 'net of cost' which is derived as the difference of the absolute cost of an impact in two different cases (e.g., with the project and without the project cases). This indicates that formulating equations to evaluate the absolute cost of each impact for a given case is sufficient in the valuation of relative costs and benefits. Therefore this section formulates the equations to monetize travel time cost, vehicle operating cost, accident cost, emission cost, and infrastructure costs consisting of the sub-components of construction cost, operation cost, and maintenance cost for a representative case of a multi-modal transport network. The multi-modal transport network is defined as a network formed with multiple arteries or corridors and used by multiple modes to transport passengers and goods. In order to compute the said cost elements, respective equations were developed as a generic cost calculation for a single link, which can be aggregated to a corridor and then to the entire network before extending to the entire multi-modal transport network. Further, it should be noted that all these equations have been developed, starting with fundamental definitions and theories.

4.4.1.1 User Travel Time Cost

The economically valuable portion of the time costs applicable to passenger and freight transport represents the disutility arising from the expenditure of time in travel. In order to understand this, consider a multi-modal transport corridor that is made up of *l* number of links, as shown in Figure 4.5.

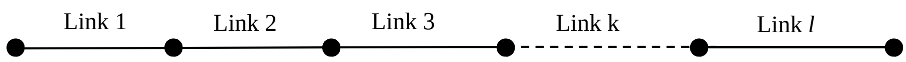


Figure 4.5: Representative transport corridor

The travel time cost of any user *p* on a link *k* in the corridor refers to the cost of time spent on transport, including waiting as well as actual travel time (Victoria Transport Policy Institute [VTI], 2012). The time cost applies to all users, including passengers as well as freight forwarders or their clients. Travel time cost can be expressed as the product of the value of the time and the amount of time spent on transport for each user. Thereby we can arrive at the travel time cost $(TTC_{p,k,t})$ for an individual user *p* on a link *k*, during a time period *t* expressed as;

$$TTC_{p,k,t} = C_p \, T_{p,k,t} \tag{1}$$

Where,

C_p - value of time for user *p*

$T_{p,k,t}$ - average travel time for user *p* on link *k* during time period *t*

The value of travel time differs between persons and by trip purpose (Amador, Gonzalez, & Ortuza, 2005; VTI, 2012). Even though traditional transport costing aggregates total link cost by assuming an average time value for users of each mode or vehicle type, this typically translates to the time cost of public transport users being valued lower than that of private vehicle users. This may not be accurate as a high-quality public transport mode, environmentally conscious users, or intense traffic restraint measures could divert a significant portion of high-income users to public transport. Moreover, diverting a specific group of users, such as those who drive to work, to a new mode could be an objective of urban transport interventions. As such, it is important to express total user time cost representing the impacts to the different socioeconomic user groups and not as an average representing particular users of a mode of transport or vehicle category. Hence the Equation to estimate the total travel time cost of a user group *i* made up of users *p*, for the link *k* for a given time period *t* is written as follows;

$$TTC_{i,k,t} = P_{i,k,t} \,.\, C_i . T_{i,k,t} \qquad (2)$$

Where,

$P_{i,k,t}$ - flow of user type *i* on link *k* in time period *t*

C_i - value of time for user type *i*

$T_{i,k,t}$ - average travel time for user type *i* on link *k* in time period *t*

It should be noted that this assumes that different user groups can have different travel times, which can happen when different types of vehicles having different operational features that are used on the same infrastructure, such as a highway. Moreover, all vehicles may be assumed to carry both passengers and freight with different time values for each user type and freight type. Equation 3 gives the total user cost for link *k* for time period *t.* when individual users *p* are aggregated to users groups *i* across all modes of transport *j* expanded to further identify passenger and freight transport:

$$TTC_{k,t} = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(P_{i,j,k,t} \,.\, C_i . T_{i,j,k,t} + L_{i,j,k,t} \,.\, C'_i . T_{i,j,k,t} \right) \qquad (3)$$

Where,

$P_{i,j,k,t}$ - flow of user type *i* on link *k* on mode *j* during time period *t*

$L_{i,j,k,t}$ - flow of freight type *i* on link *k* on mode *j* during time period *t*

$T_{i,j,k,t}$ - travel time for user type *i* on link *k* on mode *j*

C_i - unit value of time for passenger type *i*

C'_i - unit value of time for freight type *i*

Hence total travel time cost for all modes of transport in a corridor composed of links *l* over a time period *t* ($\mathrm{TTC_t}$)is given as;

$$TTC_{\mathrm{t}} = \sum_{k=1}^{l}\sum_{j=1}^{m}\sum_{i=1}^{n}\left(P_{i,j,k,t}\,.\,C_i.\,T_{i,j,k,t} + L_{i,j,k,t}\,.\,C'_i.\,T_{i,j,k,t}\right) \tag{4}$$

4.4.1.2 Vehicle Operating Cost

Each vehicle is associated with an operating cost. Vehicle operating costs vary with usage and include costs of fuel, tires, maintenance, repairs, crew, and depreciation (Odoki & Kerali, 2007). Projects usually affect the variable vehicle operating costs, depending on distance traveled, travel speed, condition of roadway surfaces, or roadway geometry, but not on the fixed operating costs such as registration fees, financing, time-dependent depreciation, insurance, and residential parking.

The vehicle operating cost for a particular vehicle type *j* ($\mathrm{VOC_j}$) for operating on link *k* during time period *t* ($VOC_{j,k,t}$) can be expressed as;

$$VOC_{j,k,t} = \; V_{j,k,t}\,.\,O_{j,k,t}.\,D_{j,k} \tag{5}$$

Where,

$D_{j,k}$ - travel distance of vehicle type *j* on link *k*

$V_{j,k,t}$ - flow of vehicle type *j* on link *k* during time period *t*

$O_{j,k,t}$ - cost for vehicle type *j* to operate a unit length on link *k* during time period *t*

The vehicle operating cost for a unit length of a given mode of transport depends on travel-way features of link speed, roadway conditions, and geometric features (Odoki & Kerali, 2007). The Highway Development and Management Model –HDM 4 (Highway Management Research Group, 2010) estimates road vehicle operating cost for different types of vehicles at different speeds and road conditions. Similarly, operating costs can be estimated for other modes of urban transport. As such, the vehicle operating cost for a given link *k* during time period *t*, can be given as:

$$VOC_{k,t} = \sum_{j=1}^{m} V_{j,k,t} \, . \, O_{j,k,t} . \, D_{j,k} \tag{6}$$

Hence vehicle operating cost during the time period of *t* for the corridor of links *l* for all vehicle types *m* is given as

$$VOC_{t} = \sum_{k=1}^{l} \sum_{j=1}^{m} (V_{j,k,t} \, . \, O_{j,k,t} \, . \, D_{j,k}) \tag{7}$$

In addition to travel time cost and vehicle operating cost, other important costs generated through transport operations and imposed on the society primarily include congestion cost, accident cost, emission cost, noise cost, and costs borne through water and soil pollutions, etc. Since the magnitude and the severity of these effects are hardly quantifiable, precise cost estimation is difficult. However, most countries use approximate and often different methodologies to evaluate these secondary effects. In keeping with the focus of this thesis, only congestion cost, accident cost, and emission cost were considered to illustrate the monetization approach.

4.4.1.3 Congestion Cost

Congestion cost is estimated as the incremental user travel time and the vehicle operating cost. Most economists assume that congestion cost is included in both travel time and vehicle operating cost since it is a cost imparted on users themselves (Cerwenda & Ruhle, 2009) and its consequences are transferred only minimally to the non-users in terms of air and noise pollution. Being equation 4 and 7 calculates user travel time cost and vehicle operating cost respectively based on average travel speeds assume the presence of both the congested and uncongested flow condition prevailing on that corridor. Thus the methodology directly internalizes congestion cost without differentiation time spent in congested or uncongested travel conditions. But whenever real speeds are used in calculations, the congestion cost should be calculated as the aggregation of incremental user travel time and the vehicle operating cost.

4.4.1.4 Accident Cost

Similar to congestion cost, accident cost is also imparted on users but restricted to identifiable individual victims, whereas congestion cost is spread over all users of the road section being considered (Maibach, Schreyer, & Sutter, 2008). Hence accident costs are more a personal cost that should be evaluated separately using Equation 8, which follows the same link-based analogy adopted in previous equations. Since the insurance costs have already been eliminated from the vehicle operating cost estimate, the total accident cost (TAC) is derived as given Equation 8.

$$TAC_t = \sum_{k=1}^{l}\sum_{j=1}^{m}\left(V_{j,k,t}.D_{j,k}.A_j\right) \tag{8}$$

where

$V_{,j,k,t}$ - flow of vehicle type *j* on link *k* during time period *t*,

$D_{j,k}$ - distance travelled by vehicle type *j* in link *k*,

$A_{j,}$ - estimated accident cost per vehicle km of vehicle type *j* calculated based on national accident data.

4.4.1.5 Emission Cost

In contrast to both congestion and accident costs, emission cost affects both the user and non-user groups in the society. Emission levels and costs are usually related to fuel consumption based on vehicle type, load, and operating speed (Feng, Yun, Ming, & Bao, 2011). Thus the total emission cost for a time period *t* (TVC_t) on a multi-modal corridor composed of links *l* and modes *m* as can be formed into Equation 9.

$$TVC_t = \sum_{k=1}^{l}\sum_{j=1}^{m}\left(V_{j,k,t}.F_{j,k}.E_{j,k}.D_{j,k}\right) \tag{9}$$

where $V_{,j,k,t}$ is the flow of vehicle type *j* on link *k* during time period *t*, $F_{j,k}$ the fuel consumed per unit distance traveled by vehicle type *j* on link *k*, $D_{j,k}$ the distance traveled by vehicle type *j* in link *k*, $E_{j,k}$ the estimated value of emission cost per litre of fuel for vehicle type *j* in link *k* selected based on average link speed.

4.4.1.6 Infrastructure Cost

Infrastructure costs in transport projects include (i) construction or rehabilitation cost, (ii) restoration or periodic maintenance cost, (iii) operation cost, (iv) routine maintenance cost, and (v) emergency maintenance cost. These cost items are difficult to fit into equations as they largely depend on the nature of the project. Nevertheless, monetization of these cost elements is not difficult at the project level as each can be segregated into the usage of material, machinery, equipment, and labor in quantity, allowing to monetize them individually by assigning respective market values. Such itemized costs can be aggregated to reach a total cost. In practice, a marginal value increase in the form of physical and financial contingencies is added to cover up uncertainties in the above estimations.

All the above cost items are estimated for a base-year, which is the year that they start to incur. Its futuristic effects over project life should be handled through an appropriate forecasting technique. Such forecasting techniques are not detailed in this thesis as they are beyond the scope of this research.

4.4.2 Review of AHP and ANP: Theoretical Formation & Application Procedure

This sub-section sets out to select the most appropriate method between AHP and ANP to use in the BVM as its benefit valuation tool (refer Step 4 of Section 4.3). Thus, it first compares the theoretical formation of both methods in relation to the transport project evaluation and thereby selects the best-fitted method. The application procedure of the selected method, i. e. of ANP, is eventually detailed since it becomes a part of the new evaluation process.

4.4.2.1 AHP & ANP: A Comparison

Both AHP and ANP were developed by Saaty: the former in the 1970s (Saaty, 1987) and the latter in the 1990s as a generalization of the former (Saaty, 2006). The AHP, the one that developed first, is a multi-criteria decision-making tool that can be used to solve complicated decision-making problem by decomposing the general decision-making process into a multilevel hierarchical structure of objective, criteria, and alternatives (refer Figure 2.2) (Gorener, 2012; Sharma, Moon, & Bae, 2008). It is used to derive ratio scales from both discrete and continuous paired comparisons, which are taken from actual measurements or a fundamental scale, which reflects the relative strength of preferences and feelings (Saaty, 1987). Such performed pairwise comparisons derive relative importance of the elements in each level of the hierarchy and/or appraise the alternatives in the lowest level of the hierarchy in order to make the best decision among alternatives (Gorener, 2012).

The key assumptions of AHP are that higher-level elements of the hierarchy are functionally independent from all its lower-level elements, and the importance of the former determines the latter in the hierarchy (Lee & Kim, 2000). However, many decision problems cannot be structured in hierarchical form because they show dependencies of higher-level elements on lower-level elements and vice versa in addition to show interaction among the elements at the same level (Saaty, 1996b). Moreover, as the importance of higher-level elements (criteria) determines the importance of the lower-level elements (alternatives) in a hierarchy, the importance of the alternatives themselves determines the importance of the criteria as well (Lee, 2010; Saaty, 1996a). These characteristics of the decision-making process demand that the hierarchical structure of AHP to be generalized into a network structure, making it possible to model various aspects in the decision making process without bothering about the order of events and their relationships. This way of representing a problem, with fewer constraints compared to the structural form of the AHP, is closer to real situations where the elements act in a non-hierarchical way. Considering the above facts, Saaty T. L introduced ANP in 1996 to represent the decision-making problem in network structure (Gencer & Gumpinar, 2007; Meade & Sarkis, 1999; Taslicali &

Ercan, 2006). This development background makes ANP a generalized form of the AHP, or in other words, AHP becomes a special case of ANP (Gorener, 2012; Meade & Presley, 2002; Saaty, 2006; Wey & Wu, 2007). The structural differences between AHP and ANP are illustrated in Figure 4.6.

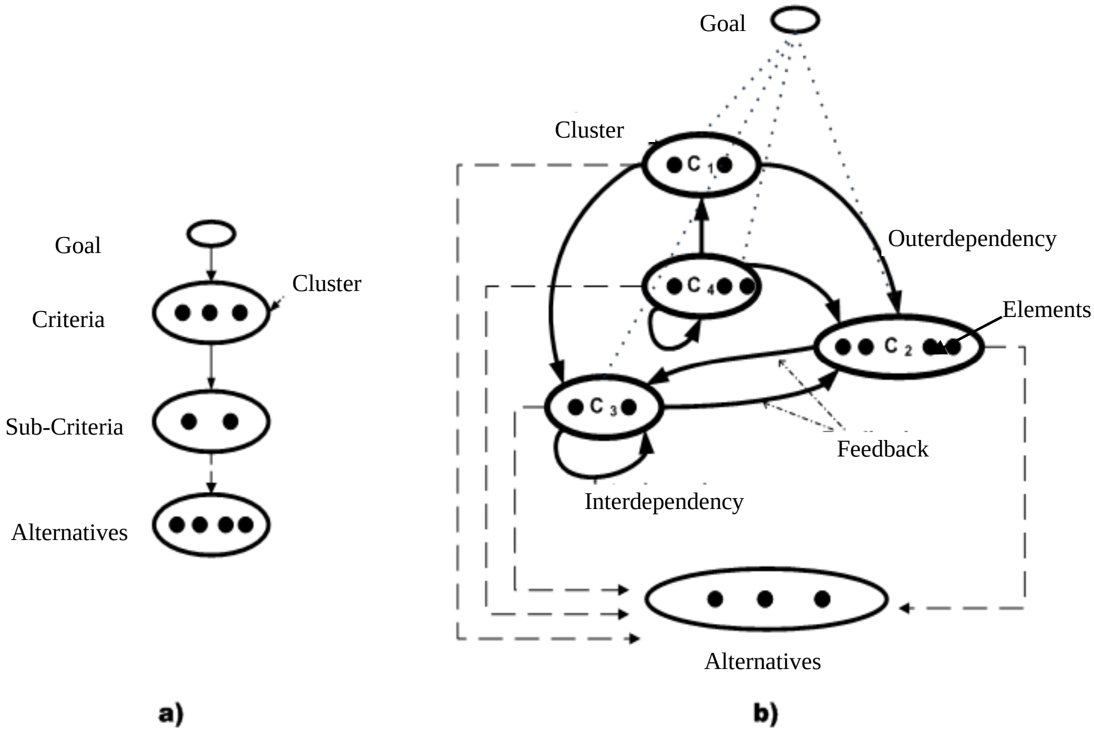


Figure 4.6: Structural difference between hierarchy (a) and network (b) processes
Source: Gorener (2012)

The network form of ANP comprises clusters of elements, with the elements in one cluster being connected to some or all elements in another cluster by outer dependencies or the same cluster by inner dependencies (Saaty, 2006). These dependencies (or relationships) are represented by arcs, where the directions of arcs signify the dependence (Chung, Lee, & Pearn, 2005; Saaty, 1996a). Interdependency between elements in two clusters, termed as an outer dependency, is represented by a two-way arrow while the same relationship among the elements in a single cluster, termed as an inner dependency, is represented by a looped arc (Chung et al., 2005). As shown in Figure 4.6, the levels of AHP correspond to clusters of ANP. There are three types of clusters in ANP: source cluster, intermediate clusters, and sink clusters. A source cluster is an origin of dependencies and never a destination of such, a sink cluster is a destination of dependencies, and never an origin of such, and an intermediate cluster can have both origin and destination of dependencies (Saaty, 1999, 2006).

4.4.2.2 Which is the most suited MCA Technique for the BVM? AHP or ANP?

The generalization of any form of a model or a methodology improves its applicability to a real-world problem. Undoubtedly this argument provides ANP an edge over AHP irrespective of the nature of the problem intended to solve using it. However, AHP being simpler in its application, T.L. Saaty has recommended to use it to solve the problems of independence among alternatives or criteria whereas ANP to solve the problem of dependence among alternatives or criteria (Gencer & Gumpinar, 2007; Chung et al., 2005; Wey & Wu, 2007).

In relation to the task to be performed in the BVM, ANP becomes advantageous over AHP due to the followings:

(i) Since the BVM is designed to solve transport project evaluation problems, it associates inter-dependencies among its own elements included. For the comprehensiveness of the analysis, it is required to count all those inter-dependencies as much as possible. Sarkis and Sundarraj (2006) emphasized that ANP is a better tool to model such inter-dependencies compared to AHP. This is because of the structural flexibility in ANP to model relationships among factors in contrast to AHP in which such modeling has been restricted by its strict hierarchical structure (Sarkis & Sundarraj, 2006).

(ii) Moreover, the BVM has designed to group monetizable and non-monetizable impacts (or criteria) separately as those must be treated in different ways in the valuation process. Such grouping would provide clarity in the final outcome in addition to ensuring accountability and transparency in the valuation process. The structure of ANP facilitates such grouping of impacts (or criteria) by means of its clusters-oriented formation, while AHP is only capable of taking all those impacts (criteria) as a whole. Those clusters in ANP, monetizable and non-monetizable in this case, can also be assigned with weights depending on their importance in achieving the desired goal.

(iii) ANP is also stronger compared to AHP in (i) mitigating method related issues such as subjectivity, arbitrariness, and double counting, (ii) minimizing ethical concerns raised due to the involvement of personal judgments, and (iii) minimizing common issues related to transparency, robustness, simplicity, and accountability. These are some demanding features in the new evaluation process (refer Section 3.2)

In addition to the above, Table 4.1, which is based on the findings of the literature, also shows that ANP is stronger than AHP in many features relevant to transport project evaluation.

Table 4.1: Performance of AHP and ANP in transport project evaluation

Criteria		**AHP**	**ANP**
Pragmatism of concept		***	*****
Unambiguity of theory		***	*****
Application procedure	Ease	****	***
	Clarity	****	****
Methodological compatibility in transport project evaluation		***	*****
Robustness of results		**	*****

Note: *****= very good; *** = good; * = not bad; AHP = Analytic Hierarchy Process, Analytic Network Process.

Source: Author

Based on the factual assessment presented above, ANP is selected over AHP to use in the BVM despite the fact that ANP is less prominent in literature in general, while AHP has been popular to date (Gorener, 2012). This lower prominence of ANP is mainly due to its late introduction, making it still a newer method among researchers and practitioners.

4.4.2.3 Application Procedure of ANP

The application procedure of ANP is described below in four sequential steps merging the demonstrations made by Gorener (2012), Lee (2010), Meade and Sarkis (1999), Piantanakulchai (2005), Saaty (2006), Sarkis and Sundarraj (2006), and Yuksel and Dagdeviren (2007).

Step 1- Model construction and problem structuring: The decision problem should be stated clearly and decomposed into a rational system, like a network. Decision-makers can form this network structure through brainstorming sessions or any other appropriate methods.

Step 2. Pairwise comparison matrices and priority vectors: ANP primarily involves two levels of pairwise comparisons. At the first level, similar to the AHP, pairs of decision elements in each cluster are compared in terms of their importance towards respective control criteria. At the second level, the clusters themselves are also compared pairwise with respect to their contribution towards achieving the set goal for the decision problem. In addition, interdependencies among elements within individual clusters must also be examined pairwise if such interdependencies exist. Like in AHP, these pairwise comparisons are conducted with Saaty’s 1-9 scale presented in Table 4.2 and are used to determine the relative importance of elements/clusters. Such derived relative importance are arranged in corresponding judgment matrices and later used those judgment matrices to form corresponding column matrices (eigenvectors) comprising local priority values (vectors) representing the influence of each element/cluster on other elements/clusters. These column matrices of local priority values (LPVs), named as priority matrices, are validated through standard consistency tests stipulated by T.L Saaty for both AHP and ANP.

Table 4.2: Pairwise comparison scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally important to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one criterion over another
5	Essential or strong importance	Experience and judgment strongly favor one criterion over another
7	Very strong importance	The criterion is strongly favored, and its dominance is demonstrated in practice
9	Extreme importance	Importance of one criterion over another affirmed on the highest possible order
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed; if needed even finer refinements such as 1.1, 1.2 … can be used)
Reciprocal	If criterion *i* has one of the above numbers assigned to it when compared to criterion *j*, then *j* has the reciprocal value when compared to *i*.	

Source: Saaty (1987)

Step 3. Supermatrix formation: The supermatrix is formed to obtain global priority values (GPVs)[6] for the alternatives, and is prepared by arranging LPVs in the appropriate columns. The supermatrix is a partitioned matrix in which each matrix segment represents a relationship between two clusters in a decision problem. Initially, the supermatrix is formed by arranging priority matrices obtained from the first level of pairwise comparison, and it is called the unweighted (or initial) supermatrix. A standard form for a supermatrix is presented in Matrix 4.1. Saaty (1996b) stated that the concept of the supermatrix is more or less the same as the Markov chain.

In Matrix 4.1, C_N denotes the N^{th} cluster, e_{Nn} denotes the n^{th} element in the N^{th} cluster, and W_{ij} block matrix is the collection of local priority vectors (w) of the influence of the elements in the i^{th} cluster with respect to the j^{th} cluster as derived in Step 2. If the i^{th} cluster has no influence on the j^{th} cluster, then $Wij = 0$.

[6] final scores showing competency of alternatives in achieving pre-set goal

Matrix 4.1: Standard form of unweighted supermatrix

<table>
<tr><td></td><td></td><td colspan="4">C_1</td><td colspan="4">C_2</td><td rowspan="2">…</td><td colspan="4">C_N</td></tr>
<tr><td></td><td></td><td>e_{11}</td><td>e_{12}</td><td>…</td><td>e_{1n_1}</td><td>e_{21}</td><td>e_{22}</td><td>…</td><td>e_{2n_2}</td><td>e_{N1}</td><td>e_{N2}</td><td>…</td><td>e_{Nn_N}</td></tr>
<tr><td rowspan="4">C_1</td><td>e_{11}</td><td colspan="4" rowspan="4">W_{11}</td><td colspan="4" rowspan="4">W_{12}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{1N}</td></tr>
<tr><td>e_{12}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{1n_1}</td></tr>
<tr><td rowspan="4">C_2</td><td>e_{21}</td><td colspan="4" rowspan="4">W_{21}</td><td colspan="4" rowspan="4">W_{22}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{2N}</td></tr>
<tr><td>e_{22}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{2n_2}</td></tr>
<tr><td></td><td></td><td colspan="4"></td><td colspan="4"></td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="4">C_N</td><td>e_{N1}</td><td colspan="4" rowspan="4">W_{N1}</td><td colspan="4" rowspan="4">W_{N2}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{NN}</td></tr>
<tr><td>e_{N2}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{Nn_N}</td></tr>
</table>

Source: Piantanakulchai (2005)

The priority matrix obtained from the second level pairwise comparison, which assesses the relative importance of clusters with respect to the goal, is applied as the cluster weights in the unweighted supermatrix. Such an application of weights sums up each column of the supermatrix to unity. This matrix is called the weighted supermatrix, and it is a stochastic matrix. But there are cases that column sums of weighted supermatrix do not add up to unity when it contains a column of which every element is zero (Piantanakulchai, 2005; Saaty, 2006). Such a zero-value column meant that there is no relationship between the respective column and row elements.

Saaty (2006) stated that raising a weighted supermatrix to exponential powers gives the long-term relative influences (importance) of the elements on each other. In accordance with the theorems of matrices, when keep raising supermatrix to exponential powers, it will converge to a steady-state eigenvector if the supermatrix is stochastic. This steady-state of the supermatrix is called the limit supermatrix. The limit supermatrix is in the same form of the weighted supermatrix, but all its columns bear the same values (Yuksel & Dagdeviren, 2007). The GPVs for all elements in the matrix can be obtained by normalizing each cluster of this limit supermatrix.

If the weighted supermatrix is not stochastic but reducible, its limitmatrix can cycle, and as such, there can be two or more N limiting supermatrices (Piantanakulchai, 2005; Saaty, 2006). Saaty (2006) suggested in such instances, a Cesaro average of those limiting matrices is used to estimate the GPVs.

In brief, if the weighted supermatrix (W) is stochastic, the limit supermatrix is obtained by Equation 10.

$$\lim_{k\to\infty} W^k \qquad (10)$$

Where, k is an arbitrary number.

If the supermatrix is not stochastic and has a cyclic effect, the Cesaro sum is calculated as given in Equation 11 to establish the GPVs (Piantanakulchai, 2005; Saaty & Vargas, 2006).

$$\lim_{k\to\infty}(\frac{1}{N})\sum_{k=1}^{N} W^k \qquad (11)$$

In addition, the limit supermatrix also can be calculated by using the basic matrix operation given in Equation 12.

$$\mathrm{W.L} = \mathrm{L} \qquad (12)$$

Where W is the weighted supermatrix, and L is the limit supermatrix.

Step 4: Prioritizing the alternatives: GPVs of the alternatives that can be found in the column of alternatives in the normalized limit supermatrix are considered as the scores to prioritize the alternatives. The alternative with the highest GPV should be given the highest priority, as it is the best performing alternative determined by matrix operations incorporated in ANP (Saaty, 2006). In other words, the priority order of alternatives should be prepared in the descending order of their respective GPVs derived.

The application procedure of AHP is not described herein since it was ignored to use in the BVM at the beginning of this section. It is well demonstrated in Bianchini (2018), Gorener (2012), Khaki and Shafiyi (2011), Lee (2010), Percin (2009), Saaty (2008b), Sadasivuni, O'Hara, and Nobrega (2009), and Sharma et al. (2008).

4.4.3 Review of TOPSIS: Theoretical Formation & Application Procedure

This sub-section demonstrates the theoretical formation and application procedure of TOPSIS, selected as the final valuation tool in the FVM for synthesizing cost criteria values of the CVM and benefit criteria values of the BVM (refer Step 5 of Section 4.3).

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was originally developed by Ching-Lai Hwang and Yoon in 1981 (Hwangand & Yoon, 1981) to solve multi-attribute decision problems, and it was further developed by Yoon in 1987 (Yoon, 1987) and Hwang, Lai and Liu in 1993 (Hwang, Lai, & Liu, 1993). Hwang et al. (1993) describe TOPSIS as suited for decision-making problems having multiple objectives or criteria that cannot be optimized simultaneously due to the inherent incommensurability and conflict between those objectives or criteria. Thus, TOPSIS is a method of making a trade-off between such objectives or criteria to get the "best compromised" solution. Section 4.3 (Step 5) cites the same strength in selecting TOPSIS as the valuation tool in the FVM.

TOPSIS is rested on the concept that the best alternative should be the closest to the positive ideal solution (PIS) and the farthest to the negative ideal solution (NIS) (Hwang et al., 1993; Shelton & Medina, 2010; Yoon, 1987). When there are only two attributes of costs and benefits involved, the PIS is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the NIS maximizes the cost criteria and minimizes the benefit criteria (Shelton & Medina, 2010). The measure adopted to count "the closeness to the PIS" and "the fartheness to the NIS" simultaneously is called relative closeness (Shelton & Medina, 2010). Figure 4.7, which graphically illustrates the positioning of alternatives' criteria values for costs and benefits related to ideal solutions in two-dimensional Euclidean space, demonstrates the calculation of relative closeness. The relative closeness for a given alternative is the ratio of its Euclidean separation from NIS to the total of Euclidean separation from PIS and NIS. The order of preference for the alternatives is prepared in descending order of relative closeness (Hwang et al., 1993; Shelton & Medina, 2010; Yoon, 1987).

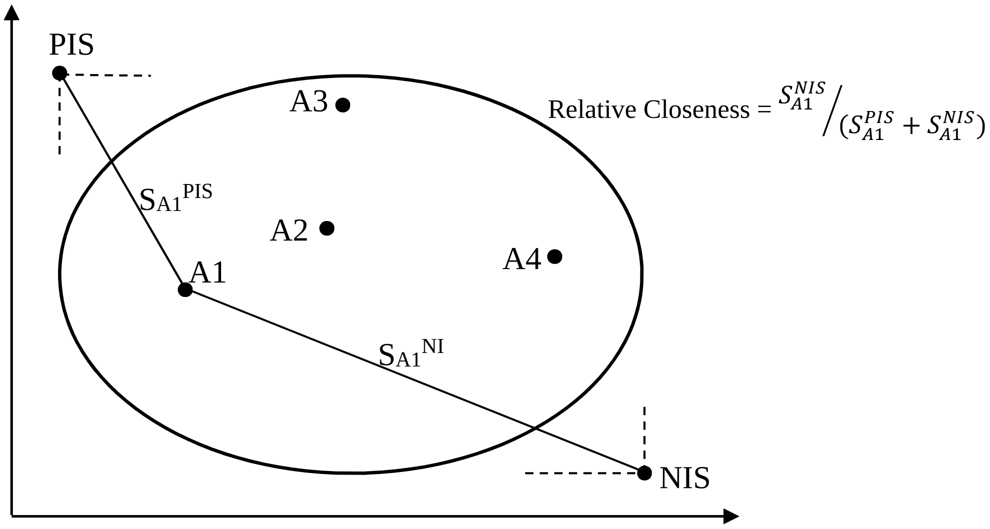


Figure 4.7: PIS, NIS and relative closeness in two-dimensional euclidean space

Source: Author

The application procedure of TOPSIS has been demonstrated by Bianchini (2018), Chang et al. (2015), Hwang et al. (1993), Karim and Karmaker (2016), Percin (2009), Shelton and Medina (2010), and Wu et al. (2010) in sequential steps for a decision problem having multiple numbers of criteria (m) and multiple numbers of alternatives (n). Since the FVM comprises only two criteria of costs and benefits to synthesize, the application procedure herein is simply demonstrated for a decision problem with two criteria and *n* number of alternatives. The calculated **cost and benefit criteria values (*q*)** in CVS and BVS, respectively, for each alternative, are arranged in a matrix named as 'appraisal matrix' and shown in Equation 13.

$$\begin{array}{c|c}
 & \begin{array}{cc} C_1 & C_2 \end{array} \\
\begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} q_{1,1} & q_{1,2} \\ q_{2,1} & q_{2,2} \\ \vdots & \vdots \\ q_{n,1} & q_{n,2} \end{bmatrix}
\end{array} \qquad (13)$$

Where, A_1, $A_2 \ldots\ldots A_n$ are the alternatives, C_1 and C_2 are the criteria, i.e., costs and benefits in this case and $q_{i,j}$ is the criteria value of alternative A_i (i = 1,2, …..n) with respect to criteria C_j(j = 1,2).

Step 1: Establish the normalized appraisal matrix.

The appraisal matrix given in Equation 13 is normalized to establish the normalized appraisal matrix. The normalized value $r_{i,j}$ corresponding to $q_{i,j}$ is calculated in Equation 14.

$$r_{i,j} = \frac{q_{i,j}}{\sqrt{\sum_{i=1}^{n} q_{i,j}^2}} \qquad (14)$$

where i = 1, 2 ….. n indicates the alternatives, j = 1,2 denotes the criteria, and $q_{i,j}$ means the criteria value of i^{th} alternative with respect to the j^{th} criterion.

Step 2: Establish the weighted normalized matrix.

If the weights for two criteria of C_1 and C_2 are w_1 and w_2 respectively, weighted normalized appraisal matrix, v, is established by multiplying normalized appraisal matrix with row matrix of weights as expressed in Equation 15:

$$v = \begin{bmatrix} r_{1,1} & r_{1,2} \\ r_{2,1} & r_{2,2} \\ \vdots & \vdots \\ r_{n,1} & r_{n,2} \end{bmatrix} [w_1 \quad w_2] = \begin{bmatrix} w_1 r_{1,1} & w_2 r_{1,2} \\ w_1 r_{2,1} & w_2 r_{2,2} \\ \vdots & \vdots \\ w_1 r_{n,1} & w_2 r_{n,2} \end{bmatrix} = \begin{bmatrix} v_{1,1} & v_{1,2} \\ v_{2,1} & v_{2,2} \\ \vdots & \vdots \\ v_{n,1} & v_{n,2} \end{bmatrix} \qquad (15)$$

Since the criteria values for costs and benefits are expressed in monetary terms or any other means, there is no underestimation or overestimation of their values compared to each other. Hence there is no requirement of weighting one or both criteria to equalize the reference. But TOPSIS weight assignment means the ‘importance’ of one criterion compared to the other. It is evident that both costs and benefits are equally important in project evaluation, as the case adopted in the conventional cost-benefit analysis. The cost-benefit analysis doesn’t weight costs and/or benefit streams and treat both of them are equally important.

When criteria are equally treated as important, both w_1 and w_2 holds the value of 0.5 or 50%. Thus, v can be expressed as in Equation 16.

$$v = \begin{bmatrix} v_{1,1} & v_{1,2} \\ v_{2,1} & v_{2,2} \\ \vdots & \vdots \\ v_{n,1} & v_{n,2} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} r_{1,1} & r_{1,2} \\ r_{2,1} & r_{2,2} \\ \vdots & \vdots \\ r_{n,1} & r_{n,2} \end{bmatrix} \qquad (16)$$

Step 3: Determine the positive ideal solution (A^*) and negative ideal solution (A^-)

PIS (A^*) and NIS (A^-) are defined in terms of the weighted normalized values. According to the weighted normalized appraisal matrix, the PIS consists of the maximum value of the benefit criterion and the minimum value of the cost criterion. Thus PIS is represented by the below given Equation 17.

$$A^* = \{v_1^*, v_2^*\} = \{(max_i v_{i,j} | j \epsilon C_b), (min_i v_{i,j} | j \epsilon C_c)\}\ ;\ i = 1,2\ldots\ldots n;\ j = 1,2 \qquad (17)$$

On the other hand, the negative ideal solution consists of the minimum value of the benefit criterion and the maximum value of the cost criterion. Thus, NIS is represented by the below given Equation 18.

$$A^- = \{v_1^-, v_2^-\} = \{(min_i v_{i,j} | j \epsilon C_b), (max_i v_{i,j} | j \epsilon C_c)\}\ ;\ i = 1,2\ldots\ldots n;\ j = 1,2 \qquad (18)$$

where C_b is associated with benefit criteria, and C_c is associated with cost criteria.

Step 4: Calculate the separation between the positive ideal solution (S_i^*) and negative ideal solution (S_i^-) for each alternative.

Values in the weighted normalized appraisal matrix are represented in two-dimensional Euclidean space (costs and benefits) together with PIS and NIS to calculate separation between the positive ideal solution and negative ideal solution for each alternative. The distance of each alternative from the PIS and the NIS is calculated with the Euclidean distance method. This method suggests the values of S_i^* and S_i^-, representing the distance of the alternative *i* from the PIS and NIS, respectively, in the Equations of 19 and 20.

$$S_i^* = \sqrt{\sum_{j=1}^{2}\left(v_{i,j} - v_i^*\right)^2} \qquad i = 1,2, \ldots \ldots . . n \tag{19}$$

$$S_i^- = \sqrt{\sum_{j=1}^{2}\left(v_{i,j} - v_i^-\right)^2} \qquad i = 1,2, \ldots \ldots . . n \tag{20}$$

Step 5: Calculate the relative closeness to the ideal solution.

The relative closeness of the alternative A_i with respect to A^* is defined as in Equation 21.

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-} \tag{21}$$

RC value varies in-between 0 and 1. When alternative A_i is closer to A^* and farther from A^-, RC_i^* approaches 1. The alternatives with larger RC values are preferred as they are closer to A^* and farther from A^-.

Step 6: Prioritization of the alternatives

The alternatives are prioritized or ranked by giving preference to the alternatives with larger values of the relative closeness (RC) to the ideal solution or, in other words, in descending order of corresponding relative closeness values. The relative closeness is being the final value used to measure the performance of an alternative, it is referred to as the ‘score’ of an alternative in the remaining work of this thesis.

4.5 Summary

This chapter first established TCEP for transport project evaluation and then analyzed it for understanding the fine-tunings required for improving its practicality in applying to evaluate transport projects. Based on this analysis, several recommendations were made for transforming the TCEP to the FCEP. Key recommendations were for (i) segregating impacts, (ii) valuing impacts, and (iii) using ANP and TOPSIS as an integral part of the evaluation process. Eventually, the chapter detailed (i) monetization of impacts and (ii) application procedure of ANP and TOPSIS to use for functionalizing the TCEP in the next chapter.

CHAPTER 5

FUNCTIONALIZATION OF THEORETICAL COMPREHENSIVE EVALUATION PROCESS

5.1 Introduction

This chapter describes the penultimate task (Task 4) of the methodology for formulating the new evaluation process, functionalizing the TCEP, by incorporating the recommendations and knowledge gathered in the previous chapter. The functionalization of the TCEP targets to improve its practicality in application to evaluate transport projects. The chapter first demonstrates the functionalization of the TCEP in module-wise, in terms of their (i) inputs and (ii) valuation tools, and then their aggregation to reproduce overall TCEP in the functionalized form, i.e., the FCEP. Eventually, the chapter analyses the FCEP to identify necessary improvements to upgrade it to the CEP.

5.2 Impact Categorization Module

The first module, the impact categorization module (ICM), was designed to identify project impacts and segregate them into the costs and benefits. The same module included in the TCEP was used in the functionalized process (i) recommending current practices for project impact identification and (ii) adopting set definitions for costs and benefits (refer Section 4.3).

In the rest of the thesis, different categories of costs and benefits are referred to as ‘criteria’ in line with the terminology of the multi-criteria analysis.

5.3 Cost Valuation Module

The cost valuation module (CVM), shown in Figure 5.1, was theoretically designed to obtain the total cost values (total cost criteria values) for each evaluating project after synthesizing its inputs of monetizable and non-monetizable cost criteria values through an in-built valuation tool. Even though the theoretical CVM included both monetizable and non-monetizable costs as inputs to be holistic, Section 4.3 argued that all cost elements could be confined only for the monetizables in accordance with the adopted definitions for the 'costs' in this research. Thus, it was not required to maintain an input called 'group of non-monetizable costs' for the CVM anymore. Therefore, this particular input item to the theoretical CVM was ignored in the functionalized form, as shown in Figure 5.1.

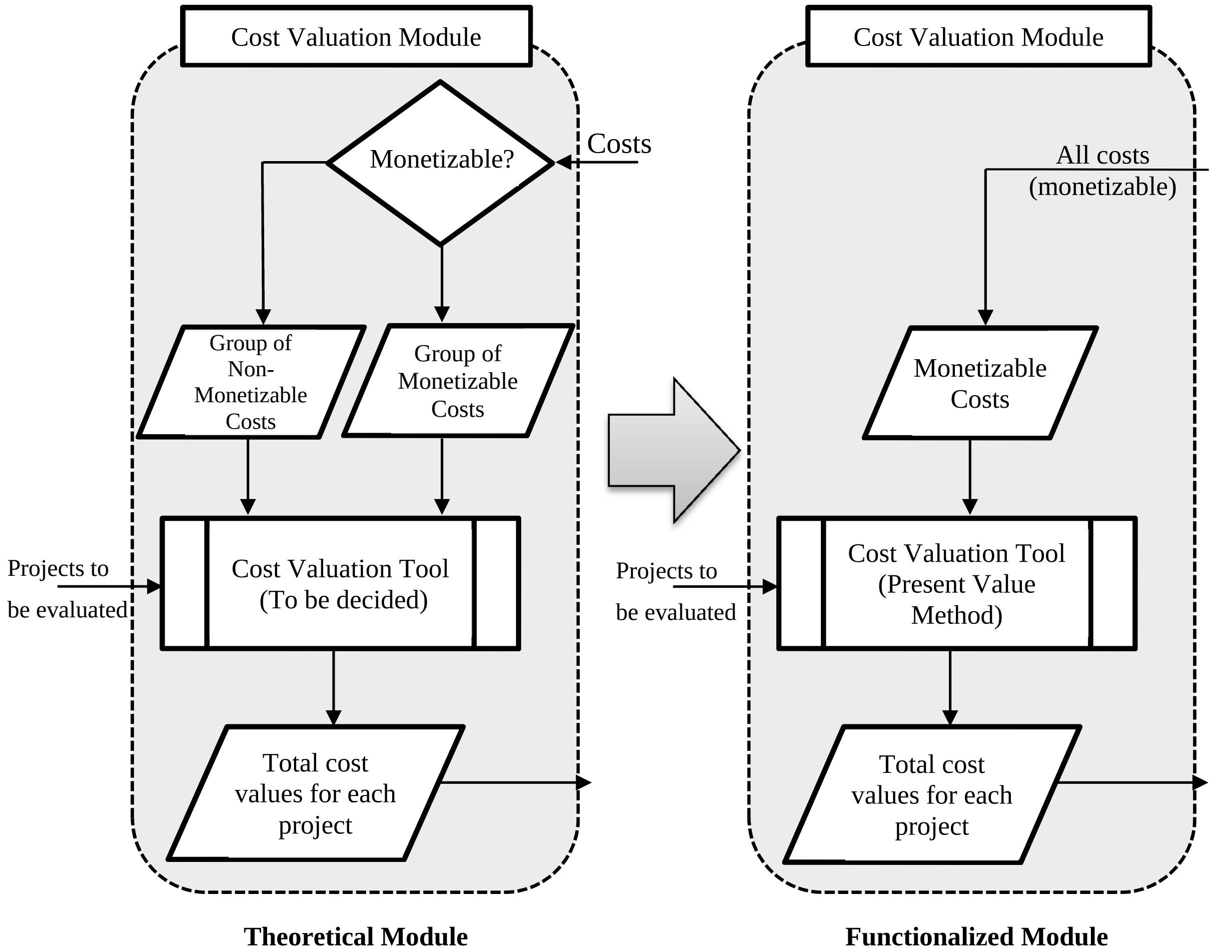


Figure 5.1: Functionalization of theoretical cost valuation module

Source: Author

Selecting a suitable cost valuation tool is the other task in functionalizing the theoretical CVM. In transport projects, usually different types of costs incur in different time frames in the project progression. For example, construction/rehabilitation cost occurs in the first two or three years, while periodic maintenance costs every ten years and operational and routine costs each year over the project life. Since there is no reliable prediction on change in money value over time, it was decided to use the present values of cost criteria in the functionalized form as in the case of conventional CBA. Such estimated present values of individual cost criteria values are aggregated by the evaluating projects to obtain their corresponding total cost values (total cost criteria values). The above estimated **total cost values** of each project become the outputs of the CVM and the inputs to the next module, the FVM.

5.4 Benefit Valuation Module

The benefit valuation module (BVM) was designed to obtain the total benefit values (total benefit criteria values) for each evaluating project by synthesizing the inputs of both monetizable and non-monetizable benefit criteria values through an in-built valuation tool. Unlike in the CVM, inputs to the BVM remain in both forms of monetizable and non-monetizable for transport projects in accordance with the definition adopted for the benefits in this research. For functionalization, the selected valuation tool for the BVM was ANP, as detailed in Sub-section 4.4.2.

The BVM mapped into a simple ANP model comprises three clusters of monetizable benefit criteria, non-monetizable benefit criteria, and evaluating projects. This ANP in-built BVM provides the immediate output of GPVs for each evaluating project synthesizing relevant monetizable and non-monetizable benefits and then provides the final output of total benefit values for each evaluating project. Figure 5.2 shows a typical representation of ANP in-built BVM, which has ***n*** number of monetizable benefit criteria (MC), ***m*** number of non-monetizable benefit criteria (NC), and ***k*** number of evaluating projects (EP).

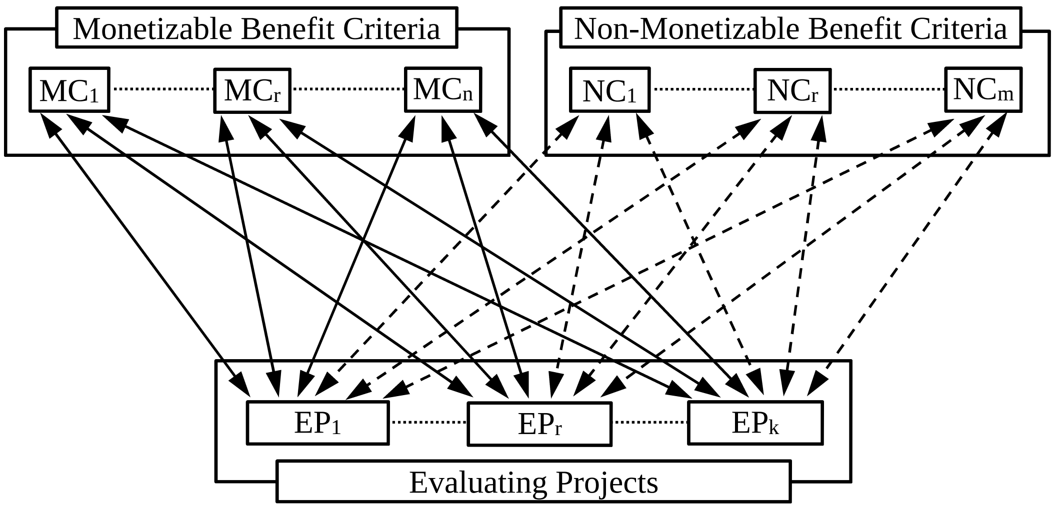


Figure 5.2: Typical representation of ANP in-built BVM

Source: Author

For ease of computations, the ANP model adopted in the BVM has not been included with inner dependencies among criteria in the same cluster and outer dependencies among criteria in different clusters. This can be done by defining criteria ensuring their mutual exclusiveness. For example, the criteria set of comfort, reliability, and safety is preferred over the set of service quality, reliability, and safety, despite both sets covers the same domain of impacts, due to the former set being mutually exclusive whereas the latter being mutually inclusive as safety and reliability partly being included in service quality. Usually, the impacts generated by transport projects are definable mutually exclusive. Thus, the above modelling is feasible in relation to the transport projects.

In addition, each criterion in the above modelling is needed to define to have a relationship or influence on each and every project under consideration. Such tidy connectivity between criteria and evaluating projects ensures fairness of the evaluation by making the same criteria reference for all projects. But there may be instances where certain criteria may have to be defined to apply only for certain evaluating projects only. For example, when two projects of public transport improvement and road improvement are considered, the criterion of service quality is a vital one with respect to the former but not to the latter. In such situations, those criteria are included in the evaluation, linking it only to the relevant projects. But it is reiterated to have a set of criteria linkable to all evaluating projects to ensure fairness of the evaluation.

In accordance with the 2nd step of the application procedure of ANP (refer Sub-section 4.4.2.3), LPVs for the typical transport project evaluation problem, demonstrated in Figure 5.2, are determined by adopting the pairwise comparison. These LPVs indicate each project's relative performance (or importance) in relation to each criterion and vice versa. They are established by adopting the pairwise comparison for (i) evaluating projects with respect to each monetizable criterion and vise versa and (ii) evaluating projects with respect to each non-monetizable criterion and vice versa. The former is carried out based on the estimated monetary values for the benefits while the latter is based on the judgement of the decision-makers. These decision-makers should be competent enough to judge the operational characteristics of evaluating projects and also be facilitated with the project-related technical documents to make their judgements more precisely. Moreover, they should also be made aware of fundamental features and execution procedure of a pairwise comparison using Saaty's scale (Table 4.2), prior to get them involved in the decision making. Eventually, the consistency of their judgements should also be tested adopting the standard consistency test stipulated by T.L Saaty (Saaty, 2008b)

Similar to cost criteria in the CVM, benefit criteria also have a future effect. If such future benefits are monetizable, those are expressed in present value, similar to the case with the costs, and used in the pairwise comparison accordingly. In the case of non-monetizable benefits, futuristic effect should be considered in the pairwise comparison based on a scientific assessment or experience of the decision-makers.

The LPVs derived as above are arranged in a supermatrix, as described in Step 3 of the ANP application procedure (refer Sub-section 4.4.2.3). Such established typical supermatrix for benefit valuation is given in Matrix 5.1.

Matrix 5.1: Standard form of supermatrix for benefit valuation of transport projects

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Evaluating Projects</td><td colspan="4">Monetizable Benefits</td><td colspan="4">Non-Monetizable Benefits</td></tr>
<tr><td>e_{P1}</td><td>e_{P2}</td><td>…</td><td>e_{Pk}</td><td>e_{M1}</td><td>e_{M2}</td><td>…</td><td>e_{Mn}</td><td>e_{N1}</td><td>e_{N1}</td><td>…</td><td>e_{N1}</td></tr>
<tr><td rowspan="4">Evaluating Projects</td><td>e_{P1}</td><td colspan="4" rowspan="4">W_{AA}</td><td colspan="4" rowspan="4">W_{AM}</td><td colspan="4" rowspan="4">W_{AN}</td></tr>
<tr><td>e_{P2}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{Pk}</td></tr>
<tr><td rowspan="4">Monetiable Benefits</td><td>e_{M1}</td><td colspan="4" rowspan="4">W_{MA}</td><td colspan="4" rowspan="4">W_{MM}</td><td colspan="4" rowspan="4">W_{MN}</td></tr>
<tr><td>e_{M2}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{Mn}</td></tr>
<tr><td rowspan="4">Non-Monetizable Benefits</td><td>e_{N1}</td><td colspan="4" rowspan="4">W_{NA}</td><td colspan="4" rowspan="4">W_{NM}</td><td colspan="4" rowspan="4">W_{NN}</td></tr>
<tr><td>e_{N2}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{Nm}</td></tr>
</table>

Source: Author

Where e_{Mn} denotes the n[th] element in the monetizable benefit cluster, and W_{MN} block matrix consists of LPVs (w) demonstrating the influence of the elements in the monetizable benefit cluster with respect to the non-monetizable benefit cluster. If a cluster has no influence on any other cluster, the respective block matrix should be zero. As such W_{AA}, W_{MM}, W_{NN}, W_{MN}, and W_{NM} should be zero block matrices. The full matrix obtained in this step is called the initial or unweighted supermatrix as per the terminology used in ANP.

As described in Step 3 of the application procedure for ANP, cluster weights are applied to this unweighted supermatrix to transform it into a weighted supermatrix. The cluster weights for the block matrices in the first column are shared as W_{AA}: W_{MA}: W_{NA} = $0:x:y$ where x and y add up to unity and are assigned based on an agreed judgment of decision-makers. This simply can express as the cluster weights of monetizable: non-monetizable = $x:y$. For the other two columns, cluster weights are shared as $W_{AM}:W_{MM}:W_{NM}=1:0:0$ and $W_{AN}:W_{MN}:W_{NN}=1:0:0$. The weighted supermatrix, which is in the form of a stochastic matrix, is used to obtain its limit matrix and thereby establish the GPVs for the evaluating projects as described in the afore-said Step 3 of ANP application procedure. These GPVs provide the shares of the benefit accrued by each project.

The above determined GPVs for each project are sensitive to the assigned weights ratio for the monetizable and non-monetizable benefit clusters (hereafter referred to as benefit cluster weight ratio). Thus, the assignment of suitable weights for monetizable and non-monetizable benefit clusters in the BVM is crucial to derive a dependable solution from the evaluation process. Hence it is necessary to have clarity on (i) the meaning of the cluster weights and (ii) approaches to be adopted in their assignment.

Meaning of the cluster weights: The cluster weights represent the relative importance of each cluster in achieving the set objective of the decision problem. For example, if decision-makers assume that given two clusters are equally important in achieving the set goal, weights of 50:50 are applied. The assignment of weights for monetizable and non-monetizable benefit clusters becomes easier if those two clusters can be fitted into a rationalized grouping. For example, monetizable benefits of user cost savings, accident cost savings, and emission cost savings; and non-monetizable benefits of improved service quality, comfort, and reliability can be treated as ‘primary direct benefits’ and ‘secondary direct benefits’ respectively. This particular grouping as ‘primary direct benefits’ and ‘secondary direct benefits’ instead of ‘monetizable benefits’ and ‘non-monetizable benefits’, is more convenient for the decision-makers to assign respective weights logically. Thus, as the first step in assigning cluster weights, it is important to investigate the elements in each cluster to see whether they can be treated as different rationalized groups instead of monetizable and non-monetizable benefits. The nature of the transport project impacts supports the afore-mentioned rationalized grouping.

Assignment of cluster weights: The assignment of the weights for monetizable and non-monetizable benefit clusters in the BVM is recommended to execute with the agreement of decision-makers. But there are cases, decision-makers do not agree on a specific ratio of cluster weights. In such a case of ‘no agreement’, all possible combinations, i.e., monetizable benefits: non-monetizable benefits ranges from 0:1 to 1:0, are considered in the determination of GPVs. The above two approaches result in two distinct scenarios for the output of BVM;

a) **Scenario 1:** When the decision-makers agree on a specific weight ratio for monetizable and non-monetizable benefit clusters, the BVM derives a specific GPVs for each project under evaluation, and

b) **Scenario 2:** When the decision-makers have no agreement on the above benefit cluster weight ratio, the BVM produces multiple sets of GPVs for each evaluating project, with respect to all weight ratio combinations considered for the monetizable and non-monetizable benefit clusters.

The GPVs, produced by ANP model in-built to the BVM, only provide the shares of the benefit accrued by each project equaling their total to unity. Instead of shares, benefits accrued by each project are translated to absolute values (in monetary units) by multiplying the GPVs with a single constant of which value is indeterministic. The value of this constant varies with the weights assigned for the monetizable and non-monetizable benefit clusters. However, it becomes a redundant value at the end of the overall evaluation process, nullifying its influence on the final results.

Figure 5.3 presents the functionalized form of the theoretical BVM for Scenario 2, incorporating (i) monetizable and non-monetizable benefits as inputs, and (ii) ANP as the evaluation tool. This produces multiple total benefit values (total benefit criteria values) for each project, as stated above. It should be noted that Scenario 1 is one specific occurrence of Scenario 2 resulted from limiting the benefit cluster weight ratio to a specific ratio. Under Scenario 1, only a unique total benefit value for each evaluating project is generated.

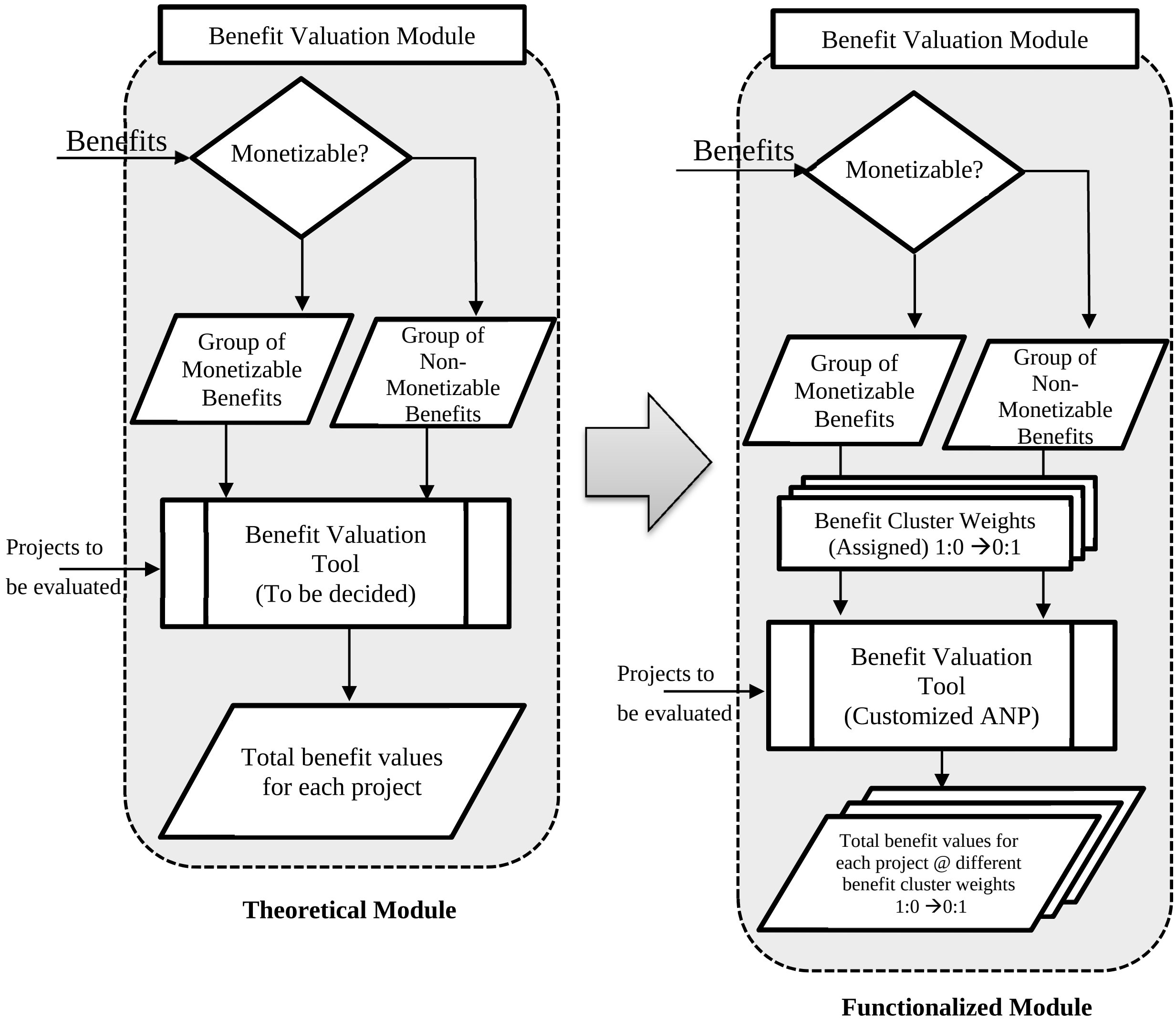


Figure 5.3: Functionalization of theoretical benefit valuation module

Source: Author

The above derived absolute values in monetary terms represent the **total benefit values (total benefit criteria values)** for the evaluating projects and are the outputs of BVM and the inputs to the FVM. It should be noted that there is only a single set of total benefit values (one each for a project) for Scenario 1 (in agreement for benefit cluster weight ratio), whereas multiple sets of total benefit values (several for a project) for Scenario 2 (no agreement for benefit cluster weight ratio).

5.5 Final Valuation Module

The final valuation module (FVM) was designed to obtain the scores for each evaluating project by synthesizing the respective outputs of the CVM (total cost values) and the BVM (total benefit values) through an in-built valuation tool. This valuation tool refers to the evaluation method in Figure 1.1. These scores derived become the final output of the evaluation process and are used to test the implementation feasibility of evaluated projects and their prioritization. The selected valuation tool to use in the functionalized form of the FVM was TOPSIS, as detailed in Sub-section 4.4.3. Being both outputs of the CVM and the BVM, total cost and total benefit values respectively, are in monetary terms, they are qualified to be inputs for the TOPSIS based FVM.

Depending on the nature of assigning weights for monetizable and non-monetizable benefit clusters in the BVM, the FVM derives its outputs differently for two scenarios mentioned in Section 5.4.

a) **Scenario 1:** When the decision-makers are in agreement for the weight ratio of monetizable and non-monetizable benefit clusters in the BVM, the FVM produces a single set of ‘scores’ for the evaluating projects (one each for an evaluating project)

b) **Scenario 2:** When the decision-makers have no agreement for the above weight ratio, the FVM initially produces multiple sets of ‘scores’ for the evaluating projects (several for an evaluating project) and later unified them into a single set.

Deriving scores for the above two scenarios are elaborated in detail below:

Scenario 1: Decision-makers are in agreement for the weights of monetizable and non-monetizable clusters in the BVM

When the decision-makers are in agreement on the weight ratio for monetizable benefits: non-monetizable benefit clusters in the BVM, it produces a unique total benefit value for each evaluating project. Those total benefit values are synthesized with corresponding total cost values from the CVM in the FVM and produce a single score for each evaluating project. This particular score is produced in terms of 'relative closeness to the positive ideal solution' in the TOPSIS platform and termed as 'Isolated Score' in the rest of the thesis considering its relation to a specific weight ratio of monetizable: non-monetizable benefit clusters. These Isolated Scores are used to test the implementation feasibility of each evaluated project and their prioritization when there is an agreement among the decision-makers on the weight ratio of monetizable: non-monetizable benefit clusters in the BVM. The implementation preference of the projects declines in the descending order of respective Isolated Scores. Further, it is evident that final results derived through this approach associate a certain degree of subjectivity since it involves personal judgment in cluster weight assignment in the BVM.

Scenario 2: Decision-makers are not in agreement for the weights of monetizable and non-monetizable clusters in the BVM

When there is no agreement among the decision-makers on the weight ratio of monetizable: non-monetizable benefit clusters in the BVM, the above-said ratio ranges between 1:0 →0:1, i.e., all possible combinations for the particular ratio. When all these combinations are considered, the BVM produces multiple **total benefit values** for each evaluated project, and consequently, the same become inputs to the FVM. These multiple inputs (total benefit values) from the BVM are synthesized with corresponding inputs from the CVM (total cost values) within the FVM to produce multiple scores for each evaluating project. Each of these scores becomes an 'Isolated Score' for its corresponding combination of the weight ratio of monetizable and non-monetizable benefit clusters in the BVM.

The above Isolated Scores, derived for each evaluated project, can be plotted in a graph against their corresponding combinations of the weight ratio of monetizable: non-monetizable benefit clusters in the BVM (1:0 →0:1 or x: 0 →1; where x is the share of non-monetizable benefits). Figure 5.4 shows an illustration of such Isolated Scores against the said cluster weight combinations for an evaluation problem which has evaluating projects of P_i ; $i = 1,2,\ldots n$ and generating corresponding graphs for the Isolated Scores with the functions of $f_i(x)$; $i = 1,2,\ldots n$; where x is the share of non-monetizable benefits in the BVM.

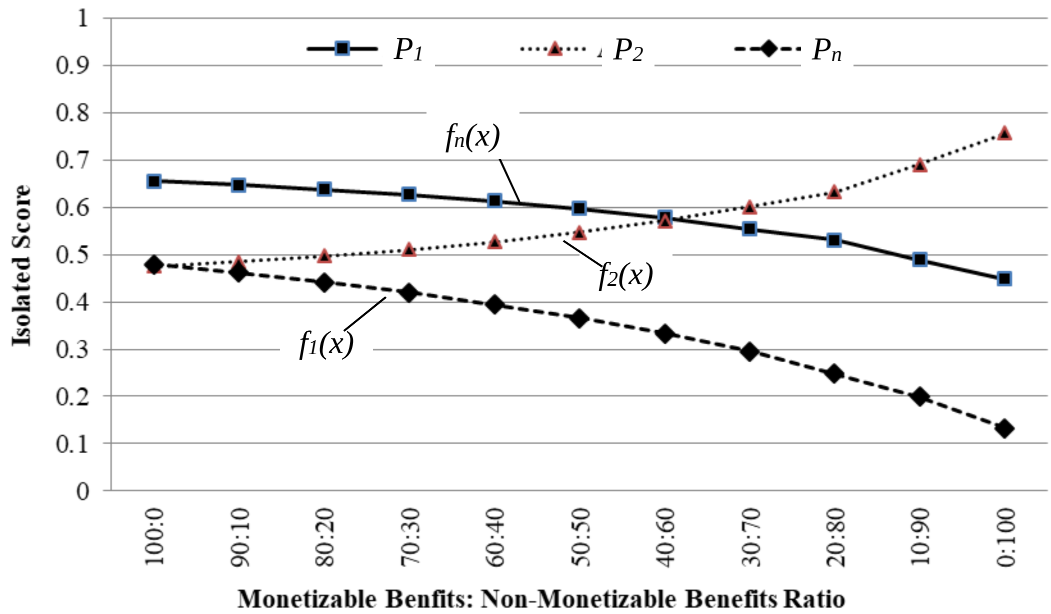


Figure 5.4: Variation of Isolated Scores against benefit cluster weights

Source: Author

The area below the graph of an evaluated project in the above chart aggregates its Isolated Scores at all possible weight ratio combinations of monetizable: non-monetizable benefit clusters (in BVM). Hence, it qualifies as a better proxy to demonstrate the performance of the corresponding evaluated project. As such, this area, termed as 'Universal Score' for a given evaluated project in the rest of the thesis, is used to test the implementation feasibility of each evaluated project and their prioritization when there is no agreement among the decision-makers on monetizable: non-monetizable benefit cluster weight ratios in the BVM. Like in Scenario 1, the implementation preference of projects declines in the descending order of respective Universal Scores. Unlike in Scenario 1, the final result derived in this approach is free of subjectivity due to the elimination of personal judgments in cluster weight assignment in the BVM.

The mathematical formula in Equation 22 calculates the area below the graph of P_i shown in Figure 5.4. As described above, this area is considered as the Universal Score, U_i, for P_i.

$$U_i = \int_{x=0}^{1} f_i(x) \;\; ; i = 1,2, \dots \dots \dots . n \qquad (22)$$

Where

x = Share of non-monetizable benefits; $0 \rightarrow 1$

U_i = Universal Score of the Project, P_i ; $i = 1,2,\dots n$

Figure 5.5 presents the transformation of theoretical FVM to its functionalized form, incorporating

(i) monetized costs and benefits as inputs,

(ii) TOPSIS as the evaluation tool, and

(iii) two different types of outputs (Isolated Scores and Universal Scores) resulted with two scenarios of ‘in agreement’ and ‘no agreement’ of the decision-makers in assigning weights for benefit clusters in the BVM.

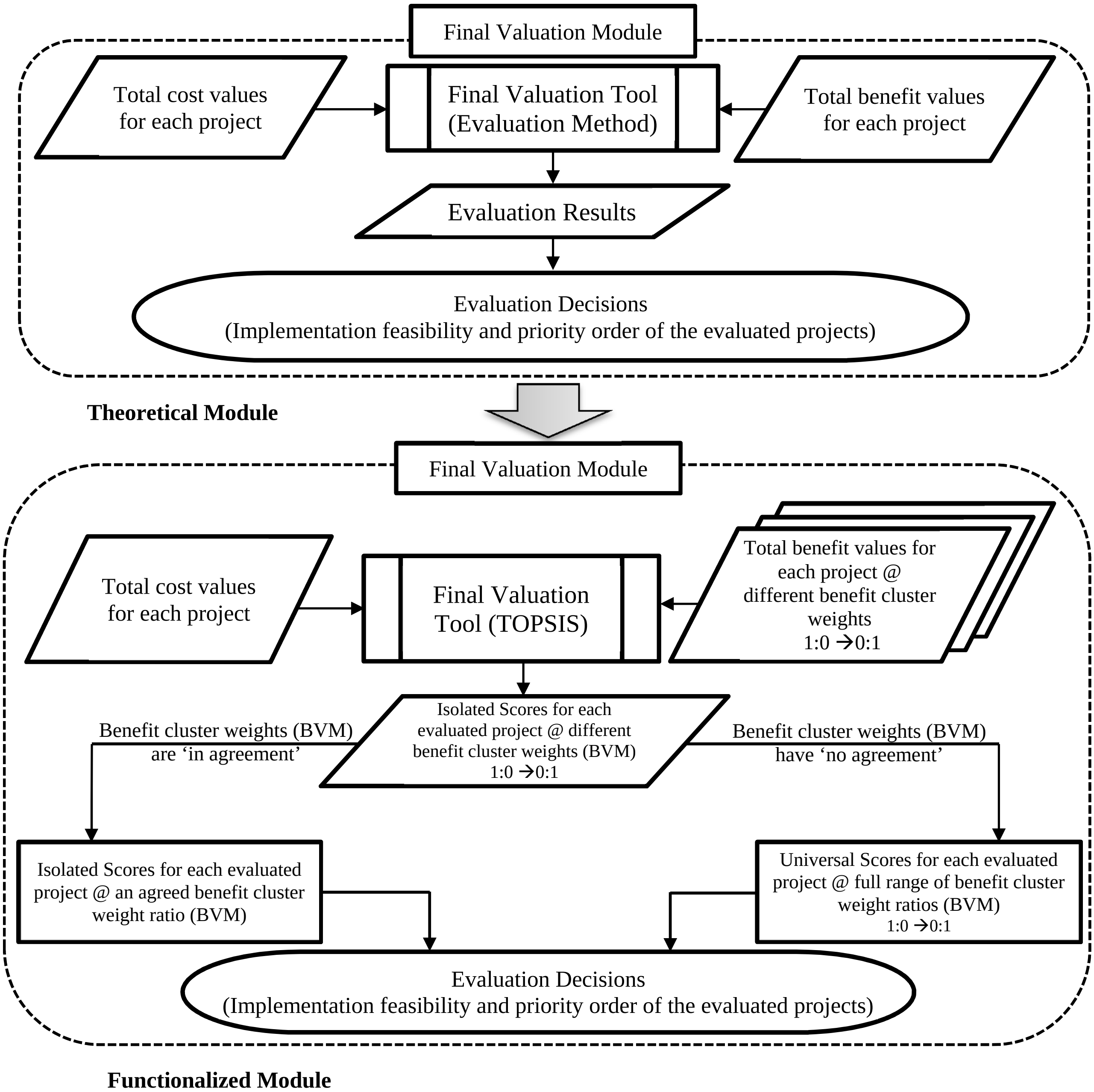


Figure 5.5: Functionalization of theoretical final valuation module
Source: Author

5.6 Functionalized Comprehensive Evaluation Process

Figure 5.6 presents the FCEP for transport projects re-assembling CVM, BVM, and FVM in the TCEP given in Figure 4.2 with corresponding functionalized modules produced in Sections 5.2 to 5.5.

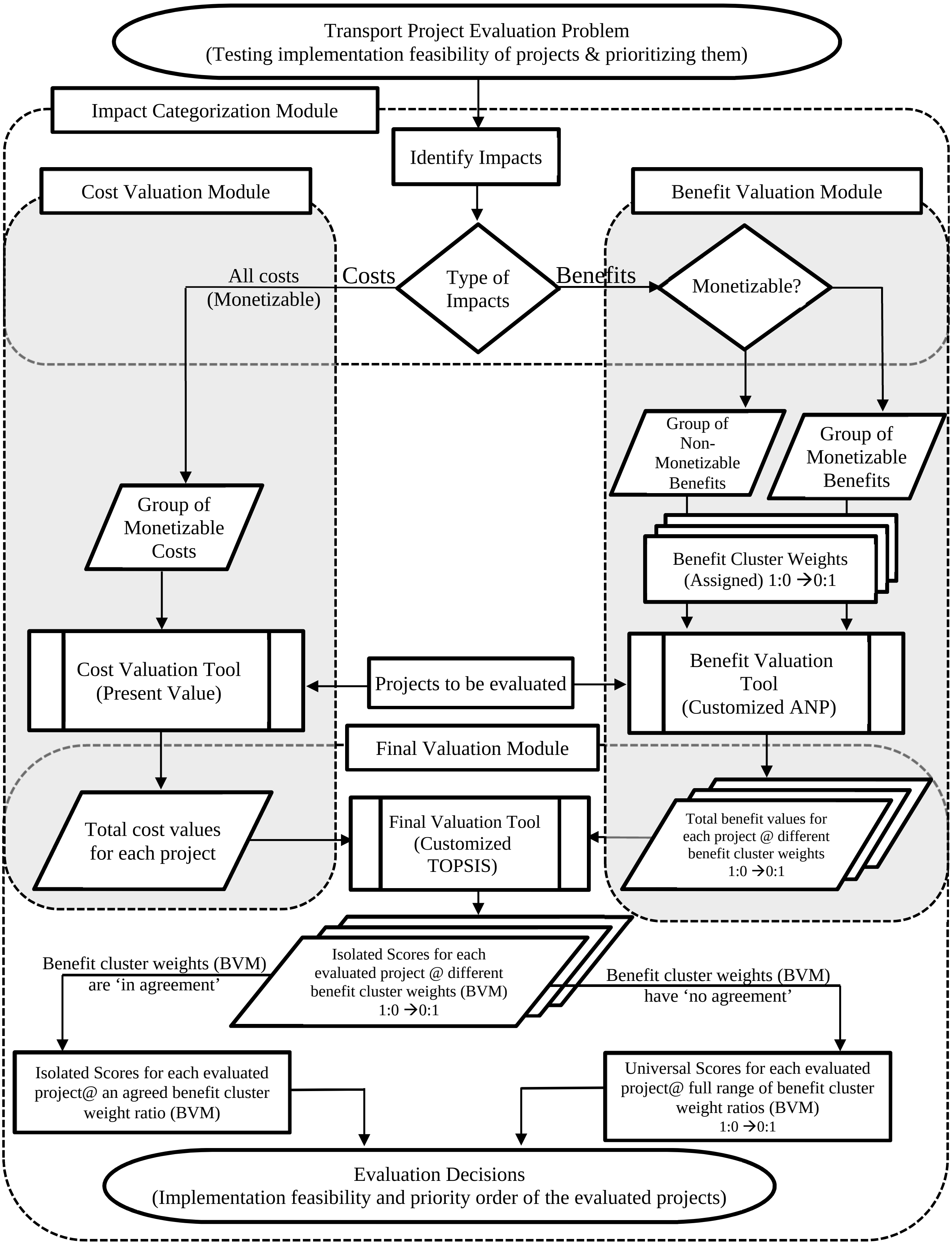


Figure 5.6: Functionalized comprehensive evaluation process

Source: Author

As discussed thus far, the new evaluation process performs the following in sequence;

(i) Impact categorization,
(ii) Cost valuation for determining **total cost values** for each project,
(iii) Benefit valuation for determining **total benefit values** for each project, and
(iv) Final valuation to produce **scores** for each project by synthesizing the corresponding total cost and benefit values above

5.7 Assessment of Input and Result-Completeness of the FCEP

The functionalization of the TCEP was carried in a way that it ascertains the input-completeness while improving TCEP's practicality in the application to evaluate transport projects. However, during this functionalization ascertaining the result-completeness was not targeted explicitly. Thus, assessing FCEP's ability to ascertain the result-completeness is a prerequisite to declaring it as the CEP or incorporating necessary improvements for transforming it to the CEP.

The FCEP ultimately produces a score for each project, in the form of an Isolated Score or Universal Score depending on the scenario used to represent the decision-makers' agreement and disagreement on the weight ratio assigned to the monetizable and non-monetizable benefit clusters in the BVM. Such derived scores demonstrate the performances of corresponding evaluated projects and are intended to use for testing their implementation feasibility and prioritization. However, though the scores derived themselves can be used to prioritize the evaluated projects, they are not usable for testing the implementation feasibility of those projects due to the absence of a threshold score. This indicates that this functionalized form still needs improvements to ensure the result-completeness explicitly, despite the fact that it has now been enhanced for practically applying to evaluate transport projects ensuring the input-completeness. The required improvement is a threshold score for testing the implementation feasibility of the evaluated projects. The next chapter elaborates on a procedure for determining the said threshold score and thereby ensures the result-completeness for this process. With that threshold score, the FCEP becomes eligible to be the CEP as it is then practically applicable for evaluating transport projects, ensuring both input and result-completeness.

5.8 Summary

This chapter established the functionalized form of the TCEP, the FCEP, for transport project evaluation. This functionalized form is practically applicable for evaluating transport projects ensuring the input-completeness counting both monetizable and non-monetizable impacts. However, the results generated in this process, in the form of ‘scores’, are still not usable for determining the implementation feasibility of the evaluated projects due to the absence of a threshold score, although they are usable for prioritizing projects. Thus, the FCEP must be incorporated with a said threshold score to ensure its result-completeness. With this incorporation, the FCEP can be upgraded to the CEP. The next chapter elaborates on the determination of this threshold score.

CHAPTER 6

TESTING IMPLEMENTATION FEASIBILITY OF PROJECTS

6.1 Introduction

The FCEP presented in the previous chapter ultimately derives a score for each evaluated project indicating their performances in achieving the set goal for the investment. Even though such derived scores are directly usable for the prioritization of the evaluated projects, they are not usable for testing the implementation feasibility of those projects due to the absence of a threshold score. A threshold score is regarded as a 'minimum score' for the evaluated projects to achieve to declare them as feasible. This chapter introduces a methodological adjustment to the FCEP to derive the above-mentioned threshold score. This introduction completes the last task (Task 5) of the methodology for formulating the new evaluation process and in turn, establishes the CEP. Eventually, the chapter discusses the application of the CEP in different contexts.

6.2 Threshold Score for Testing Feasibility

The FCEP requires two distinct threshold scores for the Isolated Scores and the Universal Scores which are related to the two different evaluation scenarios stipulated in the previous chapter and restated below.

> **Scenario 1- Isolated Scores (IS):** these scores are derived when benefit cluster weights in the BVM are assigned with a specific ratio.
>
> **Scenario 2- Universal Scores (US):** these scores are derived when benefit cluster weights in the BVM are assigned with all possible combinations of ratios or a specific range of ratios.

At the outset, this section discusses the establishment of a threshold value for the Isolated Score (Scenario 1) and later adopts it for the Universal Score (Scenario 2).

6.2.1 Feasibility Threshold Score for Isolated Scores

In the FCEP, Isolated Scores for the evaluated projects were established by synthesizing corresponding total cost values from the CVM, and corresponding total benefit values from the BVM. This sub-section defines a threshold value for such derived Isolated Scores by mapping the features of the threshold value of the conventional CBA into the new process. For this purpose, a dummy project of which Isolated Score would be equal to the threshold value is introduced. This particular threshold value (or the Isolated Score of the dummy project) is assumed to have the feature of equal costs and benefits, as in the case of CBA, to produce unity in the cost-benefit ratio. This is achievable if the dummy project has only monetizable costs and benefits and no non-monetizable costs and benefits. If there are non-monetizable costs and benefits, ensuring the unity or any specific value in the cost-benefit ratio is not possible. Since it was stated that all costs are monetizable in the functionalization of the TCEP (refer Section 5.3), it is a matter of restricting the benefits of the dummy project only to the monetizable benefits.

The dummy project, which has only the monetizable costs and benefits in equal amounts, sets with all other projects in the FCEP and derives its Isolated Score. This particular score becomes the threshold value in the new evaluation process corresponding to the threshold value of B/C = 1 in CBA. At this point, the following four questions are needed to answer for having better clarity of the way forward.

- Q1. How does the dummy project embody to the evaluation process?
- Q2. Is there an influence on the Isolated Scores of the original projects when adding the dummy project?
- Q3. How is the correlation between B/C ratio and the Isolated Scores?
- Q4. What is the appropriate equal value to be used for the costs and benefits of the dummy project?

Below answers to the above questions after further detailing them.

Q1. How does the dummy project embody to the evaluation process?

As stated above, the dummy project is placed in the evaluation domain alongside all other evaluating projects. In the BVM, the dummy project is linked with all benefit criteria in the monetizable cluster, similar to all other evaluating projects in the domain. But it is not required to create such links between the dummy project and benefit criteria in the non-monetizable cluster since the dummy project assumes to have a 'zero or negligible' amount of non-monetizable benefits, as mentioned before. Further, the links between the dummy project and the monetizable benefit criteria should be limited to forward dependencies (criteria influence on evaluating projects) only. The backward dependencies are not created here since the dummy project should not be influenced on criteria weights as it is not part of the original evaluation domain. Thus, the dummy project only represents the pairwise comparison of 'projects with respect to monetizable criteria'. In this particular pairwise comparison, the dummy project should be evaluated with its assigned values for the monetizable criteria.

Q2. Is there an influence on the Isolated Scores of original evaluating projects when adding the dummy project?

Yes, there is an influence. But it can be nullified.

As mentioned in the previous chapter, since the FCEP is built on ANP and TOPSIS platforms, the new addition of a project to the evaluation domain changes the scores of original projects. Such changes in scores may change the preference order of the projects, sometimes leading to completely reverse the order if changes in scores are significant. However, in the literature, there are recommended adjustments to preserve the original preference order of projects in ANP and TOPSIS platforms, nullifying the influence of a new addition. Such recommended adjustments available for ANP and TOPSIS are detailed in Section 6.3.

Q3. How is the correlation between B/C ratios and Isolated Scores?

It is a linear relationship, providing the same order of preference for the evaluated project in B/C ratios and Isolated Scores.

The correlation between the B/C ratios and Isolated Scores is important since the threshold value of the FCEP is to establish as its equivalent value to the B/C=1.

An empirical test was designed for several sets of projects to assess the correlation between their B/C ratios and Isolated Scores: first, only considering monetizable benefit criteria and then expanding it to incorporate non-monetizable benefit criteria. The test reveals that the relationship between the B/C ratios and Isolated Scores is directly proportional when monetary costs and benefits are included. Thus, for a given set of projects, preference order in both CBA and FCEP would be the same. Table 6.1 provides the results for one such set of projects tested in the empirical study.

Table 6.1: B/C ratios and Isolated Scores for a sample set of projects

Projects	**Cost**	**Benefit**	**B/C Ratio**		**Isolated Score**	
			Value	**Rank**	**Value**	**Rank**
A	15,000	25,000	1.67	2	0.50	2
B	18,000	50,000	2.78	1	0.64	1
C	20,000	15,000	0.75	4	0.32	4
D	30,000	30,000	1.00	3	0.36	3

Note: TOPSIS used for the calculation of Isolated Scores is incorporate with rank preservation adjustment demonstrated in Section 6.3.
Source: Author

Being the correlation between B/C ratios in the CBA and Isolated Scores in the FCEP is directly proportional when the costs and benefits are expressed in monetary terms, it can be declared that any project having its Isolated Score above the Isolated Score of the dummy project is feasible for implementation, simply because the dummy project has corresponding B/C ratio of unity. For example, assume project D, with an Isolated Score of 0.36 in Table 6.1, is the dummy project. Then all other evaluated projects having the Isolated Score equal to or above 0.36 are feasible for implementation (projects A & B) while the rest is unfeasible (only project C).

However, when benefits with respect to the non-monetizable criteria are incorporated, both B/C ratios in the CBA and Isolated Scores in the FCEP are expected to change (increase or decrease) for all projects except for the dummy project. The dummy project becomes an exception since it is assumed with zero non-monetizable benefits.

But it was found that the Isolated Score of the dummy project also varies when non-monetizable benefits are added, despite it accrues nothing. Such variation is because of varying weights assigning to the monetizable clusters. This change in Isolated Score of the dummy project does not prevent using it as the threshold value since the equality of its cost and benefit is kept intact. In other words, this indicates that the threshold value is not a constant, and it is also varying with the weight combinations assigned for the monetizable and non-monetizable benefit clusters in the BVM.

Figure 6.1 demonstrates the probable changes that could happen in B/C ratios and Isolated Scores of a sample set of projects when incorporating benefits with respect to non-monetizable criteria.

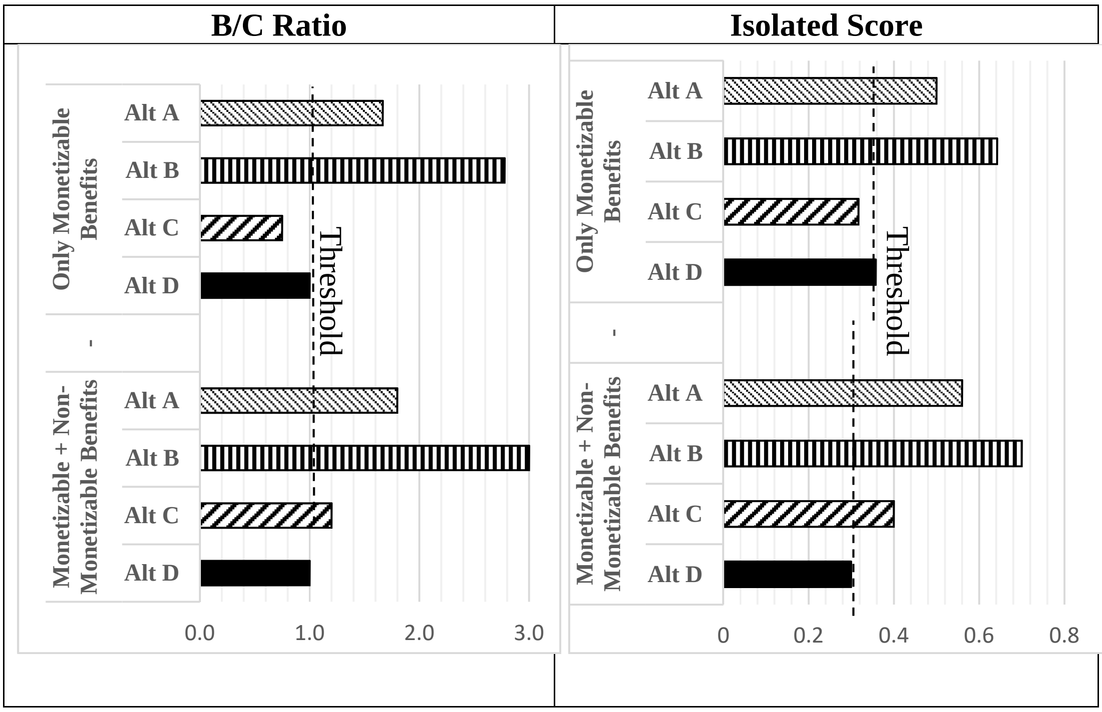


Figure 6.1: B/C ratios and Isolated Scores with and without non-monetizable benefits
Source: Author

When incorporating benefits with respect to the non-monetizable criteria, it is important to take the following concerns into account.

(i) The phenomenon of 'dummy project with a threshold value for the feasibility test' is only applicable when all other projects in the evaluation domain are supposed to derive ‘positive’ benefits with respect to each of the non-monetizable benefit criteria. The reason for this limitation can be explained in relation to the fundamentals in calculating B/C ratios and Isolated Scores. If a project derives a negative value in benefits with respect to a non-monetizable criterion, its B/C ratio gets lowered compared to without case of such benefits, sometimes below the threshold value of unity, making it unfeasible. But, in the FCEP, the same project may still show a marginal increase in Isolated Score staying over the corresponding threshold value, indicating it is feasible for implementation. This is a false indication, as there is a chance to appear the particular project as feasible in the FCEP while actually being unfeasible in the CBA with B/C ratio less than the unity. The Isolated Scores always tend to increase when adding benefits, despite their nature (monetizable or non-monetizable, or positive or negative), since those are established based on a comparative analysis, which takes only the pairwise preferences into account. Thus, having the projects generating negative benefits with respect to non-monetizable criteria should be ignored in the feasibility test of the FCEP and considered as one of the limitations of the process. Such an issue is not associated with ‘positive benefits’ since they cause to increase both B/C ratios and Isolated Scores maintaining their linear relationship.

(ii) The Isolated Score of the dummy project, which is the threshold value for testing the feasibility of the projects, has different values at different combinations of weights assigned for monetizable and non-monetizable benefit clusters.

Q4. What is the appropriate equal value to be used for the costs and benefits of the dummy project?

As mentioned before, total cost and total benefit values for the dummy project should be established as equal amounts in monetary terms since it is required to maintain the unity in the benefit: cost (B/C) ratio. The appropriate value for this equal amount was established through an empirical test which examined the suitability of aggregation of (i) average values of individual monetizable benefit criteria values of all other evaluating projects in the evaluation domain, (ii) minimum values of individual monetizable benefit criteria values of all other evaluating projects in the evaluation domain, (iii) average values of cost criteria values of all other evaluating projects in the evaluation domain, (iv) minimum values of cost criteria values of all other evaluating projects in the evaluation domain. The suitability of the above values for the dummy project was determined depending on their ability to maintain the same preference order in CBA and FCEP when criteria values for other imaginary projects were changed. The test was conducted for several sets of imaginary projects with different cost and benefit criteria values expressed in monetary terms.

The empirical test reveals that the most suitable value to use for the equal amount of cost and benefit of the dummy project is the 'aggregation of average values of individual monetizable benefit criteria values of all other evaluating projects in the evaluation domain'. Thus, the dummy project has its each criterion value equal to the average of respective criterion values for all other evaluating projects. All other values tested for the equal amounts of cost and benefit for the dummy project did not demonstrate strong suitability compared to the afore-mentioned value in terms of ensuring compatibility of B/C ratios and Isolated Scores in the empirical tests.

The above-mentioned selected value for costs and benefits makes the dummy project a representative project for the evaluation domain. Table 6.2 provides one of the imaginary project combinations tested for justifying the above-selected value for the dummy project (Project D represents the dummy project). It shows that preference orders in both the CBA and the FCEP are the same.

Table 6.2: Benefit criteria values for dummy project alternative

Projects	**Total Cost (LKR)**	**Benefits (Savings in), LKR**				**B/C Ratio**		**Isolated Score**	
		User Cost	**Accident Cost**	**Emission Cost**	**Total**	**Value**	**Rank**	**Value**	**Rank**
A	15,000	18,000	4,500	2,500	25,000	1.67	2	0.50	2
B	18,000	38,000	8,500	3,500	50,000	2.78	1	0.64	1
C	20,000	10,000	3,500	1,500	15,000	0.75	4	0.32	4
D	30,000	22,000	5,500	2,500	30,000	1.00	3	0.36	3

Note: TOPSIS used for the calculation of Isolated Scores is incorporate with rank preservation adjustment demonstrated in Section 6.3.

Source: Author

In brief, the dummy project which provides an Isolated Score equal to the threshold value of projects’ implementation feasibility inherits the following features;

(i) It does not accrue non-monetizable benefits but only monetizable benefits,

(ii) Its criteria values are equal to the average of respective criteria values for all other evaluating projects, thus

(iii) Its equal cost and benefit are valued at the average of total monetizable benefit criteria values for all other evaluating projects in the evaluation domain.

6.2.2 Feasibility Threshold Score for Universal Scores

The Isolated Score derived for the dummy project is specific to an assigned weight ratio for monetizable and non-monetizable benefit clusters in the BVM. This particular Isolated Score of the dummy project can be translated to the Universal Score under Scenario 2, taking all possible combinations of monetizable and non-monetizable benefit cluster weights into account, as suggested in Chapter 5. Such derived Universal Score of the dummy project becomes the threshold value when determining the implementation feasibility of the evaluated projects in Scenario 2. The same procedure applies to calculate the threshold value when the FCEP is used for a specific range of weight ratios in monetizable and non-monetizable benefit clusters in the BVM.

It is evident that the threshold values, in the form of an Isolated Score or a Universal Score, are valid only for the evaluation problem for which it was derived. This is in contrast to the fundamentals of the threshold value in CBA (minimum acceptable EIRR of 12% and cost-benefit ratio of 1 for infrastructure projects in Sri Lanka), which is applicable to any evaluation problem to determine the implementation feasibility of the projects. The threshold value in CBA derives by using country-specific economic parameters, and hence it is country-specific, not evaluation problem-specific. But the feasibility threshold value developed herein is only evaluation problem-specific.

6.3 Adjustments to the FCEP

As demanded in Sub-section 6.2.1, adjustments are required to the FCEP, specifically to ANP based BVM and TOPSIS based FVM, to handle rank reversal that could possibly happen when adding a new project in the form of a dummy project to the evaluation domain. Usually, in analysis frameworks comprising AHP, ANP, and TOPSIS, adding a new project or removing an existing project from the evaluation domain may lead to change the order of preference since that particular order is reinforced with the mutual influences of original projects considered in the domain. In some cases adding or removal projects may lead to what is called a total rank reversal, where the order of preferences is totally inverted, that is to say, that the project considered as the best, with the inclusion or removal of a project from the process, then becomes the worst (García-Cascales & Lamatab, 2012; Kong et al., 2016; Schenkerman, 1994). Such a phenomenon violates the invariance principle of utility theory and hence not acceptable (García-Cascales & Lamatab, 2012). Thus, the following sub-sections discuss using methodological adjustments suggested by Kong et al. (2016) and García-Cascales and Lamatab (2012) to eliminate possible rank reversal or, in other words, preservation of rakings of original projects in ANP built into the BVM and TOPSIS built into the FVM respectively.

6.3.1 Rank Preservation in ANP

Since ANP is recently introduced, the literature is hardly available on (i) its rank reversal tendencies and (ii) rank preservation methods adoptable in case of rank reversal. The work done by Kong et al. (2016) appears as the only research relevant to the above matters. Even that research has not proposed a generalized methodological adjustment that can apply to all evaluation problems using ANP. Its proposed adjustment is only applicable for a simple evaluation problem having only two clusters (criteria and projects) with equal weights. Thus, such is unusable to preserve the rankings of original projects in ANP used in the BVM.

Due to the absence of an improved rank preservation adjustment for ANP, an alternative approach is required to avoid possible rank reversal/alteration of the original projects when using the FCEP to test their feasibility. The alternative approach suggesting herein is to test the similarity of rankings of original projects under two cases of with and without the dummy project. If the ranking alters or reverses, the feasibility test cannot proceed. But, an empirical test conducted suggests that rank reversal or alteration is highly unlikely in the customized ANP model inbuilt to the BVM when the dummy project is added. This is primarily because of not adopting back-ward dependencies for the dummy project in this customized ANP model in the BVM (refer Sub-section 6.2.1). Such a strategy does not allow the dummy project to change the criteria weights and thereby its influence on the final scores of the original projects is eliminated. Thus, the ranks of original projects remain the same under both with and without the dummy project.

However, since rank preservation is not fully guaranteed, it is required to conduct the above-mentioned sensitivity test to assure there is no rank reversal or alteration when the dummy project is added to the evaluation domain. Since conducting such a test is time-consuming and its rare failure may lead to cease the feasibility test, incorporating an appropriate rank preservation technique to ANP in-built to the BVM would certainly improve the cause of using the FCEP in the feasibility test. But this thesis does not attempt to develop such a rank preservation technique as it is beyond the scope herein. Thus, it will remain as an element to be treated in future studies.

6.3.2 Rank Preservation in TOPSIS

García-Cascales and Lamatab (2012) suggested two changes to the conventional application procedure of TOPSIS, described in Sub-section 4.4.3, to preserve the ranking of the original projects when introducing a new project or removing an existing project from the evaluation domain. These changes are demanded to (i) re-define ideal solutions and (ii) revise the normalization technique.

Redefining Ideal Solutions: The conventional TOPSIS application demands PIS to hold the lowest cost criteria value and the highest benefit criteria value of all other projects in the domain while for NIS to hold the highest cost criteria value and the lowest benefit criteria value (refer Sub-section 4.4.3). In line with the rank preservation method suggested by García-Cascales and Lamatab (2012), the cost criteria value of PIS and benefit criteria value of NIS has to bring down to the theoretical minimum of 'zero' while unchanging the value for other criteria in the pair. In other words, García-Cascales and Lamatab (2012) recommend;

(i) PIS to hold 'the highest of all benefit criteria values of other projects' for its benefit criteria value and the theoretical minimum of 'zero' for the cost criteria value.

(ii) NIS to hold 'the highest of all cost criteria values of other projects' for its cost criteria value and the theoretical minimum of 'zero' for the benefit criteria value. It should be noted that the theoretical minimum value of benefit criteria was able to assume as 'zero' as per the assumption made previously to consider all projects are supposed to derive positive benefits only (refer Sub-section 6.2.1).

Revising Normalization Techniques: In conventional TOPSIS application, cost and benefit criteria values are normalized by dividing each of them by square root of aggregated squares of respective criteria values (refer Step 1 in Sub-section 4.4.3). The rank preservation adjustments suggested by García-Cascales and Lamatab (2012) demands to divide each criteria value by its respective maximum value. Table 6.3 shows the selected ideal solutions and normalized criteria values for three imaginary projects derived by following the rank preservation method suggested by García-Cascales and Lamatab (2012).

Table 6.3: Ideal solutions and normalized criteria values in rank preservation method

Projects	**Criteria Values**		**Normalized Criteria Values**	
	Cost	**Benefit**	**Cost**	**Benefit**
A	15,000	25,000	0.50	0.50
B	18,000	50,000	0.60	1.00
C	20,000	15,000	0.67	0.30
D	30,000	30,000	1.00	0.60
PIS	0	50,000	0.00	1.00
NIS	30,000	0	1.00	0.00

Note: NIS = Negative Ideal Solution, PIS = Positive Ideal Solution.

Source: Author

It is evident that if the FCEP is going to use only for prioritizing a pre-defined set of projects, without adding or removing projects later on, there is no need to incorporate rank preservation methods in the BVM and the FVM. In such instances, using the BVM and the FVM with conventional application procedures of ANP and TOPSIS would make calculation simple and less time-consuming. The rank preservation techniques are only required to incorporate when the FCEP is going to use for testing the implementation feasibility of the evaluating projects.

6.4 Upgrading FCEP to CEP

The FCEP supported with the above-detailed adjustment for deriving a threshold score makes it qualified to be the CEP since it is now practically applicable for evaluating transport projects, ensuring both input and result-completeness. Earlier the FCEP was only able to ensure the input-completeness in its practical application but failed to ascertain the result-completeness explicitly due to the absence of a threshold score for testing the implementation feasibility of the evaluated projects. Hereafter the new evaluation process is referred to as the CEP in this thesis.

6.5 Application of CEP in Different Contexts

The CEP enables ranking all evaluated projects on their performances in the descending order of the scores giving the highest priority to the highest scored. Thus, it can be used for selecting the best project or several projects for implementation, if their feasibility is assured. It is a common practice to select (i) the best or several when independent projects are evaluated and (ii) only the best when alternative projects (non-independent) are evaluated (See below box for the definition of independent projects and alternative projects). When selecting several independent projects, the highest-ranked feasible projects in the performance-based prioritized list, limited by the available fund, can be selected. In this selection, the basis would be the performance credibility, not the effective fund utilization (refer Sub-section 8.2.3.2 for further detail)

Definitions for independent projects and alternative projects

Independent Projects: Projects that are technically implementable simultaneously (spatially separated) are called independent projects. When improving public transport on Galle Corridor, improving its existing public bus transport and parallel rail line improvement are independent project. In road network improvement project, improvements of sub-sections also become independent projects (spatially separated).

Alternative Projects: Projects that become alternatives to each other in achieving particular objective are called alternative projects. In a road surfacing work, asphalt concrete or double bituminous surface treatment would be alternative projects. In a public transport improvement project, modernizing existing bus service, or introducing Bus Rapid Transit are alternative projects. These are not technical implementable simultaneously. Thus, they also can be introduced as non-independent projects.

Thus far, discussion on the CEP was to apply, (i) when benefit clusters in the BVM are assigned with specific weight ratio or all possible combinations of weight ratios, and (ii) for projects included in a single evaluation domain. This statement leaves the following two questions to be answered to demonstrate the comprehensiveness of the new evaluation process.

Q1. Can the CEP be used when the decision-makers agree to a **specific range** of benefit cluster weights in the BVM?

Q2. Is it possible to use the CEP for evaluating projects included in **different evaluation domains**?

Below discusses the above two questions in detail and answers accordingly.

Q1. Can the CEP be used when the decision-makers agree to a specific range of benefit cluster weights?

Yes, it can be used. The specific weight ratio assigned for monetizable and non-monetizable benefit clusters in Scenario 1 involves a higher degree of subjectivity concerns due to the involvement of the decision-makers, whereas treating all possible combinations for the same said ratio in Scenario 2 eliminates such subjectivity concerns due to no involvement of the decision-makers. However, these two scenarios represent two extremes. There would be an intermediate scenario where the decision-makers can agree on a 'specific range' of weight ratio for monetizable and non-monetizable benefit clusters with 'a moderate level of subjectivity' concerns. The evaluation in such a situation can be executed by customizing the procedures adopted in Scenario 2 as appropriate.

In this evaluation, the full ratio range of monetizable and non-monetizable benefit cluster weights adopted in Scenario 2, i.e., 1:0 →0:1 or x: 0 →1; where x is the share of non-monetizable benefits, should be confined to the specific range agreed by the decision-makers. If the decision-makers believe non-monetizable benefit share *(x)* varies from p to q (i.e., monetizable share varies from $1-p$ to $1-q$), the Universal Scores of U'_i ; $i = 1,2,\ldots n$ for respective projects of P_i ; $i = 1,2,\ldots n$ can be expressed as in Equation 23;

$$U'_i = \int_{x=p}^{q} f_i(x) \quad ; i = 1,2, \dots \dots \dots . n \qquad (23)$$

The Universal Score, U'_i, is simply the area below the graph of P_i bounded with the agreed range in benefit cluster weights in the chart of Isolated Scores versus monetizable: non-monetizable benefit cluster weight ratio in the BVM. Such derived Universal Scores are used for making evaluation decisions as in the case of Scenario 1 and 2.

Q2. Is it possible to use the CEP for evaluating projects included in different evaluation domains?

No. it is not possible. The TCEP was developed for an evaluation domain in which projects are defined rationally to have a common set of criteria for evaluating their performance. The functionalization of this process was carried out without changing the aforesaid ideology, and hence the results generated through this functionalized TCEP for evaluated projects, in the form of Isolated Scores or Universal Scores, exclusively depend on the original criteria considered for the evaluation domain. Thus it is evident that those results are specific to the evaluation problem or domain considered. This limitation of results, presented as scores, primarily because of using two MCA techniques of ANP and TOPSIS in this new process. Further, this limitation indicates that the scores obtained from this process for the projects coming under different evaluation domains cannot be comparable. In other words, the results generated from this new process are not absolute comparable but only relatively comparable. Thus, it can be concluded that scores of this new process usable only for comparing projects evaluated in a single evaluation domain but not for the projects evaluated in different evaluation domains. This is highlighted as one of the limitations of this process and hence it will not be treated in the rest of this thesis.

6.6 Summary

This chapter improved the FCEP to test the implementation feasibility of evaluated projects by incorporating a methodological adjustment to introduce a threshold value. This adjustment recommends to evaluate original projects together with a dummy project which has a cost-benefit ratio of unity. Any original project achieving an Isolated Score or Universal Score above that of the dummy project is declared as feasible for implementation. However, this method of testing the implementation feasibility has several concerns since (i) the threshold score not being generalized across different evaluation domains, (ii) all projects are expected to derive only positive benefits, and (iii) rank preservation is not being fully assured when the dummy project is introduced. Out of those three concerns, the first two can be treated as limitations while the last demands further improvement in future researches, particularly in relation to ANP.

With the introduction of the afore-said threshold score, the FCEP ascertains the result-completeness too, enabling both evaluation decisions of testing implementation feasibility of the evaluated projects and their prioritization, in addition to ensuring the input-completeness in its practical application. In other words, the FCEP supported with the methodological adjustments for generating the feasibility threshold score ensures both input and result-completeness in its practical application. Thus this enhanced version of the FCEP is considered as the CEP targeted to achieve in the research aim stipulated in Section 1.4.

This chapter together with Chapter 4 and 5 achieves Research Objective 3 (RO3), developing the new evaluation process (refer Section 1.7).

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CHAPTER 7

DEMONSTRATION & VALIDATION

7.1 Introduction

This chapter demonstrates the application of the CEP in an actual transport project evaluation problem. The selected evaluation problem for this purpose is the proposal to improve the passenger transportation on Galle Road Corridor in Sri Lanka presented in Strategic Plan for Traffic Management in Colombo Metropolitan Region (University of Moratuwa, 2015). The Strategic Plan has tested several alternative projects through a CBA to find out the best performing one to implement for achieving the targeted goal. This chapter tests the same alternative projects through the CEP and eventually compares its results with CBA to investigate their compatibility. If there are deviations in the results, those would be justified through rational reasoning. The above-mentioned compatibility test and rational reasoning would provide an acceptable validation for the new evaluation process. This chapter covers the last research objective (RO4), demonstration and validation of the new evaluation process developed.

7.2 Evaluation Problem in Brief

The Strategic Plan has evaluated the following three alternative projects for the selection of the best performing one to improve passenger transportation on Galle Corridor from Pettah to Panadura.

- Alternative 1 –Railway Modernization (RWM)
- Alternative 2 – Bus Rapid Transit (BRT)
- Alternative 3 – Bus Priority Lane (BPL)

The evaluation presented in the Strategic Plan has taken only the monetizable impacts into account since it has adopted CBA. Thus, it has estimated three categories of monetizable benefits: user cost savings, accident cost savings, and emission cost savings; and three categories of costs: construction cost, maintenance cost, and operation cost for each alternative project separately to carry out the evaluation. Such estimated benefits and costs over a benefit period of 15 years have been expressed in the present value of 2015 and presented in Table 7.1. The Strategic Plan has used the Benefit/Cost (B/C) ratio as the decision criteria for prioritizing the alternative projects and determining their economic feasibility. In accordance with the norms in CBA, the alternative projects are prioritized in the descending order of B/C ratio, giving the highest preference to the alternative with the highest B/C ratio, and declaring the alternative projects with B/C ratio equal or above the unity as economically feasible for the implementation. Table 7.1 shows the calculated B/C ratio and accordingly assigned preference rank.

Table 7.1: Benefits, costs, and results of CBA used in the Strategic Plan

Alternatives	**Project Benefits (Monetizable), SLRs, million**			**Project Cost[a], SLRs, million**	**B/C Ratio**	**Rank**
	User Cost Saving	**Accident Cost Saving**	**Emission Cost Saving**			
1. Railway Modernization (RWM)	22,934	1,100	1,180	42,800	0.59	2
2. Bus Rapid Transit (BRT)	26,477	814	1,202	23,250	1.23	1
3. Bus Priority Lanes (BPL)	5,000	610	100	18,700	0.31	3

Note: [a] Project cost is an aggregation of present values of construction, maintenance, and operation costs; SLRs = Sri Lankan Rupees

Source: University of Moratuwa (2015)

As shown in Table 7.1, CBA has ranked alternative 2: Bus Rapid Transit (BRT) as the most preferred alternative while alternative 1: Railway Modernization (RWM) and alternative 3: Bus Priority Lanes (BPL) as the second and the third preferred. Table 7.1 also indicates that only alternative 2 is economically feasible for implementation as it maintains a B/C ratio just above the cut-off value of unity. The other two alternatives are not economically feasible as their B/C ratios are well below the cut-off value.

The CBA presented in the Strategic Plan and summarized above has been completely based on the monetizable benefits and costs. Thus, the decision to select BRT as the most preferred alternative project to implement is also based only on the monetizable benefits and costs. But, being all the above proposed alternative projects are related to passenger transportation, non-monetizable benefits such as reliability, affordability, comfort, and safety of the services are also very important criteria to be considered together with the afore-said monetizable benefits. However, these important non-monetizable benefits cannot be taken into account in the conventional CBA simply because of their inability to convert into monetary terms. Thus, the CEP developed herein to count non-monetizable benefits alongside monetizable benefits appears as the most appropriate process to solve this evaluation problem comprehensively. The following sub-sections demonstrate the evaluation of the above mentioned three alternative projects using the CEP and eventually compare the results of CEP with those of CBA, presented in Table 7.1, for the validation. The evaluation presented herein is carried out for two scenarios detailed in Chapter 5 and 6:

Scenario 1- With an agreed Weight Ratio for Benefit Clusters in the BVM: This scenario uses an agreed weight ratio by the decision-makers for monetizable and non-monetizable benefit clusters in the BVM. The Isolated Score (IS) is the evaluation output used for decision making.

Scenario 2- No agreed Weight Ratio for Benefit Clusters in the BVM: This scenario uses the whole spectrum of weight ratio combinations for monetizable and non-monetizable benefit clusters in the BVM since there is no agreement among the decision-makers (Refer Section 5.4). The Universal Score (US) is the evaluation output used for decision making.

When applying the CEP for the above two scenarios, it is required to incorporate the necessary methodological adjustments recommended in Chapter 6 to test the implementation feasibility of given alternative projects. Accordingly, the dummy alternative project (DAP) is added to the evaluation domain as the first adjustment. As defined in Sub-section 6.2.1, this DAP should carry only the monetizable benefits valued at SLRs 18,137 million of user cost savings, SLRs 841 million of accident cost savings, and SLRs 827 million of emission cost savings. Consequently, its total cost should also be equal to the total benefit of SLRs 19,806 million to produce unity in the B/C ratio.

7.3 Scenario 1: With agreed Weight Ratio for Benefit Clusters in BVM

This section demonstrates the application of the CEP to evaluate the said alternative projects when there is an agreement among the decision-makers on the weight ratio to be assigned for the monetizable and non-monetizable benefit clusters in the BVM. In line with the application procedure of the CEP given in Chapter 5, the following tasks are needed to execute sequentially to complete the evaluation.

1. Define the evaluation problem
2. Impact categorization
3. Cost Valuation
4. Benefit Valuation
5. Final Valuation

Executions of the above tasks are demonstrated in subsequent sub-sections sequentially.

7.3.1 Define Evaluation Problem

As the first step in the CEP, it is required to define the project evaluation problem clearly indicating its set goal to achieve and alternative projects selected to achieve such set goal. For this evaluation, the goal and the alternative projects are already set in the Strategic Plan and are summarized below:

Goal: Selecting the most economically feasible alternative project to improve the passenger transportation on Galle Corridor

Alternative Projects: Railway modernization, Bus rapid transit, and Bus priority lanes

7.3.2 Impact Categorization

Out of four modules in-built in the CEP, impact categorization is the first module to execute (refer Section 5.2). The impacts generated after the implementation of a project are broadly categorized as costs and benefits first and then as monetizables and non-monetizables. Table 7.1 shows the cost and benefit items identified for the CBA of the Strategic Plan. As indicated in Section 7.2, all those items are monetizable. In addition to those monetizable cost and benefit items used in the CBA, this evaluation uses non-monetizable benefits related to comfort, reliability, and affordability aspects of the alternative projects. Below summarizes the categorized cost and benefit items intended to use in this evaluation. In the evaluation, cost and benefit items are introduced as cost and benefit criteria, respectively.

Costs	Monetizable	Project cost (include construction, maintenance, & operation costs)
	Non-Monetizable	None
Benefits	Monetizable	User cost saving, accident cost saving, emission cost saving
	Non-Monetizable	Service comfort, reliability, and affordability

7.3.3 Cost Valuation

The second module to execute in the CEP is the CVM (refer Section 5.3). This module ultimately produces total cost criteria values for each alternative project. In this evaluation, the CEP is only to deal with a single monetizable cost criterion, i. e. project cost of each alternative project. Those are valued at SLRs 42,800 million for modernizing railway, SLRs 23,250 million for bus rapid transit, and SLRs 18,700 million for bus priority lanes, as indicated in Table 7.1.

7.3.4 Benefit Valuation

Benefit valuation is the third module to execute in the CEP (refer Section 5.4). This module ultimately produces total benefit criteria values for each alternative project by synthesizing monetizable and non-monetizable benefits after modeling benefit valuation in ANP platform (refer Section 5.4). The following Sub-sections describe (i) modeling benefit valuation and (ii) determining total benefit criteria values for alternative projects.

7.3.4.1 Modelling Benefit Valuation in ANP Platform

As indicated in Sub-section 7.3.2, the selected criteria for representing the monetizable benefits are user cost savings, emission cost savings, and accident cost savings, whereas for the non-monetizable benefits are comfort, reliability, and affordability.

Those criteria are inter-linked with alternative projects of BRT, BPL, RWM, and DAP to model the benefit valuation problem in ANP platform, as shown in Figure 7.1. As recommended in Section 5.4, all the alternative projects, except the DAP, are linked with all the criteria with forward and backward dependencies. The DAP is only linked to monetizable benefit criteria with forward dependencies only (refer Sub-section 6.2.1).

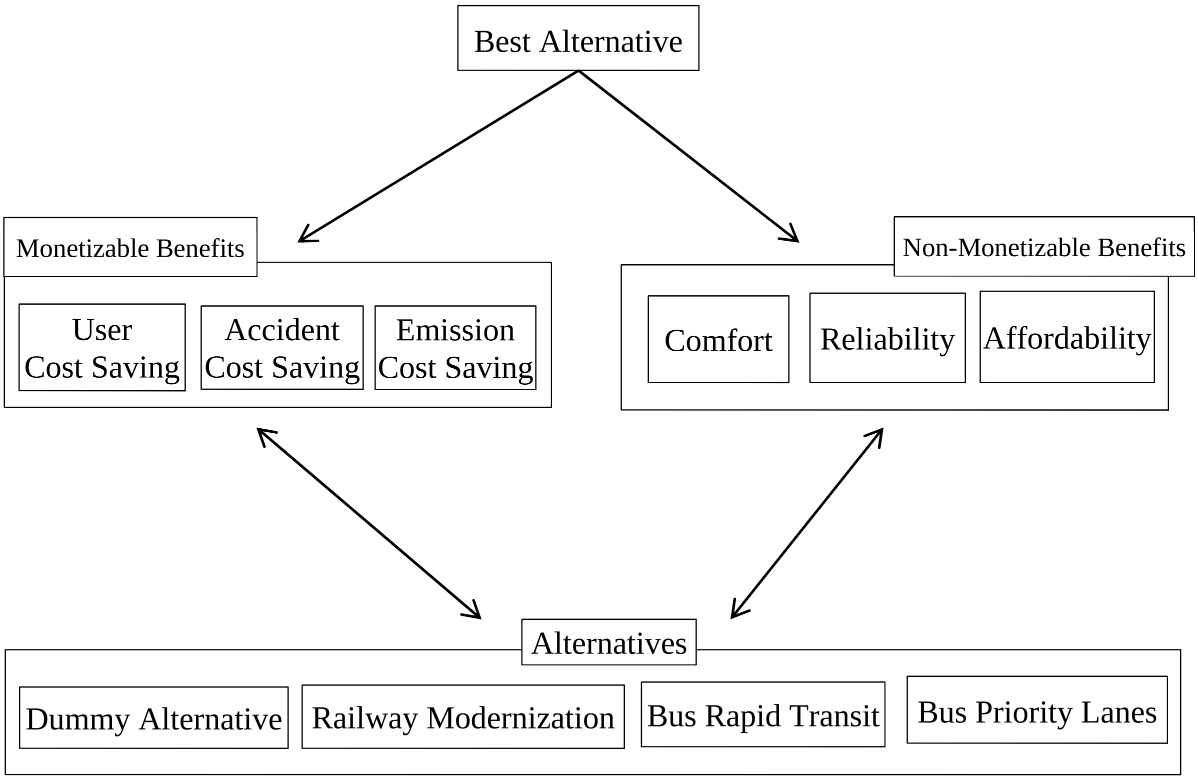


Figure 7.1: Benefit valuation in ANP platform

Source: Author

7.3.4.2 Determining Total Benefit Criteria Values for Alternative Projects

Total benefit criteria values for the alternative projects are determined by following sequential application steps demonstrated in relation to the BVM (refer Section 5.4);

a) Determination of LPVs for alternative projects with respect to monetizable benefit criteria & vice-versa,
b) Determination of LPVs for alternative projects with respect to non-monetizable benefit criteria & vice-versa,

c) Preparation of unweighted supermatrix including LPVs,
d) Preparation of weighted supermatrix,
e) Calculation of GPVs for alternative projects,
f) Assessment of DAP's influence in rank alteration/reversal, and
g) Calculation of total benefit criteria values for alternative projects.

a) Determination of LPVs for alternative projects with respect to monetizable benefit criteria & vice-versa

The LPVs for the alternative projects are determined by assigning a number from a comparison scale developed by Saaty (1980, 1996) to represent the pairwise relative importance of the alternative projects with respect to a given criterion. The reverse of the same process is adopted to determine the LPVs for the criteria with respect to the alternative projects. Saaty's scale for the pairwise comparison is given in Table 4.2 and reproduced its simplified version in Table 7.2 below.

Table 7.2: Pairwise comparison scale

Intensity of Importance	Explanation
1	Two criteria contribute equally important to the objective
3	Experience and judgment slightly favor one over another
5	Experience and judgment strongly favor one over another
7	One criterion is strongly favored over another, and its dominance is demonstrated in practice
9	Importance of one criterion over another affirmed on the highest possible order
2,4,6,8	Used to represent a compromise between the priorities listed above

Source: Table 4.2

By using the values given in Table 7.2, alternative projects are compared pairwise with respect to each monetizable benefit criteria of user cost savings, emission cost savings, and accident cost saving. The results of the pairwise comparison for the alternative projects with respect to (w.r.t) user cost saving criteria are presented as a judgment matrix in Table 7.3.

Table 7.3: Pairwise comparison for alternative projects w.r.t. user cost savings

BRT is slightly important (over performing) than RWM with respect to User Cost Saving

	RWM	BRT	BPL	DAP
Railway Modernization (RWM)	1	1/2	6	2
Bus Rapid Transit (BRT)	2	1	7	3
Bus Priority Lanes (BPL)	1/6	1/7	1	1/5
Dummy Alternative Project (DAP)	1/2	1/3	5	1

Source: Author

The pairwise comparison given in Table 7.3 is normalized by dividing each element by its column total first and then averaging by row elements for obtaining LPVs for alternative projects with respect to the criterion of user cost savings. Such obtained normalized pairwise comparison is presented in Table 7.4.

Table 7.4: Normalized pairwise comparison for alternative projects w.r.t. user cost savings

	RWM	BRT	BPL	DAP	LPVs w.r.t User Cost Saving
Railway Modernization (RWM)	0.27	0.25	0.32	0.32	0.29
Bus Rapid Transit (BRT)	0.55	0.51	0.37	0.48	0.48
Bus Priority Lanes (BPL)	0.05	0.07	0.05	0.03	0.05
Dummy Alternative Project (DAP)	0.14	0.17	0.26	0.16	0.18

Note: LPVs = Local Priority Values, w.r.t = with respect to.
Source: Author

Consistency of the pairwise comparison is needed to test for endorsing the above derived LPVs. This is executed by determining the Consistency Ratio (C_r) as recommended by T. L. Saaty (Saaty, 2008b). If C_r< 10%, the pairwise comparison is accepted as consistent in accordance with the norms of ANP. If this consistency test is failed, the pairwise comparison should be repeated until it becomes successful.

In calculating the Consistency Ratio (C_r) weighted sum vector is calculated first by multiplying the judgment matrix (Table 7.3) with corresponding LPVs (the last column in Table 7.4) and then dividing it by respective LPVs to establish the Consistency Vector. Below demonstrates this calculation.

a. Calculate the weighted sum vector by multiplying the judgment matrix with corresponding priority values

	RWM	BRT	BPL	DAP				
RWM	1	1/2	6	2		0.29		1.19
BRT	2	1	7	3	X	0.48	=	1.95
BPL	1/6	1/7	1	1/5		0.05		0.20
DAP	1/2	1/3	5	1		0.18		0.73

b. Establish the consistency vector by dividing the weighted sum vector by corresponding LPVs

1.19/0.29		4.10
1.95/0.48	=	4.06
0.20/0.05		4.00
0.73/0.18		4.06
Average (λ)		4.06

Once the consistency vector is established in a matrix form, the average value of the consistency vector is calculated as lambda (λ), which is always greater than or equal to the number of alternatives, *n*, used. This lambda (λ) value is used in Equation 24 to calculate the Consistency Index (CI), which provides a measure of deviation from the desired value.

$$CI = \frac{\lambda - n}{n-1} = 0.02 \qquad (24)$$

Where *n* = number of alternatives used, in this case, it is 4.

Consistency Ratio (C_r) is calculated by using Equation 25, as stipulated by T. L Saaty.

$$C_r = \frac{CI}{RI} = \frac{0.02}{0.89} = 2.2\% \qquad (25)$$

RI is the random index, obtained from Table 7.5, which is produced by Saaty (2008b), processing the matrices of order 1-15.

Table 7.5: Random Index (RI)

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	149	1.52	1.54	1.56	1.58	1.59

Source: Saaty (2008b)

Since the above calculated C_r is less than 10%, the pairwise comparison is sufficiently consistent, and hence the derived LPVs for the alternative projects with respect to the criterion of user cost saving are acceptable. Thus, the evaluation is proceeded.

Similarly, LPVs are established for the alternative projects with respect to the remaining two monetizable benefits criteria of accident cost savings and emission cost savings. A summary of LPVs for all four alternative projects with respect to each of the three different monetizable benefit criteria is given in Table 7.6.

Table 7.6: LPVs for alternative projects w.r.t. monetizable benefit criteria

Alternatives	**Local Priority Values (LPVs)**		
	w.r.t User Cost Saving	**w.r.t Accident Cost Saving**	**w.r.t Emission Cost Saving**
Railway Modernization (RWM)	0.29	0.60	0.41
Bus Rapid Transit (BRT)	0.48	0.17	0.41
Bus Priority Lanes (BPL)	0.05	0.07	0.04
Dummy Alternative Project (DAP)	0.18	0.15	0.15

Note: w.r.t = with respect to.

Source: Author

The same process is adopted to calculate the LPVs for the monetizable benefit criteria with respect to individual alternative projects and summarized in Table 7.7 below.

Table 7.7: LPVs for monetizable benefit criteria w.r.t. alternative projects

Alternatives	Local Priority Values (LPVs)		
	w.r.t RWM	**w.r.t BRT**	**w.r.t BPL**
User Cost Saving	0.81	0.78	0.79
Accident Cost Saving	0.10	0.08	0.13
Emission Cost Saving	0.09	0.14	0.08

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, RWM = Railway Modernization, w.r.t = with respect to.
Source: Author

The judgment matrices used to calculate all the above LPVs are given in Appendix 1, together with their consistency ratios.

b) Determination of LPVs for alternative projects with respect to non-monetizable benefit criteria & vice-versa

Unlike the monetizable benefit criteria, the non-monetizable benefit criteria of comfort, reliability, and affordability are qualitative and hence the pairwise comparison should be carried out based on the judgments of experts (refer Section 5.4). For the pairwise comparison of the alternative projects with respect to each of the non-monetizable criteria and vice-versa, opinions of 10 experts are evaluated. Before inquiring their opinions, they were made aware of the operational features related to non-monetizable criteria (affordability, reliability, and comfort) of each project as stipulated in the Strategic Plan. Their opinions were a mix of those demonstrated operational features and their own experience and expertise. Below are the indicators considered in assessing each criterion for the pairwise comparison.

- **Reliability:** technical and human resource capacity of the implementing agency, use of modern technology in managing operations, availability of road furniture facilitating uninterrupted operations (signal priority and dedicated lanes, etc.)
- **Affordability:** incremental user charge compared to their income
- **Comfort:** vehicle technology and quality of road/railway

Based on their opinions, ten sets of judgment matrices were prepared for each comparison category (e.g., alternative projects with respect to a given criterion is one category), ensuring the stipulated consistency requirement and the same matrices are used in this demonstration. There are two methods to derive LPVs from these judgment matrices.

Method 1: Produce averaged judgment matrices for each comparison category by averaging the corresponding ten individual judgment matrices. These averaged judgment matrices can be used for deriving LPVs for each comparison category.

Method 2: Produce local priority matrices for each set of judgment matrices first and then average them to form a single local priority matrix. This unified local priority matrix provides the LPVs for each comparison category.

For this demonstration, Method 1 is adopted. The averaged judgment matrices produced based on the opinions of 10 experts are presented in Appendix 2.

Table 7.8 summarizes LPVs for the alternative projects with respect to each of the non-monetizable benefits criteria, estimated based on the related averaged judgment matrices in Appendix 2. It should be noted that there are no LPVs related to DAP, as it is not linked to any non-monetizable benefit criteria.

Table 7.8: LPVs for alternative projects w.r.t. non-monetizable benefit criteria

Alternatives	**Local Priority Values (LPVs)**		
	w.r.t Affordability	**w.r.t Comfort**	**w.r.t Reliability**
Railway Modernization (RWM)	0.33	0.22	0.14
Bus Rapid Transit (BRT)	0.07	0.67	0.71
Bus Priority Lanes (BPL)	0.60	0.11	0.14

Note: w.r.t = with respect to.
Source: Author

Following the same procedure, LPVs for the non-monetizable benefit criteria with respect to each alternative project are also estimated and summarized in Table 7.9.

Table 7.9: LPVs for non-monetizable benefit criteria w.r.t. alternative projects

Alternatives	**Local Priority Values (LPVs)**		
	w.r.t RWM	**w.r.t BRT**	**w.r.t BPL**
Affordability	0.74	0.06	0.75
Comfort	0.17	0.49	0.09
Reliability	0.09	0.45	0.16

Note: w.r.t = with respect to.
Source: Author

c) Preparation of unweighted supermatrix including LPVs

The LPVs obtained above for (i) alternative projects with respect to monetizable benefit criteria and vise-versa and (ii) alternative projects with respect to non-monetizable criteria and vise-versa are arranged in the unweighted supermatrix, Matrix 7.1, as recommended in Section 5.4 and further illustrated in Figure 7.2.

Matrix 7.1: Unweighted supermatrix for local priority values

		Alternatives				Non-Monetizable Benefits			Monetizable Benefits (Saving in)		
		RWM	BRT	BPL	DAP	Affordability	Comfort	Reliability	Accident Cost	Emission Cost	User Cost
Alternatives	RWM	0.0	0.0	0.0	0.0	0.33	0.22	0.14	0.60	0.41	0.29
	BRT	0.0	0.0	0.0	0.0	0.07	0.67	0.71	0.17	0.41	0.48
	BPL	0.0	0.0	0.0	0.0	0.60	0.11	0.14	0.07	0.04	0.05
	DAP	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.15	0.15	0.18
Non-Monetizable Benefits	Affordability	0.74	0.06	0.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Comfort	0.17	0.49	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Reliability	0.09	0.45	0.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monetizable Benefits	Accident Cost Saving	0.10	0.08	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emission Cost Saving	0.09	0.14	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	User Cost Saving	0.81	0.78	0.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.
Source: Author

The above matrix is called unweighted supermatrix since two clusters of monetizable and non-monetizable benefits have not been assigned with weights yet.

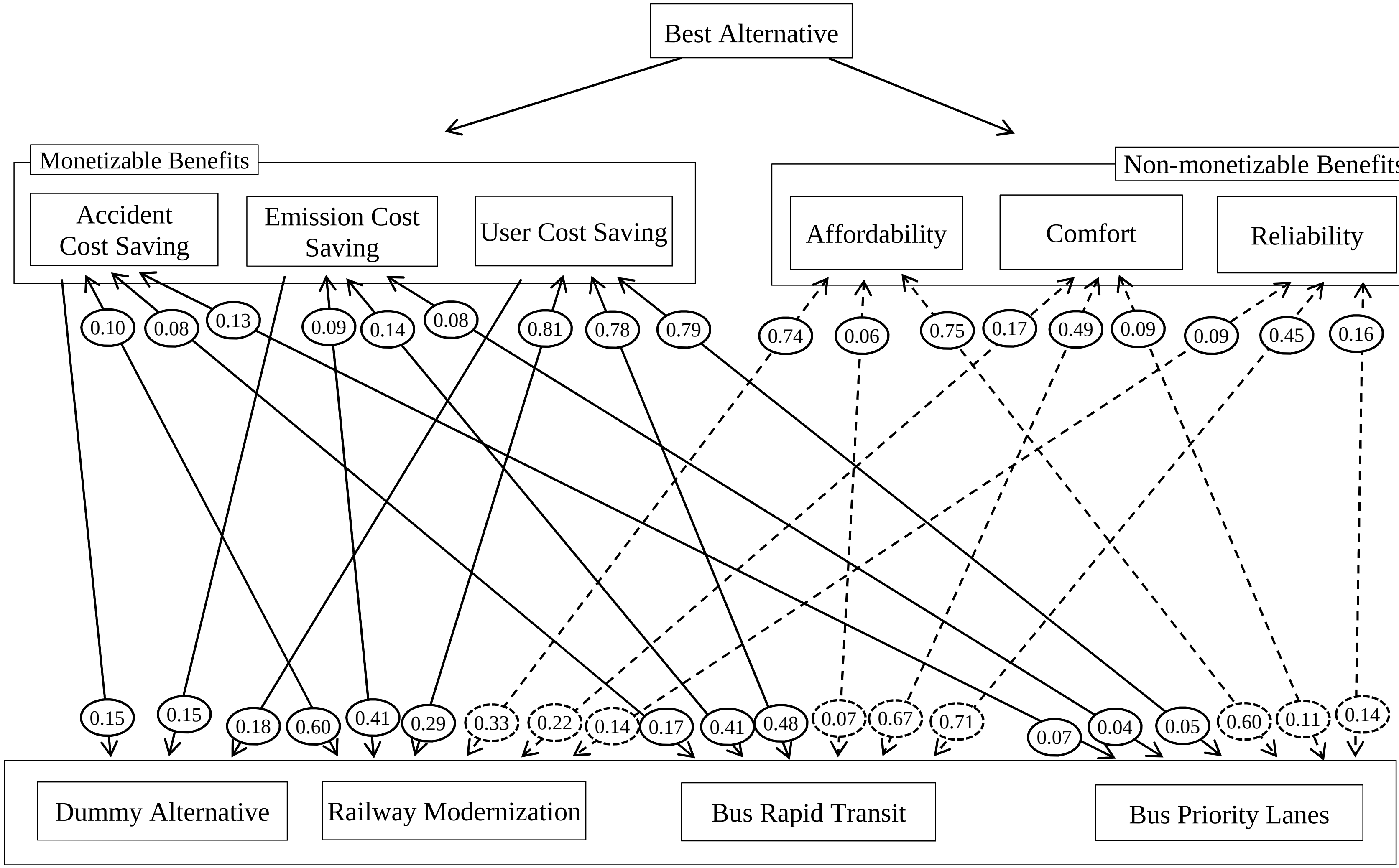


Figure 7.2: Local priority values for alternative projects and criteria

Source: Author

d) Preparation of weighted supermatrix

As demonstrated in Section 5.4, the weighted supermatrix is prepared by assigning weights for monetizable and non-monetizable benefit clusters. These cluster weights represent the expectations of the decision-makers and are determined with their agreement. In the case of this evaluation problem, the decision-makers believed that both clusters are equally important in achieving the set goal and hence the weights of monetizable benefits: non-monetizable benefits = 50:50 (equally contributed) is assigned to the above unweighted supermatrix and thereby established the weighted supermatrix as shown in Matrix 7.2. When determining the above weights for monetizable and non-monetizable clusters, their included benefit criteria are treated as 'primary direct benefits' and 'secondary direct benefits' respectively to rationalize the determination of weights (refer Section 5.4). Further, it should be noted that all columns in this weighted supermatrix are summed up to one unless zero.

Matrix 7.2: Weighted supermatrix (monetizable: non-monetizable = 50:50)

		Alternatives				Non-Monetizable Benefits			Monetizable Benefits (Saving in)		
		RWM	BRT	BPL	DAP	Affordability	Comfort	Reliability	Accident Cost	Emission Cost	User Cost
Alternatives	RWM	0.0	0.0	0.0	0.0	0.33	0.22	0.14	0.60	0.41	0.29
	BRT	0.0	0.0	0.0	0.0	0.07	0.67	0.71	0.17	0.41	0.48
	BPL	0.0	0.0	0.0	0.0	0.60	0.11	0.14	0.07	0.04	0.05
	DAP	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.15	0.15	0.18
Non-Monetizable Benefits	Affordability	0.37	0.03	0.38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Comfort	0.08	0.25	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Reliability	0.05	0.23	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monetizable Benefits	Accident Cost Saving	0.05	0.04	0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emission Cost Saving	0.05	0.07	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	User Cost Saving	0.40	0.39	0.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		1	1	1	0	1	1	1	1	1	1

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Source: Author

e) Calculation of GPVs for alternative projects

Since all columns in the above matrix are summed up to one (or zero), it is a column stochastic matrix and hence converging to a stable matrix in repetitive multiplications (by raising to n^{th} power; where n reaches to the infinity) by itself. This stable matrix provides the final GPVs for the alternative projects as well as for the criteria. There are two methods that can be adopted to reach the stable state of the weighted supermatrix and thereby obtain GPVs (refer Sub-section 4.4.2).

Method 1- Solving Supermatrix for its stable state: Repetitive multiplication of the weighted supermatrix (W) by itself will converge to a stable matrix (S) given in Matrix 7.3.

$$\lim_{n\to\infty} W^n = S$$

Matrix 7.3: Stabilized weighted supermatrix
(monetizable benefits: non-monetizable benefits = 50:50)

		Alternatives				Non-Monetizable Benefits			Monetizable Benefits (Saving in)		
		RWM	BRT	BPL	DAP	Affordability	Comfort	Reliability	Accident Cost	Emission Cost	User Cost
Alternatives	RWM	0.00	0.00	0.00	0.00	0.289	0.289	0.289	0.289	0.289	0.289
	BRT	0.00	0.00	0.00	0.00	0.436	0.436	0.436	0.436	0.436	0.436
	BPL	0.00	0.00	0.00	0.00	0.188	0.188	0.188	0.188	0.188	0.188
	DAP	0.00	0.00	0.00	0.00	0.087	0.087	0.087	0.087	0.087	0.087
Non-Monetizable Benefits	Affordability	0.208	0.208	0.208	0.208	0.00	0.00	0.00	0.00	0.00	0.00
	Comfort	0.152	0.152	0.152	0.152	0.00	0.00	0.00	0.00	0.00	0.00
	Reliability	0.139	0.139	0.139	0.139	0.00	0.00	0.00	0.00	0.00	0.00
Monetizable Benefits	Accident Cost Saving	0.048	0.048	0.048	0.048	0.00	0.00	0.00	0.00	0.00	0.00
	Emission Cost Saving	0.057	0.057	0.057	0.057	0.00	0.00	0.00	0.00	0.00	0.00
	User Cost Saving	0.396	0.396	0.396	0.396	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1	1	1

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Source: Author

The stabilized matrix given in Matrix 7.3 shows that GPVs or the benefit shares for four alternative projects at 50:50 weight ratio of monetizable and non-monetizable benefit clusters is 28.9% for RWM, 43.6% for BRT, 18.8% for BPL, and 8.7% for DAP. Alternatively, the results can be further interpreted as, at 50:50 of monetizable and non-monetizable benefit cluster weight ratio, RWM accrues 28.9 units of benefits, whereas BRT, BPL, and DAP accrue 43.6 units, 18.8 units, and 8.7 units of benefits, respectively.

Similarly, GPVs estimated for criteria are 39.6% for user cost savings, 5.7% for emission cost savings, 4.8% for accident cost savings, 20.8% for affordability, 15.2% for comfort, and 13.9% for reliability.

Method 2- Calculation of limitmatrix for the weighted Supermatrix (limit supermatrix): The weighted supermatrix (W) given in Matrix 7.2 becomes a Markov Transition Matrix as its columns are summed up to unity (or zero). Therefore,

$$W.L = L$$

Where; L is the limitmatrix of weighted supermatrix, W (limit supermatrix)

Using the afore-mentioned relationship, several linear equations are developed and solved to produce numerical elements in the limit supermatrix. After establishing the limit supermatrix, each cluster (alternative projects, monetizable benefits, and non-monetizable benefits) is independently normalized to calculate respective GPVs.

For this demonstration, Method 2 is followed for calculating the GPVs. The established limit matrix of Matrix 7.2 is presented in Matrix 7.4 while the calculated GPVs or benefit shares for the alternative projects are presented in Table 7.10. It should be noted that all columns in the limit supermatrix are also added up to the unity (or zero). Moreover, it is also found that both methods provide identical results for the respective GPVs.

Matrix 7.4: Limitmatrix of weighted supermatrix
(monetizable benefits: non-monetizable benefits = 50:50)

		Alternatives				Non-Monetizable Benefits			Monetizable Benefits (Saving in)		
		RWM	BRT	BPL	DAP	Affordability	Comfort	Reliability	Accident Cost	Emission Cost	User Cost
Alternatives	RWM	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144
	BRT	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218
	BPL	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
	DAP	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
Non-Monetizable Benefits	Affordability	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104
	Comfort	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
	Reliability	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Monetizable Benefits	Accident Cost Saving	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	Emission Cost Saving	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
	User Cost Saving	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198
		1	1	1	1	1	1	1	1	1	1

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Source: Author

Table 7.10: Calculated GPVs for alternative projects
(monetizable benefits: non-monetizable benefits = 50:50)

Alternatives	**GPVs (before normalizing)**	**GPVs (after Normalizing)**
Railway Modernization (RWM)	0.144	0.289
Bus Rapid Transit (BRT)	0.218	0.436
Bus Priority Lanes (BPL)	0.094	0.188
Dummy Alternative Project (DAP)	0.043	0.087
Total	0.500	1.000

Note: GPVs = Global Priority Values.

Source: Author

f) Assessment of dummy alternative's influence in rank alteration/reversal

As demanded in Sub-section 6.3.1, the BVM is also developed for the case 'without DAP' and its resulting normalized GPVs are compared with the above estimated for 'with DAP' case to assess whether DAP has caused the rank alteration or reversal of the original projects. Table 3A-1 and Figure 3A-1 in Appendix 3 provide the normalized GPVs for all possible combinations of benefit cluster weights in the BVM when there is no DAP included in the evaluation domain. Table 7.11 compares normalized GPVs for with and without cases of DAP at the equal benefit cluster weights.

Table 7.11: Normalized GPVs for alternative projects with and without DAP
(Monetizable benefits: Non-monetizable benefits = 50:50)

Alternative	Normalized GPVs (with DAP)	Normalized GPVs (without DAP)
Railway Modernization (RWM)	0.289	0.320
Bus Rapid Transit (BRT)	0.436	0.484
Bus Priority Lanes (BPL)	0.188	0.196
Dummy Project Alternative (DAP)	0.087	N/A
Total	1.000	1.000

Note: GPVs = Global Priority Values.
Source: Author

Table 7.11 indicates that there is no difference in the preference ranking of alternative projects in the cases of 'with' and 'without' of the DAP. Thus, it can be concluded that DAP has not caused alteration/reversal of the ranking of original projects, and hence analysis can be proceeded to assess the implementation feasibility of the alternative projects as recommended in Sub-section 6.3.1.

g) Calculation of total benefit criteria values for alternative projects

As demonstrated in Section 5.4, normalized GPVs only provide the shares of the benefit accrued by each alternative project, and hence it is recommended to translate all normalized GPVs to corresponding absolute values by multiplying them with an indeterministic single constant value. If $\boldsymbol{x}$ is the constant value, total benefit criteria values can be calculated as $28.9x$ for RWM, $43.6x$ for BRT, $18.8x$ for BPL, and $8.7x$ for DAP at the benefit cluster weight ratio of 50:50 for monetizable and non-monetizable clusters.

7.3.5 Final Valuation

The final valuation, which synthesizes total cost criteria and benefit criteria values to obtain Isolated Scores for each alternative project, is carried out by using the TOPSIS as described in Sub-section 5.5. In this valuation, proposed methodological adjustment for TOPSIS to prevent rank alterations or reversal likely to incur when adding the 'DAP' is also incorporated (refer Sub-section 6.3.2).

Table 7.12 presents the estimated total cost and benefit criteria values for each alternative project. The tabulated total cost criteria values are given in Sub-section 7.3.3, while total benefit criteria values are as estimated in Sub-section 7.3.4. The cost criterion value for DAP is estimated at SLRs 19,806 million, as described in Section 7.2.

Table 7.12: Summary of estimated costs and benefits for alternative projects (monetizable benefits: non-monetizable benefits = 50:50)

Alternatives	**Costs**	**Benefits**
Rail Modernization (RWM)	42,800	28.9x
Bus Rapid Transit (BRT)	23,250	43.6x
Bus Priority Lanes (BPL)	18,700	18.8x
Dummy Alternative Project (DAP)	19,806	8.7x

Source: Author

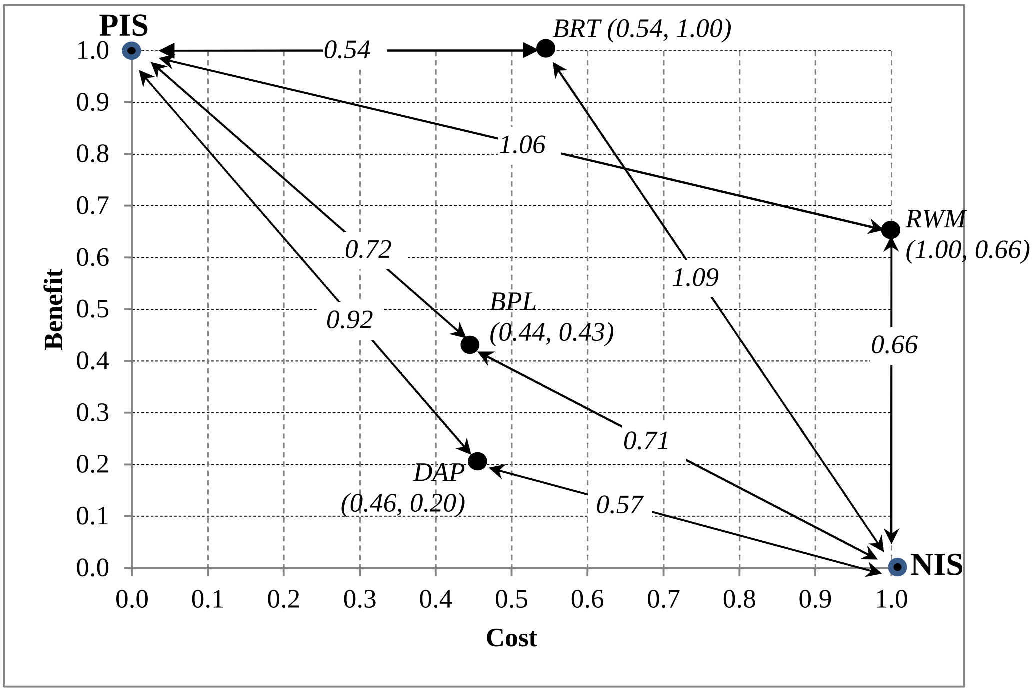
In accordance with the methodological adjustment suggested in Sub-section 6.3.2, cost and benefit criteria for the positive ideal solution (PIS) are valued at 0 and 43.6x, respectively, whereas for the negative ideal solution (NIS) at 42,800 and 0. With these PIS and NIS, estimated total cost and benefit criteria values for the alternative projects given in Table 7.12 are normalized as described in Sub-section 6.3.2 and tabulated in Table 7.13.

Table 7.13: Normalized total cost and benefit values for alternative projects (monetizable benefits: non-monetizable benefits = 50:50)

Alternatives	Costs	Benefits	Normalized Costs	Normalized Benefits
Rail Modernization (RWM)	42,800	28.9*x*	1.00	0.66
Bus Rapid Transit (BRT)	23,250	43.6*x*	0.54	1.00
Bus Priority Lanes (BPL)	18,700	18.8*x*	0.44	0.43
Dummy Alternative Project (DAP)	19,806	8.7*x*	0.46	0.20
Negative Ideal Solution (NIS)	42,800	0	1.00	0
Positive Ideal Solution (PIS)	0	43.6*x*	0	1.00

Source: Author

Figure 7.3 plots the normalized total cost and benefit values associated with all alternative projects together with PIS and NIS in two-dimensional space. It also shows calculated distances to each alternative project from PIS and NIS. It should be noted that there is no necessity to apply weights for normalized cost and benefit groups in TOPSIS platform in accordance with the argument presented in Sub- section 4.4.3.



Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, NIS = Negative Ideal Solution, PIS = Positive Ideal Solution, RWM = Railway Modernization.

Figure 7.3: Normalized total costs and benefits of alternative projects, PIS and NIS

Source: Author

As recommended in Section 5.5, the order of preferences of alternative projects is determined based on their values of relative closeness to the ideal solution, which is introduced as ‘Isolated Score’ for this thesis. The higher the Isolated Score prefers the alternative project to implement. Thus, the most preferred alternative would be the **furthest to the NIS and nearest to the PIS.** Sub-section 4.4.3 defines Isolated Score (or relative closeness) as follows;

$$Isolated\ Score\ (IS) = \frac{Distance\ from\ NIS}{(Distance\ from\ PIS + Distance\ from\ NIS)}$$

Calculated IS values for each alternative project at 50:50 of monetizable: non-monetizable benefit cluster weight ratio in the BVM are as follows;

IS_{RWM}=0.385, IS_{BRT}= 0.669, IS_{BPL}= 0.498, and IS_{DAP}= 0.383

The best alternative project would be BRT at 50:50 of monetizable: non-monetizable benefit cluster weight ratio in the BVM as it provides the highest Isolated Score of 0.669. At the same ratio of monetizable benefits and non-monetizable benefits, BPL and RWM become the second and the third most preferred alternative projects. Moreover, being the Isolated Scores of all three alternative projects are above that of DAP (i.e., 0.383), all those original three alternative projects are declared as feasible for the implementation at equal weights of monetizable and non-monetizable benefit clusters in the BVM.

The above results, derived in terms of Isolated Scores, are only applicable for Scenario 1 in which the decision-makers are in agreement on assigned weights for monetizable and non-monetizable benefit clusters in the BVM. The below section, Section 7.4, demonstrates the derivation of results, in terms of Universal Scores, for the same evaluation problem under Scenario 2, in which there is no agreement among the decision-makers on the afore-mentioned cluster weight ratio.

7.4 Scenario 2: No agreed Weight Ratio for Benefit Clusters in the BVM

As demonstrated in Section 5.4, Scenario 2 also follows the same list of tasks specified for Scenario 1 and is re-listed below.

1. Define the evaluation problem
2. Impact categorization
3. Cost Valuation
4. Benefit Valuation
5. Final Valuation

The first three tasks under both Scenario 1 and 2 are common in all aspects and thus produce the same outcomes. Therefore, outcomes of those tasks for Scenario 1 given in Sub-section 7.3.1, 7.3.2, and 7.3.3 are used in this demonstration without repeating them for Scenario 2. However, the last two tasks for Scenario 2 differs from Scenario 1 in terms of their methods of execution and hence those are performed again as required.

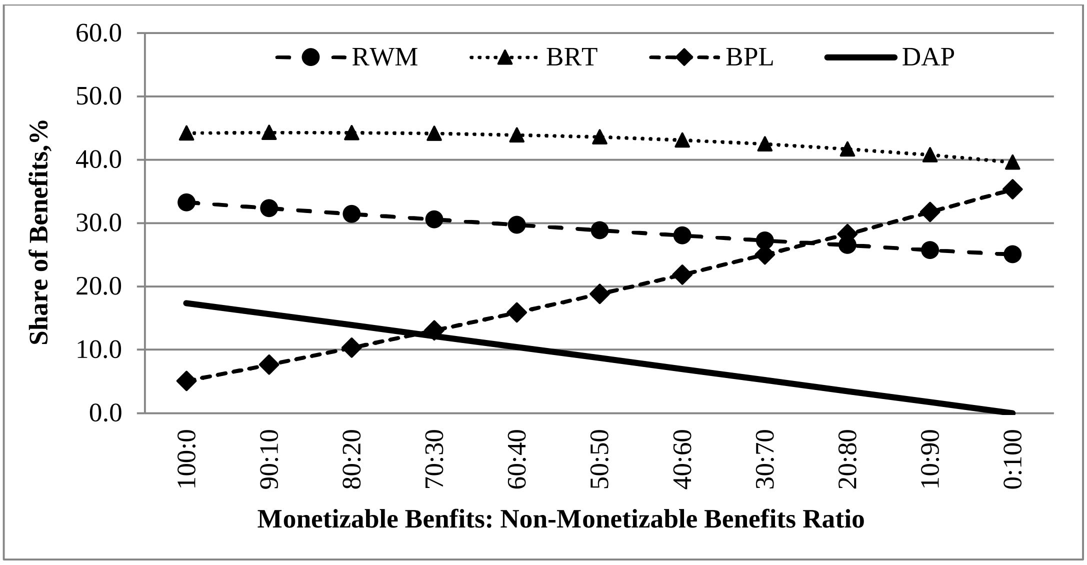
7.4.1 Benefit Valuation

The demonstration presented above for the benefit valuation under the Scenario 1 calculates GPVs first and then the total benefit criteria values for all alternative projects assigning equal weights for monetizable and non-monetizable benefit clusters of the unweighted supermatrix in Matrix 7.1. Under this scenario, since there is no agreement among the decision-makers on the benefit cluster weights, the whole spectrum of weight ratio combinations for the said clusters is required to consider (refer Section 7.2). Thus, replacing those equal weights in Matrix 7.1, different combinations of benefit cluster weights representing the whole spectrum of combinations are assigned and repeated the same calculation to obtain the respective normalized GPVs for all alternative projects. Such obtained normalized GPVs (or benefit shares) at different combinations of benefit cluster weights are tabulated in Table 7.14, while the same information is reproduced graphically in Figure 7.4.

Table 7.14: Normalized GPVs at different combinations of benefit cluster weights

Alternatives	Monetizable Benefits: Non-Monetizable Benefits										
	100:0	90:10	80:20	70:30	60:40	50:50	40:60	30:70	20:80	10:90	0:100
RWM	33.3	32.4	31.5	30.6	29.7	28.9	28.0	27.2	26.5	25.8	25.1
BRT	44.2	44.3	44.3	44.2	44.0	43.6	43.1	42.5	41.7	40.8	39.6
BPL	5.1	7.7	10.3	13.1	15.9	18.8	21.9	25.0	28.3	31.7	35.3
DAP	17.4	15.6	13.9	12.2	10.4	8.7	7.0	5.2	3.5	1.7	0.0

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.
Source: Author



Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Figure 7.4: Benefit shares of alternative projects at different benefit cluster weights

Source: Author

As in the case of Scenario 1, it is required to assess whether the addition of DAP has caused to alter or reverse the preference ranking of the alternative projects in this evaluation too. For this purpose, Table 7.14 and Figure 7.4 are compared with corresponding Table 3A-1, and Figure 3A-1 in Appendix 3 developed to represent the case ‘without DAP’. It is noted that preference ranking of the alternative projects in both cases coincide at corresponding combinations of benefit cluster weights, indicating that there is no chance for a rank alteration or reversal. Thus evaluation can be proceeded to rank the alternative projects and testing implementation feasibility as stated in Sub-section 6.3.1.

As demonstrated in Section 5.4, normalized GPVs are translated to corresponding absolute total benefit criteria values by multiplying them with an indeterministic constant value specific to each cluster weight combination. Such indeterministic constant value becomes redundant in the final valuation, as already explained while demonstrating the application of the CEP for Scenario 1.

When only total benefit criteria values are concerned, Figure 7.4 indicates that BRT remains as the most preferred alternative project at all combinations of monetizable and non-monetizable benefit cluster weights while RWM and BPL occupy the second and third places in the ranking until the monetizable benefit share reaches 20%. Thereafter, the second and third places are swapped for the remaining combinations of the benefit cluster weights. However, the ranking of alternative projects can only be finalized after synthesizing the above total benefit criteria values with corresponding total cost criteria values in the final valuation.

7.4.2 Final Valuation

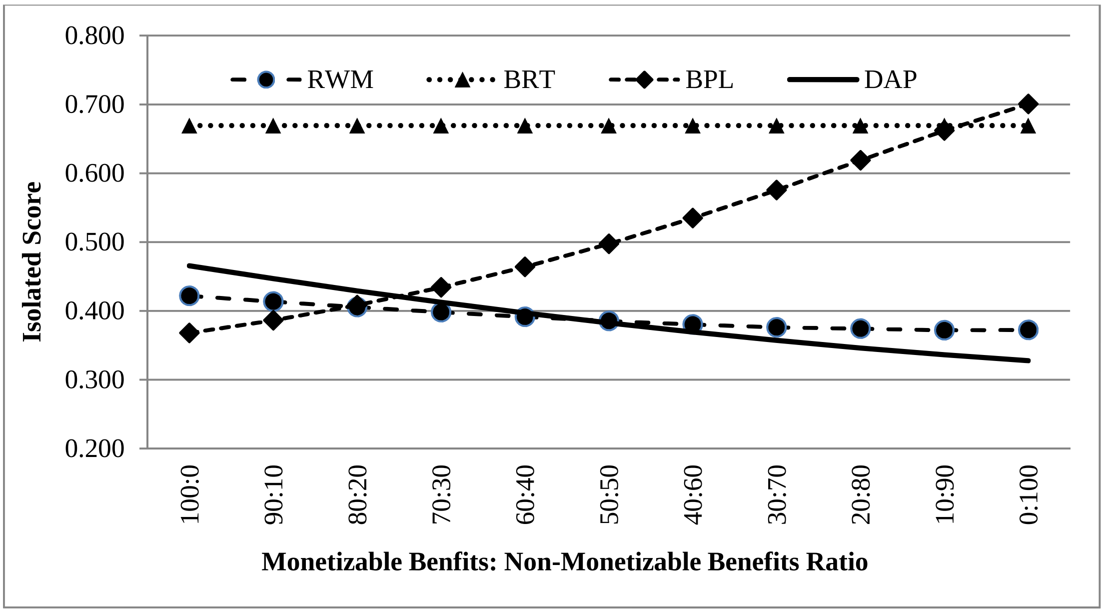
Final valuation synthesizes total benefit criteria values related to different benefit cluster weights of the BVM given in Sub-section 7.4.1, with total cost criteria values given in Sub-section 7.3.3, to obtain Isolated Scores for each combination of benefit cluster weights. The calculation procedure of these Isolated Scores is the same used in Sub-section 7.3.5. The obtained Isolated Scores for each combination of benefit cluster weights are summarized in Table 7.15 and illustrated graphically in Figure 7.5.

Table 7.15: Isolated Scores at different combinations of benefit cluster weights

Alternatives	**Monetizable Benefits: Non-Monetizable Benefits**										
	100:0	90:10	80:20	70:30	60:40	50:50	40:60	30:70	20:80	10:90	0:100
RWM	0.422	0.414	0.406	0.398	0.391	0.385	0.380	0.376	0.374	0.372	0.373
BRT	0.669	0.669	0.669	0.669	0.669	0.669	0.669	0.669	0.669	0.669	0.669
BPL	0.368	0.386	0.409	0.434	0.464	0.498	0.535	0.576	0.619	0.662	0.701
DAP	0.466	0.447	0.429	0.412	0.397	0.383	0.369	0.357	0.346	0.336	0.328

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Source: Author



Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Figure 7.5: Isolated Scores of alternative projects at different benefit cluster weights

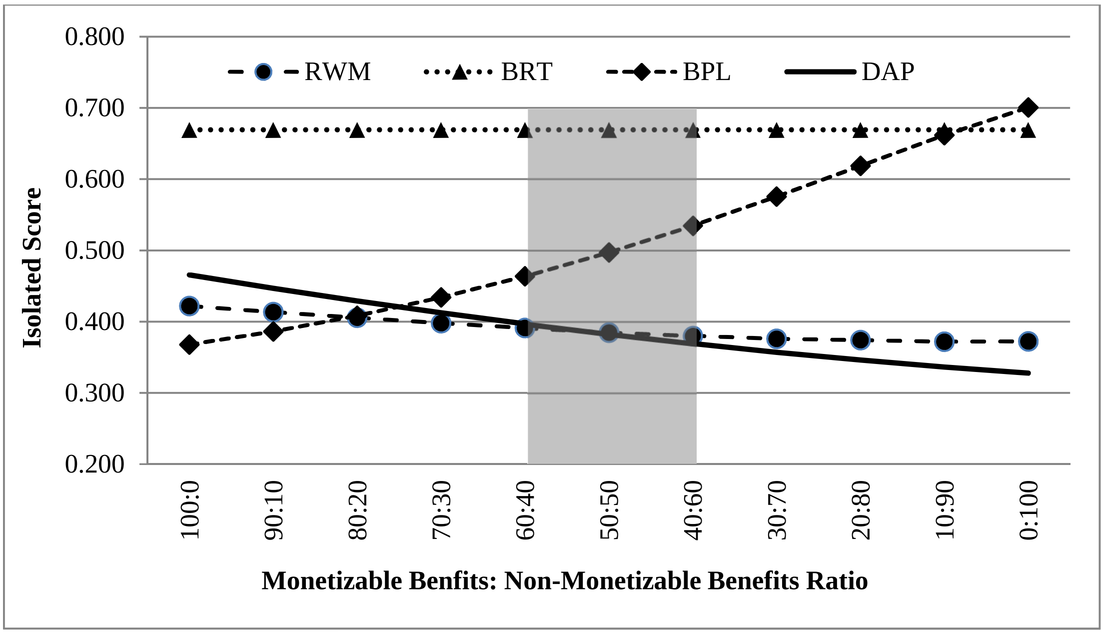
Source: Author

Multiple Isolated Scores resulted in 'no agreement' on benefit cluster weights in the BVM, are confined to a single measure in terms of a 'Universal Score' (US) introduced in Section 5.5. As recommended in Section 5.5, Universal Scores for each alternative project are calculated as the area below the corresponding graph. Such calculated Universal Scores for the alternative projects are as follows:

US_{RWM}=0.388, US_{BRT}= 0.669, US_{BPL}= 0.525, and US_{DAP}= 0.385

Scenario 2, which counted the whole range of weight combinations of monetizable and non-monetizable benefit clusters, suggests that the best alternative project to implement is BRT as it provides the highest Universal Score of 0.669 compared to the same values of all other alternative projects considered. BPL and RWM become the second and third preferred alternative projects with Universal Scores of 0.525 and 0.388, respectively. Further, all three alternative projects are feasible for implementation as their Universal Scores exceed that of the DAP. However, RWM becomes feasible marginally.

If the decision-makers agree on a specific range of benefit cluster weights, the area falling under respective graphs and bounded with a particular range is calculated to determine the Universal Scores for the alternative projects (refer Section 6.5). For example, if the decision-makers assume cluster weights of monetizable and non-monetizable benefits vary between 40: 60 to 60: 40, as shown in Figure 7.6, Universal Scores for alternative projects becomes 0.134 for BRT, 0.077 for RWM, 0.100 for BPL, and 0.076 for DAP. Thus, BRT would be the most preferred alternative projects, while BPL and RWM become the second and third preferred alternative projects. Even in this case, all alternative projects are feasible as their Universal Scores are greater than that of DAP.



Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization.

Figure 7.6: Isolated Scores of alternatives for a specific range of benefit cluster weights

Source: Author

7.5 Variation of Preference Ranking and Implementation Feasibility of Alternative Projects

Section 7.3 provides the preference ranking and implementation feasibility for alternative projects only at the benefit cluster weight ratio of 50:50 for monetizable and non-monetizable clusters. But Figure 7.5 provides the same information for all possible combinations of weight ratios assigned to monetizable and non-monetizable benefit clusters. A tabular summary of Figure 7.5 is given in Table 7.16.

Table 7.16: Evaluation decisions at different benefit cluster weight ratios

Alternatives	**Monetizable Benefits: Non-Monetizable Benefits**																					
	100:0		90:10		80:20		70:30		60:40		**50:50**		40:60		30:70		20:80		10:90		0:100	
	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	**Rank**	**Feasible?**	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?
RWM	2	N	2	N	3	N	3	N	3	N	**3**	**Y**	3	Y	3	Y	3	Y	3	Y	3	Y
BRT	1	Y	1	Y	1	Y	1	Y	1	Y	**1**	**Y**	1	Y	1	Y	1	Y	1	Y	2	Y
BPL	3	N	3	N	2	N	2	Y	2	Y	**2**	**Y**	2	Y	2	Y	2	Y	2	Y	1	Y

Note: BPL = Bus Priority Lanes, BRT = Bus Rapid Transit, DAP = Dummy Alternative Project, RWM = Railway Modernization, Y = Yes, N = No.
Source: Author

Table 7.16 indicates that the preference ranking and implementation feasibility of the alternative projects vary with the weights assigned to monetizable and non-monetizable benefit clusters. It shows that BRT is the most preferred alternative project for the range of 100:0 to 10:90 of monetizable benefits: non-monetizable benefits. From there onwards, i.e., 10:90 to 0:100, BPL turns to the most preferred alternative project making BRT is the second best. In fact, BPL is the least preferred when only 100% of monetizable benefits are counted. Before it turns to the most preferred, it surpasses RWM in ranking when the share for non-monetizable benefits is increased up to 20%. In terms of the implementation feasibility of alternative projects, BRT is the only feasible alternative project when 100% of monetizable benefits are considered. But when reaching to 60:40 weight ratio for monetizable benefit: non-monetizable benefit clusters, all the alternative projects are turned to feasible and remain feasible for all other leading combinations.

The preference ranking and implementation feasibility of alternative projects at two extreme cases of 100% monetizable benefits and 100% non-monetizable benefits are summarized below.

1. When only 100% monetizable benefits are counted, the most preferred alternative is BRT while RWM and BPL are the second and third preferred respectively. Only BRT is feasible for implementation.

2. When only 100% non-monetizable benefits are counted, the most preferred alternative is BPL while BRT and RWM are the second and third preferred respectively. All three alternatives are feasible for implementation.

The above demonstrates the application of the CEP to evaluate alternative projects. In this case, only the most preferred feasible alternative at corresponding benefit cluster weight ratio is chosen to implement. But this new process is equally applicable for evaluating independent projects to choose several of them to implement simultaneously, if feasible (refer Section 6.5). The application of the CEP to evaluate such independent projects is discussed below (Section 7.6) using several selected project roads under the Second Integrated Road Investment Program (iRoad 2) in Sri Lanka.

7.6 Evaluating Independent Projects by Using CEP

By using the CBA, the iRoad 2 has evaluated four project roads of (i) G032: Horagolla – Makilangamuwa Road, (ii) G122: Nalla Road, (iii) G217: Madagama – Halpe Road, and (iv) G221: Nawana – Diyagampola Road (Road Development Authority, 2017). The results of this evaluation suggest that only G032 and G217 are feasible for implementation as their B/C ratios are above the unity. However, this analysis has considered only the monetizable benefits of vehicle operating cost savings, travel time cost savings, and non-motorized cost savings. It has not considered the non-monetizable benefits accruing due to agricultural developments, industrial developments, and social developments, although these roads are located in rural areas. Therefore, the above four roads were reevaluated by using the CEP, considering both monetizable and non-monetizable benefits mentioned above. A detailed demonstration of this reevaluation is given in Appendix 4 while a summary of results in terms of projects' preference ranking and implementation feasibility is presented in Table 7.17.

Table 7.17: Evaluation decisions at different benefit cluster weight ratios (iRoad 2)

Project Roads	Monetizable Benefits: Non-Monetizable Benefits																					
	100:0		90:10		80:20		70:30		60:40		50:50		40:60		30:70		20:80		10:90		0:100	
	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?
G032	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y
G122	4	N	4	N	4	N	4	N	4	Y	4	Y	3	Y	2	Y	2	Y	2	Y	2	Y
G217	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	3	Y	4	Y	4	Y	4	Y
G221	3	N	3	N	3	Y	3	Y	3	Y	3	Y	4	Y	4	Y	3	Y	3	Y	3	Y

Note: Y = Yes, N = No.
Source: Author

Table 7.17 indicates that both G032 and G217 are feasible to implement at all combinations of monetizable and non-monetizable benefit cluster weights. This aligns with the evaluation decisions taken based on the CBA results. Out of the remaining two roads, G221 becomes feasible for implementation when its non-monetizable benefit share equal to or above 20% in monetizable: non-monetizable benefit cluster weight ratio. The other remaining road, G122, becomes feasible for implementation when its non-monetizable benefit share equal to or above 40% in the above-mentioned ratio. Therefore the inclusion of G221 and G122 in the project implementation program should be reconsidered depending on the agreeable weight ratio for benefit clusters and the fund availability. When no agreement is sorted to the said cluster weights but yet keen to count non-monetizable benefits, the CEP suggests implementing all project roads as all of them are deriving Universal Scores above the corresponding feasibility threshold.

7.7 Validation of Comprehensive Evaluation Process

The new evaluation process, the CEP, is formed gradually aggregating fundamental concepts, theories, and methods already in use for transport project evaluation. In this aggregation of existing substances, rationality, transparency, and clarity are ensured through detailed illustrations and appropriate reasoning. Issues that could not be sorted out in developing this new process were clearly stated and presented as limitations in the next chapter (Chapter 8) to avoid misapplication of the process.

The common practice for validating an evaluation process of this nature is to compare its results with the results of another process that is already accepted in practice. The currently available suitable process for the afore-mentioned comparison is the conventional CBA. But, such a comparison has to be made under a constrained scenario, as CBA can count only monetizable impacts, whereas the new process can count both monetizable and non-monetizable impacts as its inputs. Thus, for ensuring comparability, results of the CEP calculated only in the presence of monetizable benefits are compared with the results of CBA in Table 7.18. Results of CBA are as per Table 7.1, while corresponding results of the CEP (only monetizable benefits included) are as per Table 7.15.

Table 7.18: Comparison of results from CBA and CEP

Alternatives	**CBA Results**			**CEP Results (monetizable benefits only)**		
	B/C Ratio	**Rank**	**Feasible?**	**IS (100:0)**	**Rank**	**Feasible?**
Railway Modernization	0.59	2	No	0.422	2	No
Bus Rapid Transit	1.23	1	Yes	0.669	1	Yes
Bus Priority Lanes	0.31	3	No	0.368	3	No
Dummy alternative	1.00	-	-	0.466	-	-

Note: CBA= Cost-Benefit Analysis, CEP = Comprehensive Evaluation Process, IS = Isolated Score.
Source: Author

The comparison given in Table 7.18 shows that both CBA and CEP rank alternative projects in the same order while declaring BRT as the only alternative feasible for implementation. Thus, it is evident that the CEP draws results compatible with the CBA in terms of ranking alternative projects and their status of implementation feasibility. Such compatibility in results provides an acceptable validation to the new evaluation process, the CEP. However, it is noted that relative differences among the Isolated Scores are not consistent with the corresponding differences in B/C ratios. These differences are mainly due to (i) the marginal inconsistencies in the pairwise comparison used for the benefit valuation in the BVM and (ii) assumptions used for calculating parameters in both processes.

The supplementary demonstration in Appendix 4 also confirms the comparability of results derived from the CBA and the CEP when only monetizable benefits are counted. Thus, it also ascertains the above validation.

7.8 Using CEP Only for Prioritizing Projects

The demonstration presented above explained how to use the CEP for prioritizing (ranking) projects as well as testing their implementation feasibility. The requirement of testing the implementation feasibility of the projects demanded to incorporate several methodological adjustments, including adding a dummy project and rank preservation technique for the BVM and the FVM (refer Chapter 6). But, those adjustments can be ignored if the CEP is only used for prioritizing projects.

7.9 Summary

This chapter demonstrates the application procedure of the CEP by using it to evaluate an actual transport project. The demonstration was carried out for two scenarios: first, it explained the application of the CEP when the decision-makers agree to a specific weight ratio for monetizable and non-monetizable benefit clusters, and second when there is no agreement among the decision-makers on the aforesaid ratio. In both cases of the application, derived results were used to determine the preference ranking and feasibility status of the projects considered in the evaluation. Those results were compared with the results obtained from CBA for the same evaluation problem under appropriate limitations to validate the CEP.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This chapter provides conclusions on (i) the achievement in the research aim and the objectives and (ii) contribution to the knowledge, detailing the significance and limitation of the CEP. In addition, the chapter provides recommendations to be followed when applying the CEP to evaluate transport projects. Those recommendations are scrutinized to identify future research opportunities.

8.2 Conclusions

8.2.1 Achievement of Research Aim

As stipulated in Section 1.4, this research aimed to develop a new process for the evaluation of transport projects which is capable of ensuring

(i) **Input-completeness** by taking all identified impacts, including both tangible and intangible (or monetizable and non-monetizable) impacts, into account as evaluation inputs, and

(ii) **Result-completeness** by producing results usable for testing the implementation feasibility of each individual project evaluated and enable their performance-based prioritization.

Moreover, the research aim also emphasized ensuring transparency, simplicity, robustness, and accountability in the new process as much as possible.

The achievement of the afore-mentioned research aim in terms of its targeted features is assessed below.

(i) Ability to incorporate all identified impacts, both tangible and intangible (or monetizable and non-monetizable) impacts, into account as evaluation inputs: The ability to incorporate all identified impacts of transport project into the CEP depends on (a) the ability of CVM and BVM to valuate costs and benefits (inputs) to produce total cost and benefit criteria values respectively for each project and (b) the ability of FVM to synthesize afore-said criteria values to reach a single score for each evaluated project. The latter related to the FVM has been ensured by adopting the TOPSIS which is already proven its effectiveness in the synthesis of valued costs and benefits. Thus, the former, valuating costs in the CVM and benefits in the BVM, becomes the primary determinant in ensuring the input-completeness in the CEP.

The CVM has been restricted only for the monetizable costs by its definition (refer Section 5.3), and hence there are no concerns over valuating its inputs. Meantime, the BVM, which has both kinds of inputs, monetizable and non-monetizable benefits, has adequately demonstrated its ability to valuate and synthesize them by using ANP as its evaluation tool. ANP is a powerful and sophisticated tool currently available for the anticipated task in the BVM. However, there are two concerns over input processing in the BVM. Those concerns are raised due to subjectivity-related issues incurred when assigning weights for the benefit clusters and probable mutual inclusiveness of the benefit criteria included in those clusters. The former of those concerns primarily incurred due to irrationality, arbitrariness, and biases in decision making, is recommended to minimize adopting Scenario 2 of the CEP while the latter incurred when mapping the evaluation problem into ANP platform is through the way of defining criteria (refer Section 5.4).

All in all, it can be concluded that the ability to incorporate both monetizable and non-monetizable (or tangible and intangible) impacts as evaluation inputs has been ensured satisfactorily in the new evaluation process.

(ii) Ability to produce results usable for testing implementation feasibility of each project evaluated and enable their performance-based prioritization: The CEP, primarily developed to prioritize transport projects, is used under two scenarios where the decision-makers are (i) in agreement on the benefit cluster weights in the BVM (Scenario 1) and (ii) no agreement on the benefit cluster weights in the BVM (Scenario 2). Scenario 1 adopts a specific agreed benefit cluster weight combination in the BVM, while Scenario 2 considers the whole range of benefit cluster weight combinations. Out of two scenarios, Scenario 2 has been able to eliminate subjectivity issues arising when assigning weights for the monetizable and non-monetizable benefit clusters in the BVM. It is also adoptable when the decision-makers agree to a specific range of weight combinations for monetizable and non-monetizable clusters in the BVM. Considering all these facts, Scenario 2 appears as the most appropriate form to use in the evaluation of transport projects. However, both scenarios show a strong ability to prioritize projects based on their performances despite several limitations indicated in Sub-section 8.2.3.2.

The application of the CEP is further extended to test the implementation feasibility of the evaluated projects, in addition to using it for the prioritization of evaluated projects. When using the CEP to test the implementation feasibility, necessary trials and changes are needed to adopt for preserving ranks in ANP based BVM and TOPSIS based FVM, respectively.

(iii) Characterizing new process with transparency, simplicity, robustness, and accountability: The demonstration in Chapter 7 shows that the CEP is more transparent in its execution and robust in results compared to CBA and MCA-based other evaluation processes. The execution of the CEP becomes more transparent as it is explainable step-wise rationally and generating necessary parameters within the process such as threshold value for testing implementation feasibility. Although the CEP also requires external parameters such as residual value, shadow wage rate factor, shadow exchange factor, and country-specific discount rate value like in CBA, their precision level is not as important as in their use for CBA. Further, stakeholder participation also helps to improve the transparency in executing the CEP as well as the accountability of results. These results are comparatively robust as they are generated counting all identified project impacts.

While developing the new process, all possible efforts were made to ensure its simplicity. Using a customized version of ANP in BVM has reduced the complexity of calculation, which is normally associated with full-fledged ANP. Such introduced customization is (i) mapping evaluation problem only using three clusters, and (ii) avoiding dependencies among benefit criteria by defining them as mutually exclusive (refer Section 5.4). In addition, the new process becomes simpler as it counts expert’s judgement in estimating non-monetizable benefits instead of qualitative assessment which normally requires extensive data collection and analysis. Even though the expert's judgements should also be supported with data analysis to ensure their accuracy, the necessity of data for such an attempt is minimal compared to a qualitative assessment. Moreover, not requiring to estimate external parameters such as discount rates, and residual value, etc. precisely also simplifies the application of this new process.

The above brief assessment shows that the new process formulated in this research for transport project evaluation (CEP) is competent enough to achieve originally set features in the research aim. Thus, it can be concluded that the research has successfully achieved its set research aim in Section 1.4.

8.2.2 Achievement of Research Objectives

Achievements of the research objectives which are generated in Section 1.7 to realize the stipulated research aim in Section 1.4 responding to research questions in Section 1.6 are briefly assessed below:

Responding to Research Question 1 (RQ1), R**esearch Objective 1 (RO1)** was formed to critically review currently available transport project evaluation practices and thereby to identify the best practices and their weaknesses requiring improvements. This objective was achieved by reviewing the literature on historical and current practices of transport project evaluation in Chapter 2. This review identified the weaknesses of existing evaluation processes and eventually presented necessary improvements. In the same chapter, such identified weaknesses and necessary improvements were filtered in line with the research aim and its significance to arrest the weaknesses and improvements to be treated in this research. This task accomplished **Research Objective 2 (RO2)** responding to Research Question 2 (RQ2).

Research Objective 3 (RO3), development of the new process for transport project evaluation, eliminating the identified weaknesses in the current practices and complying with the set research aim and its significance, was successfully achieved in Chapter 4, 5, and 6 responding to the Research Question 3 (RQ3). While developing this new evaluation process, the necessity of gathering additional conceptual and theoretical knowledge was raised. Thus, simultaneous to the development of the new evaluation process, such required additional knowledge was identified and gathered through a literature review.

The **final research objective, Objective 4 (RO4),** was formed to demonstrate the application and validation of the new evaluation process through a casestudy responding to Research Question 4 (RQ4). This objective was executed in Chapter 7 by applying the CEP to an actual transport project evaluation problem. The results obtained in this application were compared with corresponding CBA's results and thereby validated the CEP rationally justifying the deviations.

The above assessment proves that this research has successfully achieved all its individual research objectives set at the beginning.

8.2.3 Contribution to the Knowledge

This research produces a new process for evaluating transport projects incorporating features highlighted in the research aim. Thus, the contribution of this research to the knowledge depends on the significance of the said new evaluation process compared to the existing ones. The following sub-sections first demonstrate the significance of the new evaluation process and then highlight its limitations for precisely setting up its application boundaries.

8.2.3.1 Significance of the Comprehensive Evaluation Process

The significance of the new evaluation process (CEP) is assessed alongside the set research aim (refer Section 1.4) and gaps identified in the literature for transport project evaluation (refer Section 2.5). This new process becomes significant compared to the existing similar-kind processes for transport project evaluation due to the following distinct reasons;

1. In contrast to the existing popular processes such as the CBA, the CEP can take multiple impacts, including both monetizable and non-monetizable impacts, as well as multiple stakeholder opinions into account in its application. The CBA only considers monetizable impacts and hardly incorporates stakeholder opinions. The ability of this new process to incorporate both monetizable and non-monetizable impacts improves the comprehensiveness of the evaluation. On the other hand, it is very important to count different stakeholder opinions in an evaluation process as it makes all stakeholders responsible for the evaluation decisions leading to a speedy implementation of the project. All in all, the ability of the CEP to incorporate multiple impacts and stakeholder opinions lead to categorizing this process as a Multi-Actor Multi-Criteria Analysis.

2. The latest popular trend in developing transport project evaluation processes is to composite two MCA techniques, most probably one of them being the CBA. This new process also has followed the same trend, but it has advanced to have the essence of three MCA techniques of ANP, TOPSIS, and CBA. Hence its category can be promoted to Multi-Staged Multi-Actor Multi-Criteria Analysis. In the literature, there is no other evaluation process covering such three dimensions in transport project evaluation. Hence this evaluation process is likely to be the first of that caliber.

3. Two MCA techniques used in this process, ANP and TOPSIS, potentially minimize the common issues of MCAs such as subjectivity, arbitrariness, and double counting effects. By adopting these techniques in developing the new process, their optimistic features mentioned above are inevitably in-built into the CEP. Moreover, the manner that these MCA techniques have been used in this new process has enhanced the level of clarity of results and transparency of the process as described in Chapter 4, 5, and 6. These improved characteristics in-built in the CEP are hardly visible in other available evaluation processes, especially as one single package.

4. Many shortcomings associated with existing MCA based evaluation processes are raised due to (i) irrational nature in grouping of costs and benefits and (ii) arbitrary nature in assigning weights to them. The evaluation process presented herein has sorted out the former by distinctly separating impacts as costs and benefits first and then as monetizable and non-monetizable in line with adopted clear definitions. The latter has been rationalized by incorporating a technique of multi-stakeholder participatory pairwise comparison in the evaluation process.

5. The evaluation process presented in this thesis was developed for the transport projects. Its specific relevance to the evaluation of transport projects is assured since transport projects generate almost the same benefit categories allowing to evaluate projects compared to the same set of criteria, as demanded in the BVM. Those benefits are being definable mutually exclusive and group-able rationally further improves the relevance of this process to the transport projects (refer Section 5.4). In addition, the generality of non-monetizable benefits of the transport projects enables the pairwise comparison with personal judgments in the BVM. Nevertheless, its applicability to evaluate other kinds of projects, particularly infrastructure projects, is likely possible though it was not tested in this thesis. The literature review shows that many evaluation processes initially developed for transport projects evolved to evaluate other infrastructure projects later. The best example is the CBA (Sandmo, 2011).

8.2.3.2 Limitations of the Comprehensive Evaluation Process

The new process presented in this thesis has its own limitations in application to solve transport project evaluation problems. Those identified limitations are summarized below together with alternative approaches to avoid/minimize them.

1. In transport project evaluation, it is a common practice to define projects to be evaluated at the beginning of the evaluation process. In MCA based processes, pre-defining projects becomes a ‘must’ unless rank preservation techniques

have not been incorporated. Even if the CEP has been incorporated rank preservation techniques, it is still recommended to define the evaluating projects at the beginning of the evaluation since adding a new project or removing an existing project later may cause to change the costs and benefits values associated with 'the dummy project' designed for feasibility test (refer Section 6.2). If the CEP is to use only for prioritizing projects without using for testing their feasibility, there is a possibility to add a new project or remove an existing project later from the domain when the rank preservation techniques are incorporated. However, considering the complexity in applying the CEP when the rank preservation techniques are incorporated, even in such instances defining evaluating projects at the beginning is recommended eliminating the necessity of incorporating rank preservation techniques. All in all, defining all evaluating projects at the beginning of the evaluation is recommended for the CEP.

2. The results generated through the CEP, in the form of Isolated Scores or Universal Scores, are specific to the evaluation domain that they were derived. Thus, results generated in two different evaluation domains cannot be comparable (refer Section 6.5). In other words, the results generated through the CEP are not absolute comparable but only relatively comparable.

3. The CEP is highly recommendable for prioritization (or ranking) the projects in terms of their performances. However, it has limitations when using for assessing the implementation feasibility of the projects. As described in Sub-section 6.2.1, the implementation feasibility of an evaluated project can be assessed, with respect to a derived threshold Isolated or Universal Score, if and only if that particular project generates positive benefits for all elements in the non-monetizable benefit cluster. Moreover, the Isolated or Universal Score of a given project does not indicate the size and the rate of return of investment, similar to the corresponding indicators of the net present value and the internal rate of return in the conventional CBA.

4. The CEP encourages to define mutually exclusive impacts (or criteria) in the monetizable and non-monetizable clusters in the BVM to eliminate inner dependencies among the criteria included in the same cluster and outer dependencies among the criteria included in the different clusters (refer Section 5.4). Such an approach will simplify the analysis though it slightly weakens the actual representation of the evaluation problem in the evaluation platform.

5. The CEP encourages defining each criterion in the BVM to have a relationship with each evaluating project under consideration. Such tidy connectivity between criteria and evaluating projects will ensure the fairness of the evaluation by making the same criteria reference for all projects considered (refer Section 5.4).

6. This new evaluation process is resilient against many common drawbacks, including double counting and arbitrariness associated with similar kind of MCA based processes. But this process has not been able to deal strongly with subjectivity related concerns, which are predominantly raised due to (i) the assignment of weights for monetizable and non-monetizable benefit clusters in the agreement of decision-makers and (ii) the pairwise comparison adopted in the BVM in valuating benefit criteria values for the evaluating projects. The former can be eliminated by using Scenario 2 of the CEP, but the latter still remains as a concern. However, subjectivity associated with the pairwise comparisons has been minimized by closely monitoring their consistencies (refer Sub-section 4.4.2.3).

7. In line with the common practice, this thesis expects the prioritization of evaluating projects would be based on the credibility of their performances. That is to say that the higher performance rankers would be selected for the implementation. However, there is a debate applying this general rule when selecting projects that are constrained by the availability of funds. In such cases, certain projects with higher costs may have to be eliminated despite their

higher rank for accommodating slightly lower-ranked projects with comparatively low costs from the perspective of effective fund utilization.

8. In this new evaluation process, the futuristic effects of the non-monetizable impacts are based on the judgment of the decision-makers (refer Section 5.4). Thus it involves a certain degree of uncertainty.

9. Assessment of benefit distribution effect is not possible with this new process, although it is identified as a gap in existing evaluation processes. As such, it remains as a shortcoming of this process too, as in the case of all other processes available for transport project evaluation, including CBA.

10. Since this new evaluation process uses available theories, concepts, and methods, including the essence of CBA and MCA techniques, their in-built conceptual and theoretical flaws are reflected in this new process also.

8.3 Recommendations

The recommendations provided here emphasize critical aspects that are needed to take into account when applying the CEP to evaluate transport projects in line with its significance and limitations. Besides those, recommendations are also provided for future research, particularly to improve the application of this new process.

Key aspects that are recommended to consider when applying the new process to evaluate transport projects are as follows:

1. Use the new evaluation process to evaluate projects which are assembled in a single evaluation domain,

2. Define all evaluating projects at the beginning of the evaluation process,

3. Define criteria for evaluating projects as they are mutually exclusive,

4. Conduct a proper awareness program for the decision-makers on key aspects of the pairwise comparison before they get involved in the evaluation process, and

5. Use this process for testing the implementation feasibility of evaluating projects if the positivity of all non-monetizable benefits is assured.

In the CEP, several key limitations require attention in future research. These limitations are related to the testing implementation feasibility of the projects. They are CEP's inability to (i) take negative non-monetizable benefits into account and (ii) demonstrate the size and rate of return of the investment. Besides those, developing an appropriate rank preservation method for the BVM, precisely for ANP, is also required to make the feasibility test applicable in all circumstances.

In addition, future research is also required to develop a rationalized scientific approach for predicting the future effect of non-monetizable benefits. In this thesis, the recommended practice for this prediction is the judgment of the decision-makers (refer Section 5.4). Finally, the development of a computer application for the CEP is also proposed as a part of future research.

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APPENDIX 1

PAIRWISE COMPARISONS - ALTENATIVES AND MONETIZABLE CRITERIA

This appendix presents the pairwise comparisons (judgment matrices) for alternatives with respect to monetizable criteria and viceversa

Alternatives	**UCS**	**ACS**	**ECS**	**Total**
Rail	22,934	1,100	1,180	25,214
BRT	26,477	814	1,202	28,493
BPL	5,000	610	100	5,710
DAP	18,137	841	827	19,806

Alternatives with respect to Monetizable Criteria

1. Alternatives with respect to UCS

	Rail	BRT	BPL	DAP
Rail	1	1/2	6	2
BRT	2	1	7	3
BPL	1/6	1/7	1	1/5
DAP	1/2	1/3	5	1

Consitency Ratio: 2.2%

2. Alternatives with repect to ACS

	Rail	BRT	BPL	DAP
Rail	1	4	7	4
BRT	1/4	1	3	1
BPL	1/7	1/3	1	1/2
DAP	1/4	1	2	1

Consitency Ratio: 1.5%

3. Alternatives with respect to ECS

	Rail	BRT	BPL	DAP
Rail	1	1	9	3
BRT	1	1	9	3
BPL	1/9	1/9	1	1/4
DAP	1/3	1/3	4	1

Consitency Ratio: 1.0%

Monetizable Criteria with respect to Alternatives

1. Monetizable Criteria with respect to Rail

	UCS	ACS	ECS
UCS	1	9	8
ACS	1/9	1	1
ECS	1/8	1	1

Consitency Ratio: 2.0%

2. Monetizable Criteria with respect to BRT

	UCS	ACS	ECS
UCS	1	9	6
ACS	1/9	1	1/2
ECS	1/6	2	1

Consitency Ratio: 0.5%

3. Monetizable Criteria with respect to BPL

	UCS	ACS	ECS
UCS	1	7	9
ACS	1/7	1	2
ECS	1/9	1/2	1

Consitency Ratio: 2.5%

Abbreviations:

ACS = Accident cost savings; BPL = Bus Priority Lanes; BRT = Bus Rapid Transit; DAP = Dummy Alternative Project; ECS = Emission Cost Savings; Rail = Railway improvement; UCS = User cost savings

APPENDIX 2

PAIRWISE COMPARISONS - ALTENATIVES AND NON-MONETIZABLE CRITERIA

This appendix presents the pair-wise comparisons (judgment matrices) for altenatives with respect to non-monetizable criteria and viceversa. Each matrix given below is prepared by averaging corresponding judgement matrices of involved experts

Alternatives with respect to Non-Monetizable Criteria

1. Alternatives with respect to Comfort

	Rail	BRT	BPL
Rail	1	1/3	2
BRT	3	1	6
BPL	1/2	1/6	1

Consitency Ratio: 0.2%

2. Alternatives with repect to Reliability

	Rail	BRT	BPL
Rail	1	1/5	1
BRT	5	1	5
BPL	1	1/5	1

Consitency Ratio: 0.3%

3. Alternatives with respect to Affordability

	Rail	BRT	BPL
Rail	1	5	1/2
BRT	1/5	1	1/8
BPL	2	8	1

Consitency Ratio: 0.8%

Non-Monetizable Criteria with respect to Alternatives

1. Non-Monetizable Criteria with respect to Rail

	Comfort	Reliability	Affordability
Comfort	1	2	1/5
Reliability	1/2	1	1/7
Affordability	5	7	1

Consitency Ratio: 1.9%

2. Non-Monetizable Criteria with repect to BRT

	Comfort	Reliability	Affordability
Comfort	1	1	9
Reliability	1	1	7
Affordability	1/9	1/7	1

Consitency Ratio: 1.0%

3. Non-Monetizable Criteria with respect to BPL

	Comfort	Reliability	Affordability
Comfort	1	1/2	1/8
Reliability	2	1	1/5
Affordability	8	5	1

Consitency Ratio: 1.1%

Abbreviations:

BPL = Bus Priority Lanes; BRT = Bus Rapid Transit; Rail = Railway improvement

APPENDIX 3

NORMALIZED GLOGAL PRIRORITY VALUES AT DIFFERENT BENEFIT CUSTER WEIGHTS

This appendix presents the normalized Global Priority Values (or shares of benefits) at different benefit cluster weights for the case 'without dummy project'

Table 3A-1: Normalized GPVs (%) at different combinations of benefit cluster weights (without Dummy Alternative Project)

Alternatives	Monetizable: Non-System Monetizable										
	100:0	**90:10**	**80:20**	**70:30**	**60:40**	**50:50**	**40:60**	**30:70**	**20:80**	**10:90**	**0:100**
RWM	39.5	38.0	36.4	34.9	33.4	32.0	30.5	29.1	27.7	26.3	25.1
BRT	53.6	52.7	51.8	50.8	49.7	48.4	47.1	45.5	43.8	41.9	39.6
BPL	6.9	9.3	11.7	14.3	16.9	19.6	22.4	25.4	28.5	31.8	35.3

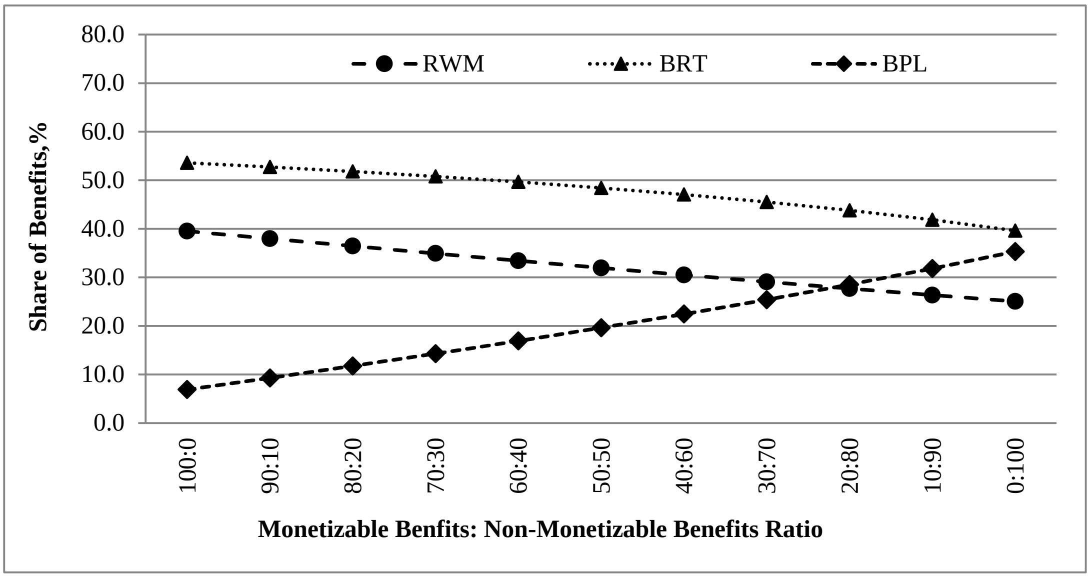

Figure 3A-1: Benefit share of alternative projects at different combinations of benefit cluster weights (without Dummy Alternative Project)

Abbreviations:
BPL = Bus Priority Lanes; BRT = Bus Rapid Transit; RWM = Railway Modernization

APPENDIX 4

SUPPLEMENTARY DEMONSTRATION

This Appendix briefly demonstrates the application of the CEP to evaluate several independent project roads which were already evaluated using the CBA under the Second Integrated Road Investment Program (iRoad 2) in 2017. The B/C ratios, costs, and benefits estimated for each project road under the evaluation of iRoad 2 are summarized in Table A4-1.

Table A4-1: Benefits, costs, and results of CBA as per iRoad 2 evaluation

Project Roads	Project Benefits (Monetizable), SLRs million			Project Cost[a], SLRs million	B/C Ratio	Rank
	Vehicle Operating Cost Savings	Travel Time Cost Saving	Non-Motorized Cost Saving			
G032: Horagolla - Makilangamuwa Road	27.72	33.63	1.01	44.2	1.41	1
G122: Nalla Road	8.28	7.8	0.59	45.3	0.37	4
G217: Madagama – Halpe Road	21.03	25.14	0.46	37.9	1.23	2
G221: Nawana – Diyagampola Road	14.84	17.84	0.19	38.5	0.85	3

Note: [a] Project cost is an aggregation of present values of construction, maintenance, and operation costs.
SLRs = Sri Lankan Rupees
Source: Road Development Authority, 2016.

The above analysis only takes monetizable benefits into account. But since these roads are located in rural areas, considering non-monetizable benefits such as agricultural, industrial, and social developments in the evaluation is important. Thus, the same four roads were reevaluated by using the CEP following the procedure described in Chapter 7 and using the results of pairwise comparisons given in Annex A4-1 and A4-2. In this evaluation, the benefits accruing to the project roads from the non-monetizable benefit components of agricultural developments, industrial developments, and social developments were considered in addition to already considered monetizable benefits of vehicle operating cost savings, travel time cost savings, and non-motorized cost savings. Moreover, a dummy project road (DPR) with an equal cost and benefit value of SLRs 41.9 million was also introduced to the evaluation domain to determine the feasibility threshold value for the evaluation domain (refer Chapter 6).

Table A4-2 and Figure A4-1 present the results of the CEP in terms of derived isolated scores at different combinations of monetizable and non-monetizable benefit cluster weights.

Table A4-2: Isolated Scores of project roads at different benefit cluster weight ratios

Project Roads	**Monetizable Benefits: Non-Monetizable Benefits**										
	100:0	**90:10**	**80:20**	**70:30**	**60:40**	**50:50**	**40:60**	**30:70**	**20:80**	**10:90**	**0:100**
G032	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506	0.506
G122	0.061	0.095	0.131	0.169	0.209	0.252	0.297	0.345	0.394	0.443	0.490
G217	0.348	0.340	0.333	0.326	0.320	0.315	0.310	0.306	0.303	0.301	0.301
G221	0.165	0.181	0.197	0.214	0.233	0.252	0.273	0.296	0.321	0.347	0.376
DPR	0.223	0.207	0.190	0.173	0.155	0.137	0.118	0.098	0.078	0.061	0.045

Source: Author

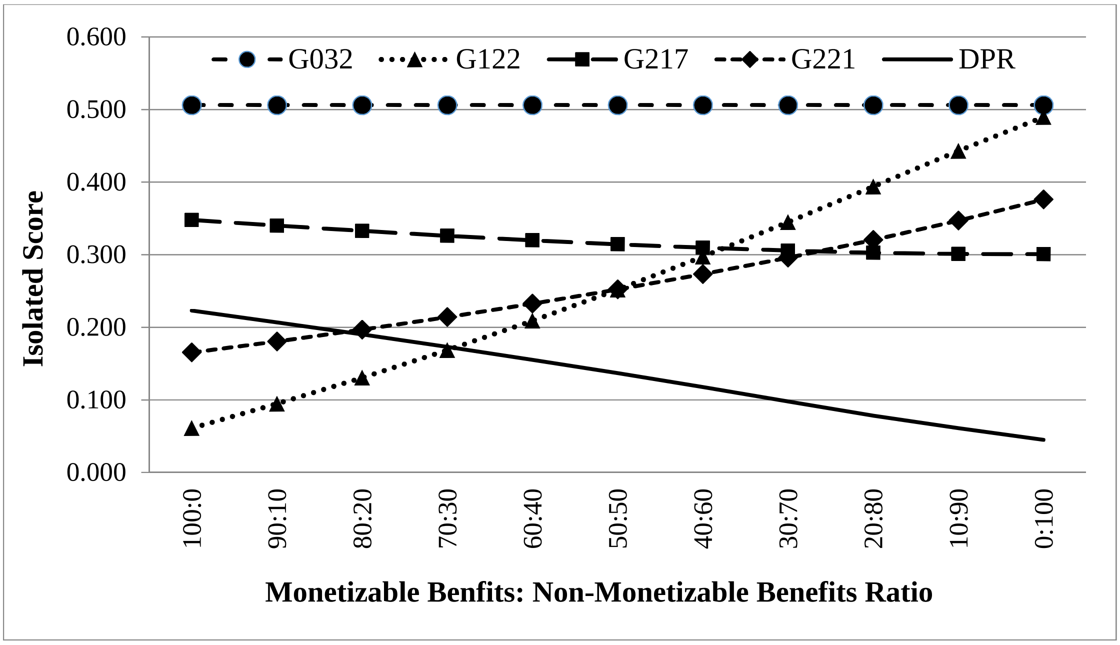

Figure A4-1: Isolated Scores of project roads at different benefit cluster weight ratios

Source: Author

Based on the above results of the CEP, Table A4-3 presents the preference ranking and implementation feasibility of project roads at different benefit cluster weight ratios.

Table A4-3: Preference ranking and implementation feasibility of project roads at different benefit cluster weight ratios

Project Roads	**Monetizable Benefits: Non-Monetizable Benefits**																					
	100:0		**90:10**		**80:20**		**70:30**		**60:40**		**50:50**		**40:60**		**30:70**		**20:80**		**10:90**		**0:100**	
	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?	Rank	Feasible?
G032	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y
G122	4	N	4	N	4	N	4	N	4	Y	4	Y	3	Y	2	Y	2	Y	2	Y	2	Y
G217	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	3	Y	4	Y	4	Y	4	Y
G221	3	N	3	N	3	Y	3	Y	3	Y	3	Y	4	Y	4	Y	3	Y	3	Y	3	Y

Note: Y = Yes, N = No.
Source: Author

Table A4-3 indicates that G032 is the most preferred project road to implement as it holds the 1st in the ranking and remains feasible for all combinations of monetizable and non-monetizable benefit cluster weights. The other three projects interchange their positions in the preference order and switch implementation feasibility status responding to varying weights assigned to monetizable and non-monetizable benefit clusters as shown in Table A4-3. The preference ranking and implementation feasibility of the project roads at two extreme cases of 100% monetizable benefits and 100% non-monetizable benefits are summarized below.

1. When only 100% monetizable benefits are counted, the most preferred project road to implement is G032. G217, G221, and G122 hold the second, third, and fourth places in the preference order respectively. At this combination of benefit cluster weights, only G032 and G217 are feasible for implementation. These results are also in conformity with CBA results presented in Table A4-1 as they should be. Table A4-4 presents the said comparison of results of two processes.

Table A4-4: Comparison of results from CBA and CEP (Only monetizable benefits)

Project Roads	**CBA Results**			**CEP Results**		
	B/C Ratio	**Rank**	**Feasible?**	**IS (100:0)**	**Rank**	**Feasible?**
G032	1.41	1	Yes	0.506	1	Yes
G122	0.37	4	No	0.061	4	No
G217	1.23	2	Yes	0.348	2	Yes
G221	0.85	3	No	0.165	3	No
DPR	1.41	-	-	0.223	-	-

Note: CBA= Cost-Benefit Analysis, CEP = Comprehensive Evaluation Process, IS = Isolated Score.
Source: Author

2. When only 100% non-monetizable benefits are counted, G032 still remains as the most preferred while G122, G221, and G217 occupy the second, third, and fourth places in the preference order respectively. At this combination of benefit cluster weights, all four roads are feasible for implementation.

When there is no agreement on benefit cluster weights among the decision-makers, the Universal Scores (US) are derived considering the whole spectrum of benefit cluster weight ratios for determining the implementation preference order and feasibility status of the project roads. Such derived Universal Scores are as follows.

US_{G032}=0.506, US_{G122}= 0.274, US_{G217}= 0.322, US_{G221}= 0.265, and US_{DPR}= 0.130

Under this scenario, scores suggest that all four project roads are feasible to implement as their scores are above the same of DPR. Moreover, project roads from the most preferred to the least preferred are in the order of G032, G217, G122, and G221.

Since these are independent projects, they can be implemented simultaneously, choosing the top-most feasible project roads in the preference order, if adequate funds are available.

Annex 4A-1: Pairwise Comparisons - Project Roads and Monetizable Criteria

This annex presents the pairwise comparisons (judgment matrices) for project roads with respect to monetizable criteria and viceversa

Roads	VOCS	TTCS	NMTS	Total
G032	27.7	33.6	1.0	62.4
G122	8.3	7.8	0.6	16.7
G217	21.0	25.1	0.5	46.6
G221	14.8	17.8	0.2	32.9
DPR	19.0	22.2	0.7	41.9

Project Roads with respect to Monetizable Criteria

1. Project roads with respect to VOCS

	G032	G122	G217	G221	DPR
G032	1	8	2	5	3
G122	1/8	1	1/7	1/3	1/5
G217	1/2	7	1	3	2
G221	1/5	3	1/3	1	1/2
DPR	1/3	5	1/2	2	1

Consitency Ratio: 1.0%

2. Project roads with repect to TTCS

	G032	G122	G217	G221	DPR
G032	1	9	3	5	4
G122	1/9	1	1/7	1/3	1/5
G217	1/3	7	1	3	2
G221	1/5	3	1/3	1	1/2
DPR	1/4	5	1/2	2	1

Consitency Ratio: 2.4%

3. Project roads with respect to NMTS

	G032	G122	G217	G221	DPR
G032	1	4	5	9	3
G122	1/4	1	2	3	1/2
G217	1/5	1/2	1	2	1/2
G221	1/9	1/3	1/2	1	1/4
DPR	1/3	2	2	4	1

Consitency Ratio: 1.2%

Monetizable Criteria with respect to Project Roads

1. Monetizable Criteria with respect to G032

	VOCS	TTCS	NMTS
VOCS	1	1/2	6
TTCS	2	1	9
NMTS	1/6	1/9	1

Consitency Ratio: 0.9%

2. Monetizable Criteria with respect to G122

	VOCS	TTCS	NMTS
VOCS	1	2	9
TTCS	1/2	1	7
NMTS	1/9	1/7	1

Consitency Ratio: 2.1%

3. Monetizable Criteria with respect to G217

	VOCS	TTCS	NMTS
VOCS	1	1/2	7
TTCS	2	1	9
NMTS	1/7	1/9	1

Consitency Ratio: 2.1%

4. Monetizable Criteria with respect to G221

	VOCS	TTCS	NMTS
VOCS	1	1/2	7
TTCS	2	1	9
NMTS	1/7	1/9	1

Consitency Ratio: 2.1%

Abbreviations:

NMTS =Non-motorized transport cost savings;TTCS = Travel time cost savings; VOCS = Vehicle operating cost savings; DPR = Dummy project road

Annex 4A-2: Pairwise Comparisons - Project Roads and Non-Monetizable Criteria

This annex presents the pairwise comparisons (judgment matrices) for the project roads with respect to non-monetizable criteria and viceversa. Each matrix given below is prepared by averaging corresponding judgement matrices of the involved experts

Project roads with respect to Non-monetizable Criteria

1. Project roads with respect to agricultural developments

	G032	G122	G217	G221
G032	1	1/7	1/3	1/2
G122	7	1	3	4
G217	3	1/3	1	2
G221	2	1/4	1/2	1

Consitency Ratio: 0.8%

2. Project roads with repect to industrial developments

	G032	G122	G217	G221
G032	1	8	5	3
G122	1/8	1	1/3	1/5
G217	1/5	3	1	1/2
G221	1/3	5	2	1

Consitency Ratio: 2.0%

3. Project roads with respect to social developments

	G032	G122	G217	G221
G032	1	1	4	2
G122	1	1	4	2
G217	1/4	1/4	1	1/3
G221	1/2	1/2	3	1

Consitency Ratio: 0.8%

Non-monetizable Criteria with respect to Project Roads

1. Non-Monetizable Criteria with respect to G032

	AD	ID	SD
AD	1	1/7	1/5
ID	7	1	2
SD	5	1/2	1

Consitency Ratio: 1.4%

2. Non-Monetizable Criteria with repect to G122

	AD	ID	SD
AD	1	9	3
ID	1/9	1	1/4
SD	1/3	4	1

Consitency Ratio: 0.9%

3. Non-Monetizable Criteria with respect to G217

	AD	ID	SD
AD	1	2	1/2
ID	1/2	1	1/3
SD	2	3	1

Consitency Ratio: 0.9%

4. Non-Monetizable Criteria with respect to G221

	AD	ID	SD
AD	1	1/5	1/7
ID	5	1	1/2
SD	7	2	1

Consitency Ratio: 1.4%

Abbreviations:

AD = Agricultural developments; ID = Industrial developments; SD = Social developments

Note: In the pairwise comparisons, indicators of extent of agricultural lands, number of factories and poor population were used to represent agricultural, industrial, and social developments respectively