Selecting Large Infrastructure Projects with Belief-Based Best-Worst Method

A Case Study of Infrastructure Development Acceleration in Indonesia

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Preface

In front of you lies my research report that I have worked on the past six months to obtain my Master's degree from Construction Management & Engineering track, faculty of Civil Engineering & Geosciences at Delft University of Technology.

This thesis started after I discussed a possible topic with a friend related to a case in Indonesia, which was my ambition to research. Unquestionably researching this topic is risky and will not be easy, but I took it eventually. I contacted Fuqi Liang, from the research group at the Faculty of Technology, Policy, & Management and we could relate the idea to the research. The committee was formed along with Professor Jafar Rezaei as my second supervisor and Professor Hans Bakker as my committee chair.

There was a strong connection between the application of the method with the existing practice in one specific government body in Indonesia. I started the process by investigating the case within the body and also learned the method. Fuqi and I discussed many trials to develop the current practice.

In the process, several issues happened inevitably. I had to learn the method in detail and modeled it in Matlab, which I was not familiar and within a short period of time. Luckily, my friends supported me when I got stuck with the progress. The data collection was not simple. Interviewing and surveying several people in Indonesia was difficult due to the distance and five-hour time difference. Besides, they were also swamped with many works. I often felt that I could not finish my research on time. I finished collecting the data very close to deadlines. Also, I had to go back to Indonesia due to personal circumstances. The meeting had to be postponed. I am so blessed to have some friends that supported me during ups and downs and kept me motivated. Special thanks to my friends: Pandji, Tumpak, Dennis, Suwig, Wira, Buts, Daniel, Ges, Jander, Yash, Isis, Malcolm, Cres, Simon, Khoa, Kesi, Karin, and everyone from PPI Delft and also CME friends.

I am very thankful to my first supervisor, Fuqi, he has guided me very well through a hard time. We always tried to find solutions to every problem. He was the one who made this topic feasible in the beginning. We organized a weekly meeting, and sometimes it took time because my English is not perfect.

My second mentor was Jafar Rezaei. He supported me and gave good feedback during our joined meetings. He provided detailed and critical comments on my thesis. Without the method that he developed, this thesis could not be conducted. Thus, I want to thank him for his role.

The committee chair, Hans Bakker, has guided me by presenting different perspectives and provided critical comments despite his busy schedule. I received his approval when I asked for an extension of my study due to several reasons and supported me by providing some suggestions to finish my thesis on time — a big thanks and respect to him.

I would like to thank everyone that provided their time for the surveys and interview, especially the project director that has given me a chance to conduct my thesis. As a result, I can fulfill my desire to contribute to the development in Indonesia.

In the end, I hope this thesis will be contributive and improve the current practice in Indonesia.

Enjoy reading,

Kevin Septian,

Delft, 9th October 2019

Executive Summary

Large Infrastructure Projects (LIPs) are essential to fulfill the needs of Indonesia. These LIPs have a substantial impact on not only the society but also the economy. The Indonesian government intends to accelerate infrastructure provision by selecting complex LIPs to be assisted by a government body, KPPIP (Committee for Acceleration of Priority Infrastructure Delivery).

The selection is difficult due to the limited information in the early-phase of a project and creates uncertainty for the Decision-Makers (DMs). Besides, KPPIP does not have a structured approach in selecting the projects in Indonesia. Another challenge is the non-comprehensive list of KPPIP selection criteria. The process cannot generate good decisions. Therefore, the problem statement is formulated as "KPPIP does not have a tool to handle the uncertainty of the DMs to deal with the selection of LIPs based on the project complexity."

This study has three objectives. First, generate a list of selection criteria. Second, propose a decision-making method to manage LIPs selection issues. Lastly, check the suitability and usefulness of the method. The research question is formulated as: "How do decision-makers select LIPs based on the project complexity giving the uncertainty of DMs?"

Two relevant topics are synthesized from a systematic literature review: first, the selection of LIPs. Second, two Multi-Criteria Decision-Making (MCDM) methods, i.e., Best-Worst Method (BWM) and Evidential Reasoning (ER) approach. This research proposes a methodology that comprises three main processes. First, a set of selection criteria is created. Secondly, criteria weights are obtained with Belief-Based Best-Worst Method (B-BWM). Lastly, projects' scores are acquired by an ER approach.

The findings show significant changes in the weights and various preferences on the critical criteria among four sectors compared to those obtained from KPPIP's current assessment. The weights from four sectors are computed as the group weights and more reliable because it considers the reliability of the DMs. The results show that the previously critical criteria are not considered as necessary in the new assessment and discover several criteria to be added to the existing criteria set. The projects' score demonstrates the non-comprehensiveness of the existing criteria set.

The sensitivity analysis shows a less sensitive result on the group weights and higher robustness of Group B-BWM due to the use of interval collective weights. The weights' change implies a biased understanding of the criteria's importance and shows the non-comprehensiveness of the criteria in KPPIP current assessment. The application of Belief Structure (BS) form in both the B-BWM and ER approach can handle the non-quantifiable criteria which cannot be managed in the KPPIP method.

The challenges in the selection of LIPs are identified: the complexity of LIPs, the uncertainty of the DMs, non-comprehensiveness of KPPIP current criteria, and limitation of KPPIP current methods. Five confirmed important criteria are found: "Project Development Fund support," "determination of funding scheme," "executive direction," "technological newness/innovation of the project/products," and "availability of people, material, and resources due to sharing." A procedure comprises of Group B-BWM and ER approach is proposed and offers some advantages, such as considering the reliability of DMs, flexibility, compatibility, and more robust methods. The proposed methodology is confirmed to be fit-for-purpose in LIPs selection.

Four recommendations for the selection of LIPs are proposed: Establish comprehensive criteria set, implement Group B-BWM and ER approach, and set the grades definition. For future research: Use a project complexity criteria framework from literature, conduct group project scoring, conduct multiple case studies, use more samples, and conduct concurrent validity.

Keywords: large infrastructure project, multi-criteria decision-making, best-worst method, belief-based best-worst method

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List of Abbreviations

AU	= Aggregated Uncertainty
BS	= Belief Structure
BWM	= Best-Worst Method
B-BWM	= Belief-Based Best-Worst Method
DM	= Decision-Maker
EE	= Energy & Electricity (Sector)
ER	= Evidential Reasoning (Approach)
GDM	= Group Decision-Making
IR	= Inconsistency Ratio
KPPIP	= The Committee for Acceleration of Priority Infrastructure Delivery
LIPs	= Large Infrastructure Projects
MCDM	= Multi-Criteria Decision-Making
RB	= Road & Bridge (Sector)
RD	= Reliability Degree
s.t.	= Subject to
TOE	= Technical-Organizational-External (Categories)
TT	= Transportation (Sector)
WS	= Water & Sanitation (Sector)

Chapter I. General Introduction

Selecting Large Infrastructure Projects (LIPs) involves unavoidable complexities and uncertainties. Understanding these attributes plays a key role in assessing the projects during their early stages. Chapter 1 explains why and how the research related to LIPs selection is performed.

This chapter is divided into two sections: Section 1 (“Introduction”) presents the background, and Section 2 (“Research Design”) describes the planning and methodology of the study.

“An hour of planning can save you ten hours of doing.”

- Dale Carnegie -

1 Introduction

Section 1.1 depicts the general context of infrastructure developments and Multi-Criteria Decision-Making methods (MCDMs). Section 1.2 analyzes the motivation of the subsequent research. Section 1.3 introduces the problem statement. Lastly, Section 1.4 provides the reading guide for this report.

1.1 Research Context

An infrastructure project provides impacts not only to the government but also to society (Dunović et al., 2014). According to the data from World Bank (The World Bank Group, 2019), 13.543 Large Infrastructure Projects have been initiated by governmental bodies around the world. A majority of these projects occurred in emerging economies, such as Brazil (425 projects), China (425 projects), India (643 projects), Russia (81 projects), Indonesia (396 projects), Mexico (259 projects), the Philippines (211 projects), Turkey (218 projects). Aiming to reach a higher Gross Domestic Product, these countries exploit LIPs to stimulate their development. As stated by Marcelo et al. (2016), infrastructure is widely deemed critical to economic development, including social welfare, public health, and trade connectivity. Governmental projects such as roads, railways, bridges, power plants, telecommunications, ports, are indispensable to achieve socio-economic goals of a country. Therefore, infrastructure development optimization should be among the top-priorities in a country's development plan (Sibirskaya et al., 2015)

LIPs development entails a wide range of complex issues, such as massive investment (Ziara et al., 2002) and complexity in the project preparation, funding, coordination, and policy. Theoretical developments revealed that megaprojects had strikingly weak performance records in terms of economic benefit, environmental impact, and public support (Flyvbjerg et al., 2003). The poor performance stemmed from interdependent factors in different phases of a project: early-stage stage, construction stage, and operational stage. One critical issue is the decision-making in a portfolio.

Priemus (2010) summarized main pitfalls in the early stage of the decision-making process, i.e., (1) Absence of proper problem analysis, (2) lack of project alternatives, (3) ambiguities about the scope of the project, (4) no program of functional requirements, and (5) dissemination of contested information. There are some other problems with complexity, such as long project timespan, dynamic environment, and multi-players, which further complicated the decision-making.

Infrastructure development in Indonesia

This study focuses on LIPs selection in Indonesia. As one of the new emerging markets, Indonesia is striving to boost its economic development by proposing an exhaustive list of 396 governmental projects. The list keeps expanding year after year in all sectors such as infrastructure, energy, education, information technology, environment, and many more (KPPIP, 2016). This enormous number of infrastructure projects comprises of small, medium, and large ones. The required investment and projected benefit vary according to the scale of the project. The larger the project, the higher the investment. Consequently, thorough planning is of paramount importance in developing the LIPs.

To facilitate this massive number of LIPs, the government formed the Committee for Acceleration of Priority Infrastructure Delivery (KPPIP, shortly in Indonesian) (KPPIP, 2016). The role of the committee is assisting the government in developing the LIPs, ranging from controlling the process of pre-selection to delivering over €6.3 million investment. Above all, KPPIP is confronted with the arduous task of prioritizing LIPs every year.

KPPIP's primary problem is its lack of structured approach and decision-making methods. They make decisions based on discussion within the organization (Erian, 2019). The issue worsens when KPPIP needs to prioritize LIPs because it involves high complexity and uncertainty. Besides, the selection process implies grappling with the relative exigency, efficiency, and effectiveness of investments (Marcelo et al., 2016). A systematic approach is essential in this process because selecting the correct LIPs is crucial to the country's economy. It is time for KPPIP to develop the necessary tools to compare various alternative projects (Utomo & Haryanto, 2016).

In short, the above-mentioned issues relate to both the characteristics of LIPs and the inadequacy of the current approach. A structured decision-making method will help to deal with this complex issue. Decision support has received substantial interest in the scientific body of knowledge, and some of the common methods include Cost-benefit Analysis (CBA) (Quah & Haldane, 2007) and Multi-criteria Decision Making (MCDM) (Zionts, 1979). However, CBA is questionable because it does not incorporate multiple criteria as well as does not justify social and environmental issues (Annema et al., 2015). Therefore, MCDM is chosen to be the focus of this research as it can handle a complex case such as LIPs selection.

Multi-Criteria Decision-Making

MCDM is one of the most used instruments in selecting, sorting, or ranking alternatives. MCDM can manage the complexity of decision-making by incorporating various criteria in the process. In this research, MCDM is implemented to select LIPs in Indonesia. MCDM itself comprises numerous methods, each of which has its strengths and weaknesses.

The development of MCDM has evolved over time, starting from the simple Weighted Sum Model (Fishburn, 1967) and Weighted Product Model (Miller, 1963). A review of decision-making models presented the application, strength, and weakness (Kumar et al., 2017) of Analytical Hierarchy Process (AHP) (Saaty, 2000), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) by Hwang and Yoon (1981), Preference Ranking Organization method (PROMETHEE) (Mareschal et al., 1984), and *Vise Kriterijumska Optimizacija I Kompromisno Resenje* (VIKOR) (Opricovic, 1998). Other methods that can be found in the literature are *Elimination Et Choix Traduisant la Realité* (ELECTRE) (Roy, 1968), Complex Proportional Assessment of Alternatives (COPRAS) (Zavadskas & Kaklauskas, 1996), Analytical Network Process (ANP) (Saaty, 1996).

Each of MCDM methodology has different characteristics, applications, and limitations (Adler et al., 2002). For instance, PROMETHEE, one of the most applied ranking methods, was unable to give a complete ranking of the alternatives (Wang et al., 2009). Other MCDM methods that apply pairwise comparisons, such as AHP, lack consistency in practice (Herman & Koczkodaj, 1996). Despite being the most commonly used pairwise comparisons-based method, AHP causes a relatively imprecise judgment and faults (Yang & Chen, 2004). TOPSIS has an issue during the assessment process, which makes it difficult for the Decision-Maker (DM) to assign precise performance ratings to alternatives (Sun, 2010). Some efforts have also been made to combine MCDM methods with fuzzy sets and fuzzy logic to eliminate the uncertainty in terms of fuzziness (Klir & Yuan, 1995), but the resulting combination still cannot handle other types of uncertainty, such as discord and non-specificity.

Besides the characteristics, other papers showed the advantages and disadvantages (Mulliner et al., 2016; Zanakis et al., 1998). A study suggested a different approach to estimate the societal Net Present Value of the projects (Marcelo et al., 2016). However, this method is not feasible for most developing countries due to their lack of capability and resources, and it ignores several unmonetized criteria.

All things considered, this research will focus on the selection of LIPs, using KPPIP as a case study, and exploring the appropriate decision-making method for managing complex characteristics of LIPs.

1.2 Problem Analysis

LIPs selection can be characterized as a case within a complex and uncertain environment (Lessard et al., 2014). For instance, some researches describe that LIPs are characterized by complexities such as sociopolitical, organizational, and structural factors (Bakhshi et al., 2016; Bosch-Rekveldt et al., 2011; Nguyen et al., 2015). Thus, a study of the criteria in the LIPs selection is crucial in the first place to understand the complexity of the projects.

Nevertheless, KPPIP determined the level of importance of the criteria in selecting LIPs by mere discussion, and as a result, nearly all the criteria had the same weights (Source: KPPIP). The problem with such an implementation was that the assessment was unjustified. Additionally, another problem emerged during the selection process, such as the subjectivity of the observers. Their inability to consider the uncertainty or hesitancy (Corning, 1998) might lead to a non-precise assessment.

LIPs have a broad scope as well as other complicated aspects, such as institutional features or the interaction of various external stakeholders. These aspects are measured based on expert opinions and challenging to measure (Vodopivec et al., 2014). In other words, it is affected by many phenomena such as project complexity, characteristics, nature, and the relations between these factors (Książek et al., 2015). Unfortunately, KPPIP did not implement the right approach when constructing the criteria set. The resulting set might not reflect the comprehensiveness of LIPs selection.

Many research projects investigated numerous cases of comparing civil projects. However, there were very few available tools for analyzing various LIPs that have different characteristics. The process of comparing multiple large-scale projects has many challenges for DMs (Książek et al., 2015). LIP was not immune to the economic, social, and environmental conditions that were affected by the project itself and these interdependencies finally created complexities and uncertainties as a whole (Salet et al., 2012).

Another problem is how to measure project complexity. Hass and PMP (2008) found that the inability to understand the complexity led to failure in meeting projects' objectives. Many studies had attempted to measure project complexity, but most measures had a wide range of limitations, such as non-intuitive for end-users, lack of reliability, and difficulty in calculating (Vidal et al., 2011a).

A high-quality decision-making process is considered necessary to improve transparency and also to avoid inconsistency, to decrease variability, and to enhance the predictability of a decision (Thokala et al., 2016). However, the current approach of KPPIP is ineffective and inefficient because their method is both unsystematic and slow due to KPPIP's multiple discussion meetings. Alexander (2006) stated that there was a growing need for informed advice and guidance on decision-making, which grew hand in hand with the increase of the project size and complexity. Most importantly, very few researches, to the authors' knowledge, have investigated the selection of LIPs. Therefore, selection of LIPs by KPPIP was chosen to be the case study in this thesis.

1.3 Problem Statement

There is currently very little information regarding the solution for LIPs selection in literature. Usually, a decision-making tool is implemented for addressing a selection issue. In this research, the theory of project complexity will be aligned with the implementation of the decision-making method. It implies that there is a need for research in the initial project development process to be able to manage the complexities of projects and the uncertainty in the selection process of LIPs. Based on this implication, the problem statement in this thesis is:

"KPPIP does not have a tool to handle the uncertainty of the decision-makers and to deal with the selection of LIPs based on the project complexity."

1.4 Research Outline

This section presents the outline of this report. Section 1 introduces the general context for this project and the research design in Section 2. Section 3 and Section 4 present the related theoretical studies, LIPs selection, and MCDM, respectively, to support the content of the research. The methodology to conduct the research is explained in Section 5. Then, Section 6 displays the case study and the data provided by the associated party. Section 7 shows the application of the proposed method and presents the result. Section 8 provides a discussion of the findings and the limitation of the research. Finally, Section 9 and Section 10 close the report with the conclusion and recommendation. Section 11 is provided as the reflection from the author. Last but not least, several appendices are provided for further detailed information.

2 Research Design

This section will propose the research design to solve the problems stated in Section 1.2. Section 2.1 describes the objectives of this research, while Section 2.2 suggests the research question. Section 2.3 explains the framework of the study. Lastly, Section 2.4 clarifies the scope of this research.

2.1 Research Objectives

There are three objectives to be achieved at the end of this thesis:

1. Generate a list of criteria for the case of LIPs selection. The criteria aim to reflect the project complexities and uncertainties within the selection process. A list of criteria will help the DMs to understand project complexities.
2. Propose decision-making methods to deal with LIPs selection process. These methods intend to be able to manage the complexities and uncertainties within the LIPs selection process.
3. Validate the methods. The chosen methods will be tested for its suitability and usefulness in assessing LIPs in a complex environment.

With these objectives in mind, the main goal of this study is to find out how the DMs can deal with complex characteristics of LIPs and manage the uncertainty of the selection process.

2.2 Research Question

Following the main objectives, the research question is:

How do decision-makers select LIPs based on the project complexity giving the uncertainty of DMs?

In answering the main research question, the research is divided into five sub-questions as follow:

1. What are the challenges in the current decision-making process of selecting LIPs based on the project complexity?

LIP has a complex environment, and it creates some challenges. This part identifies the problems that occurred in the case study and the effect on the decision-making process.

2. What are the criteria that must be considered in selecting LIPs based on project complexity?

The selection criteria may vary for a different type of infrastructure. Therefore, we need to understand the mission of the case and how well-suited the criteria are for the situation. The criteria need to be identified to prevent misconception and wrong interpretation in the pairwise comparison in the later process.

3. How to obtain the weights of the criteria when considering the uncertainty of the DMs and the complexity of LIPs?

Weights of the criteria are essential to quantify their importance. In the selection process, the level of importance of the criteria might vary and consequently affect the scoring. The weights are difficult to assess because DMs may have different perspectives, and LIPs are inherently complex.

4. How to incorporate the project complexity into the selection of LIPs?

One method for criteria weightings and project scoring is proposed to manage the complex characteristics of LIPs in the selection process. This part explains how the method can address the issues.

5. Is the method fit-for-purpose for selecting LIPs based on the complexity and dealing with the uncertainty of DMs?

Sub-question 5 intends to validate the fitness of the method in the case study. The fitness means how the methods can cope with LIPs selection based on the complexity and how it can handle the uncertainty of the DMs.

2.3 Research Framework

This section further explains the research process. There are seven stages, i.e., literature study, methodology, case study, data collection, analysis & discussion, confirmation, and conclusion. The case study section provides answers for Sub-question 1. The analysis & discussion stage answers Sub-questions 2 to 4, while the confirmation accommodates Sub-question 5. The complete list of the framework is illustrated in Figure 1.

2.3.1 Literature Study

This part intends to pursue an exploratory and descriptive definition of the criteria. Thus, the information gathered is divided into two parts; the first part is the literature study related to the theories of LIPs selection. The literature study on LIPs selection will involve criteria in project governance. The Content Analysis Method is adopted to organize and elicit meaning from the data collected and to draw realistic conclusions (Bengtsson, 2016). The criteria from the literature study are gathered to be used further in the analysis. In the second part, two MCDM methods are discussed in this study, i.e., Best-Worst Method (BWM) and Evidential Reasoning (ER) approach.

2.3.2 Methodology

Section 5 explains the methodology to establish the criteria, to compute the criteria weights with Belief-Based Best Worst Method (B-BWM), and to obtain project scoring by using the ER approach.

B-BWM for Criteria Weightings

The study will be conducted by using the BWM (Rezaei, 2015), and it is incorporated with the Belief Structure (BS) (Yager, 1992). The method is integrated as B-BWM for assessing criteria weights. Pre-analysis is done to review the KPPIP criteria, which are combined with a supplementary set of criteria. This process uses semi-open questions. The format of the survey can be seen in Appendix B.

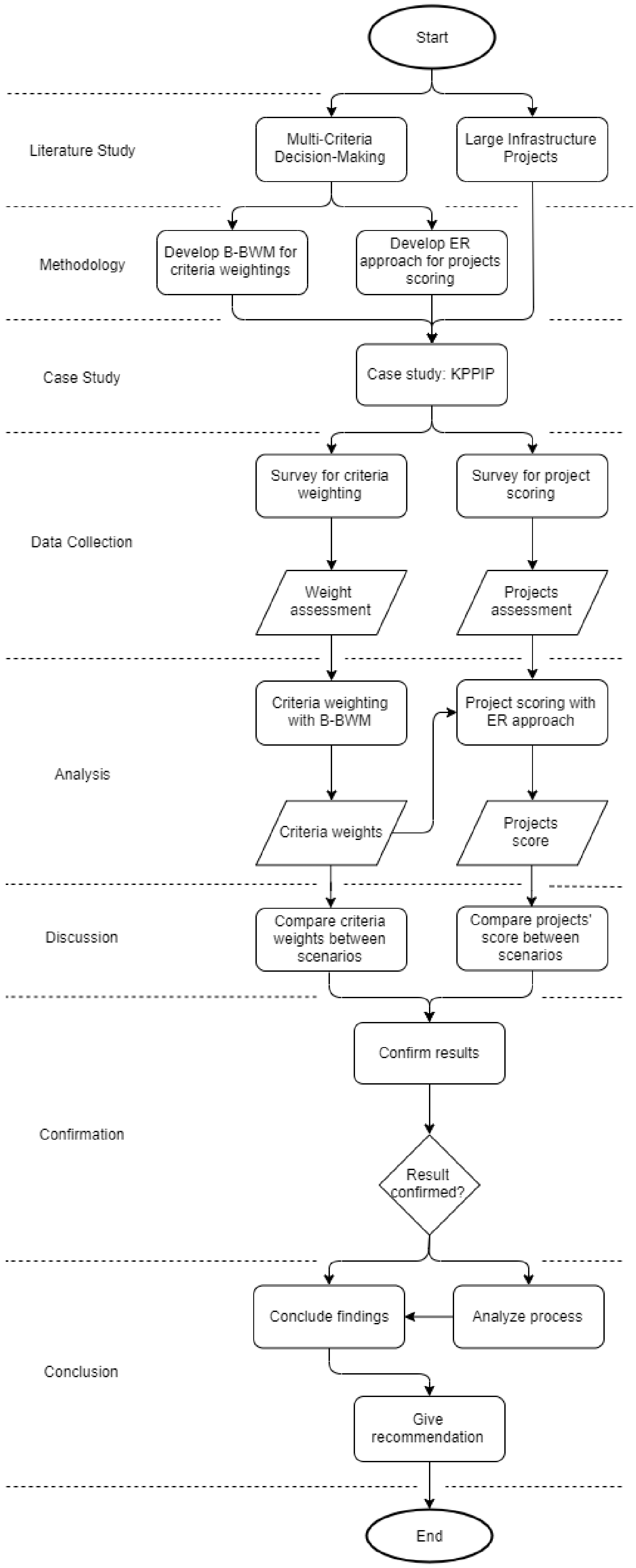

Figure 1. Thesis research workflow strategy.

2.3.3 Case Study

In Section 6, the case study of LIPs selection in Indonesia is presented. It explains the current implementation of decision-making within KPPIP. This section will answer Sub-question 1.

2.3.4 Data Collection

The data collection acquires the information through two phases of surveys in four sectors. The first round inquires the DMs to evaluate the criteria's importance, while the second round evaluates the LIPs. Survey data are collected from four respondents, with one respondent from each sector. The current project assessment is utilized in this research. Lastly, one interview is conducted to validate the result. The list of respondents is provided in Table 1.

Table 1. List of respondents.

Interviewee	Role	Sector	Phase
1	Project Expert	Energy & Electricity (EE)	1 & 2
2	Project Expert	Road & Bridge (RB)	1 & 2
3	Project Expert	Transportation (TT)	1 & 2
4	Project Expert	Water & Sanitation (WS)	1 & 2
5	Program Manager	Head of four sectors	After 1 & 2

2.3.5 Analysis & Discussion

There are three parts of analysis in this research. The first one is the analysis of the current decision-making process and the establishment of the combined set of criteria. Secondly, the study of the criteria weights from B-BWM. Lastly, the analysis of the project scoring from ER approach. This part will answer sub-questions 2 to 4.

2.3.6 Confirmation

This part intends to check if the criteria's importance is in line with the literature. The supplementary criteria are checked by the head of four sectors through an interview if it fits to be added in the current criteria set. The fitness of the proposed methods is also checked through the interview. The questions and answers are provided in Appendix D. This section answers Sub-question 5.

2.3.7 Conclusion

The conclusion of the analysis will be presented in Section 9 and the recommendation for future practice and research in Section 10.

2.4 Research Scope

LIPs might be defined differently in different cases. This research focuses on the LIPs that use the definition of KPPIP, and it is limited to projects in Indonesia. KPPIP defines LIPs according to government regulation, and they consider 80 LIPs. In this study, the criteria set is extended by conducting a literature study on project complexity. Eight articles are used to establish the supplementary criteria set.

In the selection process, KPPIP has two stages of selection criteria. The first stage is eliminative criteria that cut the number of projects from 247 to 80. This study focuses on the second stage, i.e., the scoring criteria. These 80 projects are filtered through a scoring system into 37 prioritized projects. This study will analyze the criteria weightings and the projects' ranking by implementing KPPIP and supplementary criteria. KPPIP's current project assessment is used on their current criteria is used to calculate the projects' score.

Chapter II. Literature Study

This section provides a theoretical foundation regarding LIPs and the selection criteria for MCDM. Section 3 presents literature review on LIPs selection and proposes a list of criteria from literature. Section 4 reviews the theoretical foundation of the MCDM method. Several methods that are related to the content of this research are briefly explained.

"Every decision is a wrong decision when you do not know what you want out of it."

- Sanhita Baruah -

3 Large Infrastructure Project Selection

Infrastructures are technological systems that provide essential services, typically, but not exclusively to the public (McArthur et al., 2017). It means that infrastructure is a fundamental system that serves a country or city and is necessary for its economy to function. Additionally, due to the importance of infrastructure projects, the central government takes the leading role in selecting the project as it is their responsibility to provide the basic needs of the residents.

It is essential to realize that the diversity of infrastructure types makes the decision-making difficult to handle. The infrastructure in this research comes from four sectors, i.e., energy & electricity; roads & bridges; transportation, and water & sanitation.

Section 3.1 presents different types of infrastructure projects. Section 3.2 discusses the complexity of LIPs selection criteria. Section 3.3 presents the selection criteria for LIPs that are found in the literature.

3.1 Large Infrastructure Project

The definition of LIPs is dependent on the nature of each case. LIPs are typically classified according to their investment or their impact on society. Several studies suggested that LIPs should be analyzed according to their complexity (Bosch-Rekveldt et al., 2011; Nguyen et al., 2015; Vidal et al., 2011a).

The concept of infrastructure permeates a wide range of sectors such as transportation systems, power and energy, water and waste, information and communication technologies (Stevens et al., 2006). Furthermore, a sub-category of social infrastructures is present in healthcare, housing, and education. In the transportation sector, infrastructure consists of physical objects such as roads, bridges, tunnels, railway systems, ports, and airports. In the energy sector, the infrastructures are in the form of electrical grids, power plant, refinery, and gas supply systems. They play a role in other areas such as telecommunication, industry, water management.

Infrastructure project selection in developing countries has an inherent challenge. The capital funding limits the number of infrastructures that can be developed. These countries cannot freely build all infrastructures at once due to this limitation; instead, they compare and consider which projects give more added-value when selected. Therefore, the relevant criteria in selecting LIPs are highly necessary.

3.2 Complexity of LIPs

The development of criteria for project selection can be seen from multiple perspectives. Baccarini (1996) reported a new and significant study on the complex dimension of projects in the late 1990s. Maylor et al. (2011) emphasized that the study of project complexity kept progressing to better represent the "reality." The paradigm has been shifting to build a common language to define project complexity.

A previous case study for the Channel Tunnel between France and England revealed that the three traditional areas of cost, schedule, and quality of scope, were not enough for project management (Owens et al., 2012). A highly sophisticated project management approach was needed to manage the factors that influenced the project. Some authors discussed that the complexity stemmed from the ever-growing project complexity (Vidal et al., 2011a; Whitty & Maylor, 2009). Vidal et al. (2011a) added that project complexity is challenging to understand, foresee, and keep under control, even when given complete information.

In the past ten years, several kinds of research have attempted to analyze project complexities by examining difficulties in decision-making and goal attainment (Remington et al., 2009). They added that understanding complexity is vital to project management. LeRoy (2005) identified that most project failures were caused by the inability of the stakeholders to recognize the complexity. Project managers are sometimes too late to address the complexities effectively and are unable to gain control of the issues (Dunović et al., 2014). Moreover, it is necessary to realize that each project is unique due to its different parameters, such as targets, resources, and environment (Vidal et al., 2011a).

Bakhshi et al. (2016) classified projects into several categories: simple, complicated, complex, and chaotic. A simple project is defined as a limited number of activities with a clear cause-and-effect relationship and distinct characteristics, such as self-evidence, predictability, and repeatability, in order to create products or services.

Unlike the simple project, a complicated project may not have cause-and-effect relationships between the tasks and elements. In this case, a complicated project may comprise some simple projects but is not merely reducible to them. Not only the scale but also the coordination between parties define the difference between simple and complicated projects (Glouberman & Zimmerman, 2002).

Whitty and Maylor (2009) discussed the difference between complicated and complex. They concluded that a project would be complex only when uncertainties play a role. Another study stated further that a complex project has some other characteristics such as ambiguity and uncertainty, interdependency, non-linearity, uniqueness to local conditions, autonomy, emergent behaviors, and unfixed boundaries (Bakhshi et al., 2016).

The last category is a chaotic project, which can be interpreted as an “unknown-unknown” state. As an example, Snowden and Boone (2007) illustrated a “crisis” or “disaster” as an event that cannot be predicted.

Over time, there is an increasing agreement that understanding project complexity is essential, especially for the decision-making and goal attainment (Remington et al., 2009). Hertogh and Westerveld (2010) formulated a direct connection between the complexity of a project and the management approach. Dunović et al. (2014) noticed a significant influence on the selection of a management strategy by having a clear understanding of the types of complexity. Maylor et al. (2011) focused on finding better ways to represent the “reality” of projects. The Project Management Institute supported the proposition by stating that if project complexity is appropriately measured, project managers will be better prepared, and the success rate will be higher (PMI, 2013). Several other authors confirmed this proposition (Dunović et al., 2014; He et al., 2015; Nguyen et al., 2015; Vidal et al., 2011a).

Several authors have recognized the benefit of understanding project complexity. A project with a high socio-political complexity could benefit from having a senior project manager who is capable of managing stakeholders (Maylor et al., 2011). Bosch-Rekveldt et al. (2011) advised that having clear information on project risks and project complexity, should not be considered as a goal, but as a means to manage the project instead.

The first insight into project complexity was in the late 1990s by Baccarini (1996), who introduced that project complexity was a collection of various interrelated parts and could be operationalized in terms of differentiation and interdependency. In 1999, it was stated that structural complexity has two roots, multi-objectivity, the multiplicity of stakeholders, and uncertainty (Williams, 1999). Corning (1998) stated that complexity was difficult to define, mainly because most scholars define complexity from their fields, and no consensus had been reached.

Some authors conducted more extensive studies of the components of project complexity. Cicmil et al. (2006) illustrated that complexity was related to structural elements, dynamic elements, and their interaction. This result was investigated by Whitty and Maylor (2009). Geraldi and Adlbrecht (2007) said that softer aspects such as the interaction between stakeholders played a role in influencing project complexity. Another project which reviewed past research between 1996 to 2010, revealed five different types of project complexity: structural, uncertainty, dynamic, pace, and sociopolitical (Maylor et al., 2011; Vidal et al., 2011b).

Other scholars improved the definition of project complexity. Senescu et al. (2012) associated complexity with multiplicity, causal connections, interdependence, openness, synergy, and nonlinear behavior. The Project Management Institute supposed that multiple stakeholders and ambiguity were two key characteristics of project complexity (PMI, 2013). Lu et al. (2015) studied the "hidden works" or "unknown-unknown tasks" caused by the project complexity and found that these issues affected rework, coordination, and idle work. According to Bakhshi et al. (2016), complex systems had several attributes such as self-organization, emergent properties, and non-linear behavior of the project objectives, and counter-intuition. He concluded that no conceptual definition had been unanimously agreed upon by scholars. The most recent study defined project complexity as structural, uncertainty, novelty, dynamics, pace, socio-political, and regulative complexity dimensions (De Rezende et al., 2018).

Maylor et al. (2011) investigated the correlation between the dimensions of complexity. For instance, the high number of stakeholders, which are part of structural complexity, may lead to an increase of sociopolitical complexity. Another example, the high pace of a project will require a high interdependence of tasks and high structural complexity to be able to cope with the pace. Again, a high uncertainty will increase the dynamic complexity of the project because unmitigated issues may arise and lead to unexpected changes, resulting in higher structural complexity (Williams, 1999). Identically, Bosch-Rekveldt et al. (2011) mentioned the connection between the tasks, which were not isolated, but might affect the other functions instead. These relations have complex nonlinear interactions and increase project complexity.

3.3 Criteria for Assessing the Complexity of LIPs

According to Maylor et al. (2011), the complexity assessment is subjective, and it relies on the perspective of the project manager. Thus, to develop an accurate description of complexity, the pattern of complexity must be understood to enable us to obtain enough information. This research tries to capture various criteria that are relevant to the complexity of LIPs. The content analysis method is implemented to gather the criteria. Eight pieces of research discussing the selection of infrastructure projects were analyzed.

A clear framework or a proper categorization of the criteria is needed to know the type of complexity that occurs. Some frameworks have been proposed to identify project complexity (Cicmil et al., 2006; Hass & PMP, 2008). One of the latest is the TOE framework (Bosch-Rekveldt et al., 2011), which will be adopted in this case. They described the technical view as the main content of the project, organizational view as the softer aspects, and external view as the influence from the external.

A list of criteria is presented in Table 2. It summarizes the criteria that have been categorized into TOE categories. Several criteria from the literature have been accommodated in the current KPPIP criteria set. Thus, those criteria are removed from the list. Some other criteria are renamed when a criterion is stated differently in two or more literature, but they have relatively similar meanings. Two or more criteria with a similar context, but they are stated in detail, are combined in a more general term. As a result, 33 selection criteria are proposed.

The level of importance of criteria can be different from that of each other. The level of importance is represented as the weight assigned to the criteria to measure how important they are when choosing an alternative. There is a wide choice of methods available in the literature, which will be explained in the next section.

Table 2. TOE Criteria from the literature review.

Category	Criteria	References[a]							
		1	2	3	4	5	6	7	8
Technical	Technological newness/innovation of the project/products		✓	✓	✓	✓	✓	✓	✓
	High-quality requirements/standards	✓	✓			✓		✓	
	Number & variety of project management methods and tools applied		✓	✓	✓		✓	✓	
	Quantity & variety of resources to be manipulated	✓		✓	✓	✓		✓	
	Number & variety of technological dependencies			✓	✓	✓		✓	
	Schedule and duration of the project	✓	✓	✓		✓	✓	✓	
	Number & variety of activities/tasks/process		✓	✓	✓	✓	✓	✓	
	Size in Capital Expenditure		✓	✓		✓	✓	✓	
	Number & variety of information systems			✓	✓		✓	✓	
	Number & variety of the scope/components/specifications			✓		✓		✓	
	Dynamic of plan, organization, and components	✓		✓	✓				
Organizational	Capability & competencies/skills of the team (knowledge, experience, education, training)		✓	✓		✓	✓	✓	
	Availability of people, material and of any resources due to sharing	✓		✓			✓	✓	
	Team/partner cooperation, coordination, communication, and trust		✓	✓	✓	✓	✓	✓	✓
	Number & variety of interfaces in the project organization			✓			✓	✓	
	Number & diversity of staff (experience, background, social span)		✓	✓	✓	✓		✓	
	Number & variety of languages, cultural, time zones	✓	✓	✓	✓	✓		✓	
	Number & variety of formal units/teams & departments involved		✓	✓	✓	✓	✓	✓	
	Number & variety of hierarchical levels			✓	✓		✓	✓	
	Number & variety of different occupational specializations/disciplines	✓	✓					✓	
	Number & variety of decision to be made			✓			✓	✓	
	Internal politic issue (ambiguity, hidden information, lack of support)	✓	✓					✓	
	Interconnectivity and feedback loops in the task and project networks			✓			✓	✓	
External	Interaction/interfaces between the technology system and the external environment	✓	✓		✓		✓	✓	✓
	Form of contract	✓	✓			✓		✓	
	Level of competition and conflict between stakeholders	✓	✓	✓		✓	✓	✓	
	Neighboring environment (including site access/location/difficulty)	✓	✓			✓	✓	✓	
	Number & variety of the interests/objectives/goals	✓	✓	✓	✓		✓	✓	
	Number & variety of stakeholders		✓	✓	✓	✓	✓	✓	
	Number & variety of investors/financial resources		✓	✓			✓	✓	
	Unrealistic demand/expectation	✓					✓	✓	
	Site compensation and clearance					✓			
	Social disturbance								✓

[a] References: 1 - Remington et al. (2009); 2 - Bosch-Rekveldt et al. (2011); 3 - Vidal et al. (2011a); 4 - He et al. (2015); 5 - Nguyen et al. (2015); 6 - Qureshi and Kang (2015); 7 - Bakhshi et al. (2016); 8 - (Dimitriou et al., 2016).

4 Multi-Criteria Decision-Making

In reality, selecting one out of many alternatives is a daily problem. In complex cases, it involves criteria that can be characterized by both quantitative and qualitative attributes, as well as uncertainties due to the lack of information or ambiguity of the data (Yang et al., 2006). For instance, construction clients are facing challenges in selecting projects due to their limitation of resources (Cheng & Li, 2005). Correspondingly, they have to choose the most viable projects as the strategic choice that offer the most benefit for the company (Badri et al., 2001). Nonetheless, it can be solved by MCDM methods, which can quantify subjective assessments and incorporate multiple stakeholders' opinions (Lewis et al., 2018). There exists a considerable body of literature that provided various methods for addressing project-selection problems, such as scoring ranking, programming, fuzzy logic, and Analytical Hierarchy Process (AHP).

A decision-making matrix is formed as follow:

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

$$W=[w_1 \quad w_2 \quad \cdots \quad w_n]$$

Where $A_1, A_2, \dots, A_m$ are m alternatives or projects from which to choose; $C_1, C_2, \dots, C_n$ are n criteria by which projects are measured; x_{ij} is the value of a project A_i on criterion C_j; and w_j represents the weight assigned to the criterion C_j. Then, to find the best project among a list of infrastructures, the overall value needs to be calculated. The values for each criterion are obtained through a variety of methods. The weight of the criteria $w_j \geq 0$, $\sum w_j = 1$ is assigned to the criterion C_j. After that, the overall value of alternative V_i, is obtained through a simple additive value function (Fishburn, 1967) as follows:

$$V_i = \sum_{j=1}^{n} w_j x_{ij}. \qquad (1)$$

The formula above is the basic terminology of decision-making. There are numerous methods to determine the weight and the scoring of the alternatives. The range of applications of MCDM is very diverse. In one research, the fuzzy AHP was implemented to quantify the complexity of transportation projects (Nguyen et al., 2015). In another case, the combination of MCDM, Dempster-Shafer Theory, and CBA was performed to evaluate decisions under uncertainty in the transport infrastructure sector (Shiau, 2014). In another field of study, MCDM method was executed to assess the sustainable housing affordability (Mulliner et al., 2016).

Two MCDM methods are used for this thesis, which is selected due to the superiority of the methods. The first method is BWM. In addition, BS, a form of information that can be implemented in an MCDM case will be introduced. The second method is the ER approach. Section 4.1 introduces the first method, BWM. Section 4.2 presents BS. Section 4.3 provides the development of BWM that implements BS, which is B-BWM. Section 4.4 explains about Group B-BWM. Section 4.5 presents the ER approach.

4.1 Best-Worst Method

One of the latest developments in MCDM is BWM (Rezaei, 2015). It applies a pairwise comparison approach like AHP, but it results in a higher consistency, minimum violation, less total deviation, and more conformity. It is more practical because of the simplicity of the process and a fewer number of comparisons.

Several studies have implemented BWM for decision-making. The method was implemented frequently in researches that assessed the quality of products (Ren, 2018), selection of system (Gupta et al., 2017; Nawaz et al., 2018; Rezaei et al., 2018), or generic alternatives (Gupta & Barua, 2017) in various areas. Besides, some researches compared BWM with other MCDM methods (Nawaz et al., 2018; Serrai et al., 2017).

The general application of BWM assigns a ratio of relative importance in pairs estimated by the DMs (Rezaei, 2015). Specifically, there are two evaluation vectors; the first vector compares the best criterion to other criteria, and the second vector compares other criteria to the worst criterion. The weights of the criteria are obtained from the linear or nonlinear program. The general steps of BWM are explained below.

Step 1. Determine the set of evaluation criteria $\{C_1, C_2, \ldots, C_n\}$.

Step 2. Determine the best (e.g., the most influential or the most important) and the worst (e.g., the least influential or the least important) criterion.

Step 3. Determine the preferences of the best over other criteria using a number between 1 to 9. The obtained Best-to-Others (BO) vector is: $A_b = (a_{B1}, A_{B2}, \ldots, A_{Bn})$, where a_{Bj} represents the preference of the best criterion C_B over other criteria C_j, $j = 1, 2, \ldots, n$.

Step 4. Determine the preferences of all the criteria over the worst criterion. The obtained Others-to-Worst (OW) vector is: $A_w = (a_{1W}, a_{2W}, \ldots, a_{nW})^{\mathrm{T}}$, where a_{jW} represents the preference of other criteria C_j over the worst criterion C_w, $j = 1, 2, \ldots, n$.

Step 5. Determine the weights $\left(W_1^*, W_2^*, \ldots, W_n^*\right)$ by solving the following model:

$$\text{minmax}_j \left\{ \left| \frac{W_B}{W_j} - a_{Bj} \right|, \left| \frac{W_j}{W_B} - a_{jW} \right| \right\}$$

Subject to (s.t.).

$$\sum_{j=1}^{n} W_j = 1$$

$$W_j \geq 0, \text{ for all } j. \tag{2}$$

Model (2) can be transferred into the following model:

$$\min \xi$$

s.t.

$$\left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi, \text{ for all } j$$

$$\left| \frac{W_j}{W_W} - a_{jW} \right| \leq \xi, \text{ for all } j$$

$$\sum_{j=1}^{n} W_j = 1$$

$W_j \geq 0$, for all j. (3)

4.2 Belief Structure

The evidence theory was first introduced to deal with the Multi-Attribute Decision Analysis problem under uncertainty (Yang & Singh, 1994). The Dempster-Shafer evidential structure plays a crucial role in providing a unifying framework for representing the uncertainty (Yager, 1992). It implements the Ordered Weighted Averaging (OWA) operator to provide a unifying framework for aggregation. Instead of probability, it applies a collection of possible outcomes that are determined by how optimistic or pessimistic the DMs feel. It describes each criterion or an alternative by a distributed assessment using a BS (Yang et al., 2006).

There are three different decision-making scenarios: decision-making under certainty, decision-making under risk, and decision-making under ignorance (Yager, 1992). Decision-making under certainty means that the DM knows everything about the state of nature. In contrast, the decision-making under risk assumes that it has a probability distribution over the state of nature, while the decision-making under ignorance cannot be reflected in other theories except the BS.

Making decisions by using BS has the advantage of integrating both precise data and subjective judgments with uncertainty into a consistent model under a unified framework (Yang et al., 2006). BS also solves discord and non-specificity issues (Liu et al., 2007). The application of BS assigns belief degree into a subset that accommodates the ignorance effectively.

4.2.1 Basic Terminology

Suppose the DMs are using a finite set of assessment grades $\Omega=\{h_1, h_2, ..., h_k\}$ to provide their preferences, which refers to as a frame of discernment in the D-S theory. These grades are mutually exclusive and collectively exhaustive for all of the evaluations, with $h_k \cap h_y = \emptyset$ for any $x, y \in \{1, ..., k\}$, and $x \neq y$. The power set of Ω consists of 2^k subsets of Ω can be presented as $P(\Omega) = 2^\Omega = \{\emptyset, \{h_1\}, ... \{h_k\}, \{h_1, h_2\}, ..., \{h_1, h_k\}, ... \{h_1, ..., h_{k-1}\}, \Omega\} = \{H_1, H_2 ..., H_\Omega\}$.

A basic probability assignment (bpa) to all subsets H of $P(\Omega)$ is a function $m: 2^\Omega \rightarrow [0, 1]$, which satisfies:

$m(\emptyset) = 0$ and $\sum_{H \in 2^\Omega} m(H) = 1$. (4)

The value $m(H)$ is interpreted as the degree of belief that is assigned precisely to the set H and no smaller subset. Any subset H where $m(H) > 0$ is called a focal element which can be denoted as F, and it is called a singleton if it is a one-element subset. The pair $\langle F, m \rangle$ is called the body of evidence.

Based on the belief degree (bpa), some other measures of confidence can be defined. A belief measure is a function $Bel: 2^\Omega \rightarrow [0, 1]$, which represents our confidence that the concerned element belongs to H or any of its subsets and is defined by:

$Bel(H) = \sum_{B \subseteq H \in F} m(B)$. (5)

A plausibility measure is a function $Pls: 2^\Omega \rightarrow [0, 1]$, defined by:

$Pls(H) = \sum_{B \cap H \in \emptyset} m(B)$. (6)

Pls(H) represents the extent to which we fail to disbelieve H. Thus, $Bel(H)$ and $Pls(H)$ can be interpreted as the lower and upper bound of probability to which H is supported (Yager, 1987). These two measures are related to each other:

$Bel(H) = 1 - Pls(H^c)$ and $Pls(H) = 1 - Bel(H^c)$. (7)

where H^c is the complement of H. The difference between the belief and plausibility measures of H is the degree of ignorance for H. Other notable relationships include:

$\text{Bel}(H) + Bel(H^c) \leq 1$ and $Pls(H) + Pls(H^c) \leq 1$. (8)

4.2.2 The Pignistic Probability Function

For $m(H)$ on $P(\Omega)$, its associated pignistic probability function $\beta_m:\Omega \rightarrow [0, 1]$ is defined as (Smets & Kennes, 1994):

$$\beta(h_k) = \sum_{h_k \in H \subseteq P(\Omega)} \frac{m(H)}{|H|} = \sum_{H \subseteq P(\Omega)} m(H) \frac{|h_k \cap H|}{|H|}. \quad (9)$$

Where $|H|$ is the cardinality of H. The principle underlying this procedure is called Generalized Insufficient Reason Principle because the Insufficient Reason Principal is used at the level of each focal element of the belief function. This pignistic probability can be interpreted as a belief degree to each element of the frame of discernment Ω.

The next section explains another concept of MCDM, i.e., BWM. This concept is one of the two parts that will be combined to form a novel method for this research.

4.3 Belief-Based Best-Worst Method

This section explains B-BWM, which is an extension of the BWM method. B-BWM is the most recent effort of developing BWM by incorporating the method with Dempster-Shafer theory by Yager (1992). The method extends the solvability of BWM to handle uncertain information by incorporating the ER approach (Liang et al., 2019).

B-BWM can be used adaptively to deal with uncertainty and ignorance in decision-making cases. It is handy in the decision-making of LIPs, which offer complexity in the early project development due to many factors such as the technical, organizational, external, and others. The superiority of B-BWM arises from its capability to capture two types of uncertainties, making this method more flexible than another developed approach, such as fuzzy BWM (Liang et al., 2019).

4.3.1 Belief Structure for pairwise comparisons

Suppose a finite set of assessment grades $\Omega=\{h_1, h_2, \ldots, h_k\}$ is used by DMs to provide their pairwise comparison preferences, which are dependent on each other. For instance, in BWM, a set of one to nine grades is usually defined for the importance of the pairwise comparison of criteria, which can be denoted as:

$$\Omega^{\text{IMPORTANCE}}=\{h_1, h_2, h_3, h_4, h_5, h_6, h_7, h_8, h_9\}. \quad (10)$$

Table 3 shows the scores related to the levels when DMs compare one criterion to another.

Table 3. Definition of importance grades.

Grades	Importance description	Scores
h_1	Equally important	1
h_2	Equally to slightly more important	2
h_3	Slightly more important	3
h_4	Slightly to strongly more important	4
h_5	Strongly more important	5
h_6	Strongly to very strongly more important	6
h_7	Very strongly more important	7
h_8	Very strongly to extremely more important	8
h_9	Extremely more important	9

After determining the frame of discernment, DMs can compare criteria C_i to C_j with subset $H_{l,ij}$ with $\left(l=1, \ldots, 2^k\right)$, from 2^Ω to evaluate their preference and assign, $m_{l,ij}$ (instead of calling basic probability assignment, it is called basic belief assignment in BWM) to present their basic belief degree to this subset. The basic belief assignment can be assigned to more than one subset according to DMs view for each subset of $H_{l,ij}$ alternatively, a combination of a subset.

For instance, in one comparison, the DM may assign his belief that 70% "cost" criterion is equally important as "quality" criterion (h_1), 30% "cost" criterion is equal to slightly more important than "quality" (h_2) because the DM is unsure about the importance of these two criteria.

The pignistic probability function can be implemented to obtain the belief degree $\beta_{k,ij}$ (pignistic probability) associated with each grade $h_{k,ij}$.

$$\beta_{k,ij} = \sum_{h_{k,ij} \in H_l} \frac{m(H_l)}{|H_l|}. \tag{11}$$

The assessment of each grade $h_{k,ij}$ and the belief degree $\beta_{k,ij}$ can be profiled by a BS (S_{ij}):

$$S_{ij} = \left\{\left(h_{k,ij}, \beta_{k,ij}\right), k = 1, \ldots, K\right\}. \tag{12}$$

Thus, the BS in the example above can be constructed as $S_{\text{cost, quality}} = \left\{\left(h_1, \beta_1\right), \left(h_2, \beta_2\right)\right\} = \{(h_1, 0{,}7), (h_2, 0{,}3)\}$.

4.3.2 The procedure of BWM with Belief Structure

The procedure to incorporate the BS into BWM is modeled as follows:

Step 1. Determine the set of evaluation criteria and the frame of discernment.

DMs should identify the corresponding criteria system, which is very important for evaluating the performance of the given alternatives. Suppose there are n criteria $C = \{C_1, C_2, \ldots, C_n\}$. Next, identify a set of grades for evaluating the pairwise comparisons, suppose this frame of discernment consists of K grades: $\Omega = \{h_1, h_2, \ldots, h_k\}$.

Step 2. Determine the best (e.g., the most influential or the most important) and the worst (e.g., the least influential or the least important) criteria.

DMs are asked to identify the best C_B and the worst C_W criteria from the criteria system.

Step 3. Assess the best criterion over all the other criteria with basic belief assignments.

The DMs need to provide their preferences for comparing the best criterion C_B to the other criteria C_j under the set of identified assessment grade Ω. All the subset H_l of 2^Ω will be assigned with basic belief assignment $\left(m_{l,Bj}\right)$, where $m_{l,Bj} \in [0, 1]$. The subsets with $m_{l,Bj} > 0$ will form the body of assessment.

Step 4. Assess all the other criteria over the worst criterion with basic belief assignments.

The DMs assign basic belief assignment $\left(m_{l,jW}\right)$, to all the subset H_l of 2^Ω when comparing the other criteria C_j to the worst criterion C_W. The body of assessment are the subsets with $m_{l,jW} > 0$.

Step 5. Construct BS according to the pignistic probability function.

Obtain the belief degree $\beta_{k,Bj}$ to each grade $h_{k,Bj}$ by using the pignistic probability function, and the BS of comparing the best criterion to the others that can be constructed as:

$$S_{Bj} = \left\{\left(h_{k,Bj}, \beta_{k,Bj}\right), \quad k = 1, \ldots, K\right\}. \tag{13}$$

The obtained Best-to-Others (BO) vector is: $S_B = \{S_{B1}, S_{B2}, \ldots, S_{Bn}\}$, where S_{Bj} represents the preference of the best criterion C_B over other criteria C_j, $j = 1, 2, \ldots, n$. It is evident that $S_{BB}=(1,1)$.

Similarly, the BS of comparing the others to the worst criterion that can be constructed as:

$$S_{jW} = \left\{\left(h_{k,jW}, \beta_{k,jW}\right), \quad k = 1, \ldots, K\right\}. \tag{14}$$

The obtained Others-to-Worst (OW) vector is: $S_B = \{S_{B1}, S_{B2}, \ldots, S_{Bn}\}^T$, where S_{jW} represents the preference of other criteria C_j over the worst criterion C_W, $j = 1, 2, \ldots, n$. It is obvious that $S_{WW} = (1,1)$.

Step 6. Determine the weights $\left(W_1^*, W_2^*, \ldots, W_n^*\right)$.

To determine the optimal weights, we need to make each pair of W_B/W_j and W_j/W_W equal to (or as close as possible to) the grade $h^*_{k,Bj}\left(h^*_{k,jW}\right)$ with the maximum belief degree $\beta^*_{k,Bj}\left(\beta^*_{k,jW}\right)$ in the corresponding BS $S^*_{k,Bj}\left(S^*_{k,jW}\right)$. The underlying idea is that the grade with higher certainty should be valued more, and vice versa. To operate this idea for all j, the solution where the gaps between W_B/W_j and $h^*_{k,Bj}$ (or W_j/W_W and $h^*_{k,jW}$) for all j should be minimized. Therefore, the constrained optimization problem for determining the optimal weights is constructed as follows:

$$\min\max_j \left\{ \left| \frac{W_B}{W_j} - h_{k,Bj} \right| \beta_{k,Bj}, \left| \frac{W_j}{W_B} - h_{k,jW} \right| \beta_{k,jW} \right\}$$

s.t.

$$\sum_{j=1}^{n} W_j = 1$$

$$W_j \geq 0, \text{ for all } j. \tag{15}$$

Model (15) can be transferred into the following model:

$$\min \xi$$

s.t.

$$\left| \frac{W_B}{W_j} - h_{k,Bj} \right| \beta_{k,Bj} \leq \xi, \text{ for all } j \text{ and } k$$

$$\left| \frac{W_j}{W_W} - h_{k,jW} \right| \beta_{k,jW} \leq \xi, \text{ for all } j \text{ and } k$$

$$\sum_{j=1}^{n} W_j = 1$$

$$W_j \geq 0, \text{ for all j}. \tag{16}$$

By solving Equation (16), the optimal weights $W_1^*, W_2^*, \ldots, W_n^*$ will be obtained. The optimal value ξ^* indicates that the closer it is to 0, the more consistent the DM is.

4.3.3 Interval Weights

The BWM can have multiple optimal solutions when the pairwise comparisons are not fully consistent. The method to obtain the minimum and maximum weight of each criterion was proposed in two models to calculate the lower and upper bounds of the weights of criterion C_j based on the ξ^*, which is the optimal solution of Model (15).

min W_j

s.t.

$|\frac{W_B}{W_j}-h_{k,Bj}|\beta_{k,Bj} \leq \xi^*$, for all j and k

$|\frac{W_j}{W_W}-h_{k,jW}|\beta_{k,jW} \leq \xi^*$, for all j and k

$\sum_{j=1}^{n} W_j = 1$, $W_j \geq 0$, for all j. (17)

max W_j

s.t.

$|\frac{W_B}{W_j}-h_{k,Bj}|\beta_{k,Bj} \leq \xi^*$, for all j and k

$|\frac{W_j}{W_W}-h_{k,jW}|\beta_{k,jW} \leq \xi^*$, for all j and k

$$\sum_{j=1}^{n} W_j = 1$$

$W_j \geq 0$, for all j. (18)

After solving these two models for all criteria, the weights for these criteria can be determined as intervals $[W_j^-, W_j^+]$. The operations of interval weights and the method of ranking the criteria, the reader can refer to the approach proposed in the original BWM (Rezaei, 2016).

4.4 Group B-BWM

B-BWM is equipped with a reliability measurement. It comprises three measures: Inconsistency Ratio (IR), Aggregated Uncertainty (AU), and Reliability Degree (RD). RD is essential because it measures the reliability of a DM's judgment in the decision-making process and uses it to generate collective weights based on the inconsistency measurement and uncertainty measurement.

4.4.1 Inconsistency Ratio

Pairwise comparisons are said to be consistent if they fulfill the transitivity condition $a_{Bj} \times a_{jW} = a_{BW}$; otherwise, the DM is not consistent, and it may imply some irrationality in the relative weight estimates. The formula was first adopted from the utility-based approach from Xu and Yang (2001). In this case, S_{ij} is noted as u_{ij}, and can be computed as follow:

$u_{ij} = \sum_{k=1}^{K} u(h_k)\beta_{k,ij}$. (19)

Where $u(h_k) = k$. The value of a_{ij} in BWM can be replaced by the expected utility u_{ij}, which transforms the transitivity condition into:

$u_{Bj} \times u_{jW} = u_{BW}$. (20)

According to the definition of BS, suppose the DM identifies a set of evaluation grades $\Omega = \{h_1, h_2, \ldots, h_k\}$ which is applied to pairwise comparisons, then $S_{BW} = (h_k, 1)$ is the maximum BS that can generate the highest possible value to u_{BW}. If $u_{Bj} \times u_{jW} \neq u_{BW}$, the inconsistency will occur, whether u_{Bj} x u_{jW} is higher or lower than u_{BW}. When u_{Bj} and u_{jW} have the highest value, which is equal to u_{BW}, it will result in the largest inequality. According to $(w_B/w_j) \times (w_j/w_w) = w_B/w_w$, the following equation is obtained:

$$(u_{Bj} - \xi) \times (u_{jW} - \xi) = u_{BW} + \xi. \quad (21)$$

For the maximum inconsistency with $u_{Bj} = u_{jW} = u_{BW}$, the equation can be written as:

$$(u_{BW} - \xi) \times (u_{BW} - \xi) = u_{BW} + \xi, \quad (22)$$

and the formula is formulated as:

$$\xi^2 - (1 + 2u_{BW})\xi + \left(u_{BW}^2 - u_{BW}\right) = 0. \quad (23)$$

Because $u_{BW} = u(K) = K$, $K \in 1,2,3,\ldots$, the equation is transferred as follow:

$$\xi^2 - (1 - 2K)\xi + (K^2 - K) = 0. \quad (24)$$

After solving Equation (24) for different K, the maximum possible ξ can be obtained and used as the inconsistency index in Table 4 for B-BWM. Finally, calculate the IR.

$$IR = \frac{\xi^*}{Inconsistency\ Index}. \quad (25)$$

$IR \in [0,1]$, and the closer it is to 0, the more consistent the judgments of the DMs are, which means that the DM is fully consistent when $IR = 0$.

Table 4. Inconsistency index table.

K	1	2	3	4	5	6	7	8	9
Inconsistency Index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

4.4.2 Aggregated Uncertainty

The uncertain preferences of the DMs can be managed by the AU measure, which measures the uncertainty of the given preferences. It can be formulated as:

$$AU(Bel) = \max_{p_{k,ij} \text{consistent with } Bel} \left[-\sum_{k\in\Omega} p_{k,ij} \log_2 p_{k,ij}\right]. \quad (26)$$

Where the maximum is taken over all distributions $\{p_{k,ij}\}_{k\in\Omega}$ that are consistent with $\{p_{k,ij}\}_{k\in\Omega}$ should satisfy the following constraints:

$$s.t. \begin{cases} p_{k,ij} \in [0, 1], \forall k \in \Omega \\ \sum_{k\in\Omega} p_{k,ij} = 1 \\ Bel(H_l) \leq \sum_{k\in H_l} p_{k,ij} \leq Pls(H_l), \forall H_l \subseteq \Omega \end{cases}$$

The uncertainty measure algorithm for B-BWM

The AU measure was proposed by Harmanec et al. (1996) and developed further by several scholars, which finally corrected by Huynh and Nakamori (2009). The algorithm is shown as an adapted form in the table below (Liang et al., 2019).

Table 5. The algorithm of uncertainty measurement

Input: The set of focal elements F of belief function Bel and their corresponding basic belief assignments.
Output: $AU(Bel)$, $\{p_k\}_{k\in\Omega}$ such that $AU(Bel)=-\sum_{k\in\Omega} p_{k,Bj}\log_2 p_{k,Bj}$ and $AU(Bel)=-\sum_{k\in\Omega} p_{k,jW}\log_2 p_{k,jW}$.
1. Initialize $AU(Bel)=0$.
2. Compute the belief measures for all elements of $U(F)$, which is the union of the focal elements from F.
3. Find a set $H_l \in U(F)$, ($l=1,\cdots,2^K$) such that $Bel(H_l)/\|H_l\|$ is maximal. If there is more than one such set H_l, the one with the largest cardinality should be selected.
4. For $k\in H_l$, put $p_{k,Bj}=Bel(H_l)/\|H_l\|$ and $p_{k,jW}=Bel(H_l)/\|H_l\|$; calculate $AU(Bel):=AU(Bel)-Bel(H_l)\times log_2 p_{k,Bj}$ and $AU(Bel):=AU(Bel)-Bel(H_l)\times log_2 p_{k,jW}$.
5. Set $F'=\{H_f \setminus H_l \mid H_f\in F\}\setminus\{\varnothing\}$. 1) If $F'=\varnothing$, stop. 2) Otherwise, for each $S\in F'$, put $m(S)=\sum_{H_f\in F,\, H_f\setminus H_l=S} m(H)$ and set $F=F'$.
6. If $\|F\|>1$, return to step 2.
7. If $\|F\|=1$ and $F=\{S\}$, put $p_{k,Bj}=m(S)/\|S\|$ (or $p_{k,jW}=m(S)/\|S\|$) and $AU(Bel):=AU(Bel)-m(S)\times log_2 p_{k,Bj}$ and $AU(Bel):=AU(Bel)-m(S)\times log_2 p_{k,jW}$.

Global uncertainty

The AU measure is used to quantify the total uncertainty of a given BS and takes all the basic belief assignments into consideration. The DMs' global uncertainty can be computed as the average uncertainty of the given preferences:

$$\overline{AU}=\frac{1}{2n\text{-}3}\begin{pmatrix} \max_{p_{k,Bj}\text{consistent with } Bel}\left[-\sum_{k\in\Omega} p_{k,Bj}\log_2 p_{k,Bj}\right] \\ +\max_{p_{k,jW}\text{consistent with } Bel}\left[-\sum_{k\in\Omega} p_{k,jW}\log_2 p_{k,jW}\right]\end{pmatrix}. \tag{27}$$

The uncertainty degree must be normalized in the interval [0, 1] to compare the uncertainty degrees of different frames of discernment with different grades. As the maximum value of $\overline{AU}$ is $\log_2 k$, where K is the cardinality of discernment frame, the normalization can be formulated as follows:

$$\widetilde{AU} = \frac{\overline{AU}}{\log_2 k}. \tag{28}$$

The range of AU is [0, 1], the more it closes to 0, the more certain the judgments are and means that the DM is fully certain when the $\widetilde{AU}=0$

4.4.3 Reliability Degree

The original BWM in the early development only considered the inconsistency of DMs. However, uncertain judgments are unstable and might affect reliability. Therefore, uncertainty is taken into account to determine the RD (Liang et al., 2019). The reliability of DMs in group BWM can be defined as fully reliable when they are fully consistent and completely certain. The RD can be formulated as:

$$RD = \frac{\sqrt{(IR)^2+(\widetilde{AU})^2}}{\sqrt{2}}. \tag{29}$$

4.4.4 Collective Weights

In an MCDM case, it is common that more than one assessor evaluates the project to accommodate different views on the problem. Group Decision-Making (GDM) method is needed to aggregate various preferences. An aggregation method was proposed for Group-Based B-BWM, which takes into account the RD of the DMs (Liang et al., 2019).

RD is assumed to represent the weight of the DMs, denoted as λ^g. The reliability of each DM, RD^g, must be obtained, and their weights can be computed with Equation (30).

$$\lambda^g = \frac{1\text{- } RD^g}{\sum_{g=1}^{G}(1\text{- } RD^g)}. \tag{30}$$

Finally, the aggregation of the criteria weights or the collective weight is denoted as $\widetilde{w_j}$, which can be calculated from Equation (31):

$$\widetilde{w_j} = \sum_{g=1}^{G} \lambda^g w_j^g. \tag{31}$$

4.5 Evidential Reasoning Approach

In some cases of an MCDM problem, the person has to quantify qualitative criteria by using human judgments, which has subjectivity and is inevitably associated with uncertainties due to human's inability to provide complete and precise judgments (Yang et al., 2006). Thus, the quantification of qualitative criteria is needed to construct a measurable scale for evaluation. However, there are two major difficulties (Yang & Singh, 1994). First of all, a qualitative criterion might represent an abstract concept, which is difficult to assess directly. It appears from two types of issues, i.e., ignorance or incompleteness and fuzziness or vagueness (Yang et al., 2006). Secondly, it is improper to assume a subjective judgment as a deterministic value. In other words, the DM may not always be 100% certain about the state of the factor.

Yang et al. (2006) found that the current ER approach did not take account of vagueness and uncertainty. For example, grade assessments for "good" and "very good" are difficult to be expressed clearly. Thus, he developed a framework that combining the Dempster-Shafer Theory (DST) (Yager, 1987) with model ignorance and the fuzzy set theory (Zadeh, 1963) to handle fuzziness. The framework dropped the assumption of independent grade and allowed them to be fuzzy and dependent instead, in other words, to have overlapping meanings. It changed the representation of value from singleton numerical, which represented only the average performance, into fuzzy sets, that showed the diverse nature of the subjective assessments.

Several tools can manage uncertain information, and DST is one of them. The evidence theory was introduced by Dempster (1967) and later extended and refined by Shafer (1976). This theory has several advantages (Yang & Singh, 1994): 1. Powerful evidence combination rule, 2. Reasonable valuation for basic probability assignments to provide a piece of evidence, to which the commitment of belief does not necessarily be assigned. The second advantage indicates the strength of the method to handle incomplete uncertainty, especially in a case with uncertain and complex characteristics. The ER approach described each criterion at an alternative by a distributed assessment. Then, the criteria aggregation is based on the ER rather than directly manipulating or adding the scores. It means that the criteria are treated as evidence or as a hypothesis (Yang & Singh, 1994). The theory captured the DMs' beliefs about the comprehensive indicator and the non-monetary criteria.

4.5.1 Criteria Aggregation under Uncertainty

Based on the evaluation analysis model and the evidence combination rule, the ER algorithm aggregates multiple criteria (Yang & Singh, 1994). The ER approach was developed further to handle incomplete information and aggregates both complete and incomplete information using the new weight normalization (Yang & Xu, 2002).

Suppose R distinctive evaluation grades are defined for assessing a criterion:

$$\Omega = \{H_1, H_2, \ldots, H_R\}. \quad (32)$$

Without a loss of generality, it is assumed that H_{r+1} is preferred to H_r.

A given assessment for a criterion C_j ($j = 1, \ldots, n$) in an alternative can be represented as follow:

$$S(C_j) = \{(H_r, \beta_{r,j}), r = 1, \ldots, R\}, j = 1, \ldots, n. \quad (33)$$

In the ER algorithm, $\overline{m}_{H,i}$ is the remaining probability mass in any individual grades that is decomposed into two parts: $\overline{m}_{H,i}$ and $\widetilde{m}_{H,I}$, where:

$$\overline{m}_{H,j} = 1 - w_j, \quad (34)$$

$$\widetilde{m}_{H,j} = w_j \left(1 - \sum_{r=1}^{R} \beta_{r,j}\right), \quad (35)$$

$$m_{H,j} = \overline{m}_{H,I} + \widetilde{m}_{H,I}. \quad (36)$$

$\overline{m}_{H,i}$ represents the degree to which other criteria can play a role in the assessment and $\widetilde{m}_{H,I}$ is caused due to the incompleteness of the assessment.

The combined probability masses are generated by aggregating the assessments $S(e_j)$ and $S(e_{j+1})$ with the same process in a recursive manner.

$$m_{r,j} = w_j \beta_{r,j}(a_i), r = 1, \ldots, R, j = 1, \ldots, n, \quad (37)$$

$$m_{H,j} = 1 - \sum_{r=1}^{R} m_{r,j} = 1 - w_j \sum_{r=1}^{R} \beta_{r,j}(a_i), i = 1, \ldots, L, \quad (38)$$

$$\{H_r\} : m_{r,j(j+1)} = K_{J(j+1)}(m_{r,J(j)} m_{r,j+1} + m_{r,J(j)} m_{H,j+1} + m_{H,J(j)} m_{r,j+1}), r = 1, \ldots, R, \quad (39)$$

$$\{H\} : m_{H,J(j+1)} = K_{J(j+1)} m_{H,J(j)} m_{H,j+1}, \quad (40)$$

$$K_{J(j+1)} = \left[1 - \sum_{t=1}^{R} \sum_{l=1, l \neq t}^{R} m_{t,J(j)} m_{l,j+1}\right]^{-1}, j = 1, \ldots, n-1. \quad (41)$$

After all n assessments have been aggregated, the combined degrees of belief are generated by assigning to all individual grades proportionally by using the following normalization process.

$$\{H_r\}: \beta_r = \frac{m_{r,J(n)}}{1 - \overline{m}_{H,J(n)}}, r = 1, \ldots, R, \quad (42)$$

$$\{H\}: \beta_H = \frac{m_{r,J(n)}}{1 - \overline{m}_{H,J(n)}}. \quad (43)$$

Then, the aggregated assessment can be described as:

$$S(y(a_i)) = \{(H_r, \beta_r(a_i)), r = 1, \ldots, R\}. \quad (44)$$

The utility of the evaluation grade can be denoted by $u(H_r)$. The utility of $S(y(a_i))$ is defined as:

$$u(S(y(a_i))) = \sum_{r=1}^{R} u(H_r) \beta_r(a_i). \quad (45)$$

Chapter III Methodology

This part will explain in detail the methodology that is used to solve the issues in the study case of KPPIP. It starts with the introduction of the scenarios, and it is followed by the procedure.

"The science of decision-making is to make sure there is an effective decision process in place."

- Pearl Zhu -

5 The Proposed Methodology

Firstly, the scenarios are explained in Section 5.1. The establishment of the criteria is explained in Section 5.2. Section 5.3 displays the weighting method procedure with B-BWM. Section 5.4 presents the procedure of GDM. The project scoring with the ER approach is presented in Section 5.5.

5.1 The Framework of the Case Study

The methodology involves four scenarios, which will be used to analyze the benefit of criteria weightings with B-BWM and project scoring with the ER approach. **Scenario 1** represents the original assessment of KPPIP. **Scenario 2** is a reevaluation of KPPIP criteria with B-BWM in each sector, resulting in four sets of criteria weights, while **Scenario 3** implements the group B-BWM that combines the assessment of four sectors into one set of weights. Scenario 2 and Scenario 3 give the sectoral and group project scoring that use the current project assessment in KPPIP. **Scenario 4** uses the combined criteria, which is taken from a survey of KPPIP. The project assessment will use the current assessment of KPPIP, which will be transformed into BS for the project scoring with ER approach. The illustration of the scenarios is presented in Figure 2.

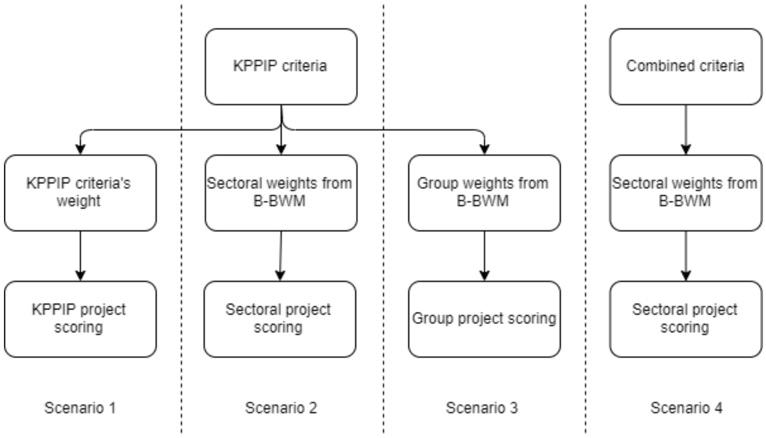

Figure 2. Scenarios of this research.

The research is performed with two rounds of surveys to assess the criteria's importance level and the evaluation of the projects. The surveys are conducted by using Excel sheets.

Criteria Assessment – Survey Phase 1

There are three steps in the survey Phase 1: (1) Assess KPPIP criteria's importance level, (2) Select the proposed supplementary criteria from the literature study, and (3) Assess the selected supplementary criteria's importance level.

The assessment of criteria's importance level will be used to compute the weight, as presented in Section 5.3. The KPPIP's criteria weight will be used for both Scenario 2 and Scenario 3, while the supplementary criteria's weight will be used for Scenario 4. The structure of the survey is provided in Figure 3 below.

Project Scoring – Survey Phase 2

The second phase survey asks the same respondents to assess the projects. In total, five project assessments from each sector will be obtained. The chosen projects belong to the prioritized list from each sector in the current assessment. The purpose is to generate more relevant and accurate information because the DM is expected to be more familiar with the projects.

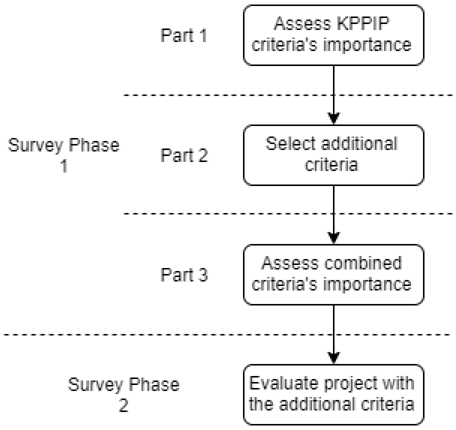

Figure 3. The steps of data collection through surveys.

5.2 Establishing the Criteria

In the Phase 1 survey, the respondents select the supplementary criteria from a list that has been acquired in the literature study, as presented in Table 2. An example of the survey is displayed in Appendix B. The criteria set can be different for each sector.

5.3 Criteria Weights Assessment with Belief-Based Best-Worst Method

The assessment of the criteria's importance level from the survey is needed in order to compute the weights. There are six steps to be followed. Six steps are conducted to obtain the criteria's weights for Scenario 2 and Scenario 4. The procedures are presented in Figure 4.

Step 1. Create a set of criteria. In this study, step 1 will obtain two sets of criteria. The first set is the existing KPPIP criteria that are used in Scenario 2 and Scenario 3. The second set is the combined criteria set that is used in Scenario 4.

Step 2. The DMs select the "Best" and "Worst" criteria in each set.

Step 3 and **Step 4.** The DMs compare the "Best" criterion to other criteria, and other criteria to the "Worst" criterion, respectively. These steps will acquire $\beta_{k,Bj}$ and $\beta_{k,jW}$ for every set of criteria.

Step 5. Construct the acquired information in Step 3 and 4 into BS as S_{Bj} and S_{jW} as in Equation (13) and (14).

Step 6. Compute the criteria's weight, W_j , and ξ, with Equation (17) and (18) by using Matlab.

5.4 Group Weights Assessment with Group B-BWM

The obtained weights from every DMs are used in order to compute the group weights. The group weights are used in Scenario 3. The procedure is illustrated in Figure 5, and the steps are as follows:

Step 7. Five sub-steps can be exercised to obtain the group weights. In this case, the set of criteria has two levels of hierarchy; thus, the global weights must be computed from the local weights. The global weights are used in all measurements in the subsequent steps.

- **Step 7a.** Compute IR with Equation (25). The average from all categories is taken as the final IR.
- **Step 7b.** Calculate AU with Equation (27) and Equation (28). The average of all categories is taken as the final AU.
- **Step 7c.** Compute RD with Equation (29) and use the obtained IR and AU.
- **Step 7d.** Compute the weights of DMs with Equation (30).
- **Step 7e.** Compute the collective weights with Equation (31).

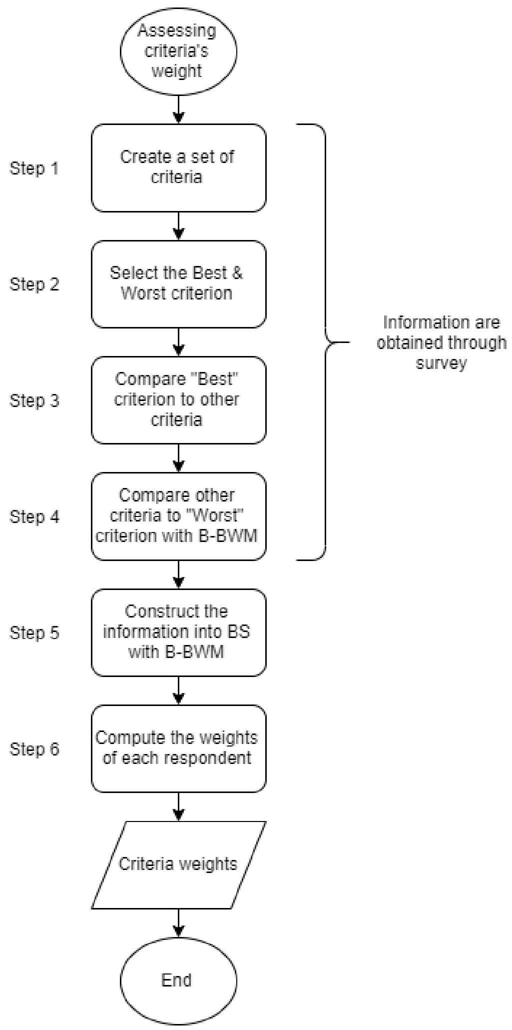

Figure 4. Procedure to Acquire Criteria Weights with B-BWM.

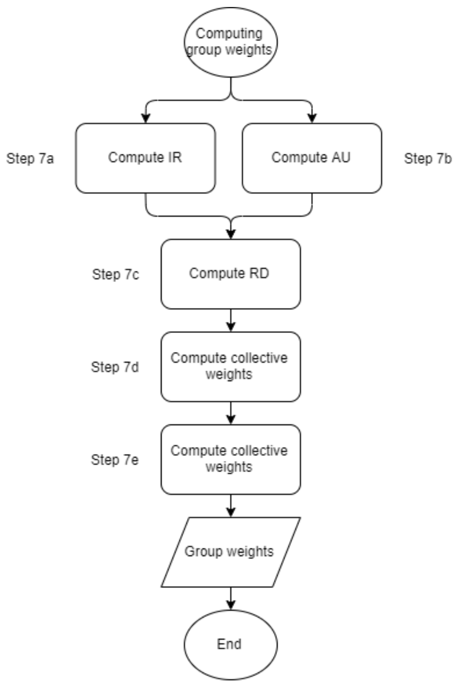

Figure 5. Procedure to Acquire Group Weights

5.5 Project Scoring Assessment with Evidential Reasoning Approach

In this section, the first part will explain the project assessment for the project scoring and the transformation of deterministic scoring that is implemented by KPPIP. The second part describes the procedures to obtain the project's score.

5.5.1 Project Assessment

The project assessment uses the criteria set and weights that are established in Section 5.3 and 5.4. The primary data to be acquired in this part is the project evaluation by using the form of BS. The survey assesses five projects in each sector, in which the name of the projects is denoted due to confidentiality.

Transformation of Deterministic Scoring into Belief Structure

The current project assessment with the KPPIP criteria set is used for Scenario 2, Scenario 3, and partially in Scenario 4 (because it uses the combined criteria). Because the KPPIP's current assessment implemented deterministic scoring in evaluating the projects, it must be transformed into BS with equivalence rules to be aggregated with the new assessment.

Suppose a large value $h_{r+1,j}$ is preferred to a smaller value $h_{r,j}$. $h_{R,j}$ is the largest feasible value and $h_{1,j}$ the smallest. Then, the assessment value h_z can be represented using the following equivalent expectation:

$$S_j(h_z) = \{(h_{r,j}, \gamma_{r,z}), r = 1, \ldots, R\}, \qquad (46)$$

Where

$$\gamma_{r,z} = \frac{h_{r+1,j} - h_z}{h_{r+1,j} - h_{r,j}}, \ \gamma_{r+1,j} = 1 - \gamma_{r,z}, \text{ if } h_{n,i} \leq h_z \leq h_{n+1,i}, \qquad (47)$$

$$\gamma_{k,z} = 0 \text{ for } k = 1, \ldots, R, k \neq n, n + 1. \qquad (48)$$

The current project assessment was implemented quantitatively and it only requires the quantitative data transformation technique. The transformation for other types of data can be found in Yang (2001).

5.5.2 Project Scoring

The project scoring procedure consists of two steps. It takes the acquired weights that follow the procedure in Section 5.3 and 5.4. Before conducting the project scoring, the transformed KPPIP current assessment (from Sub-section 5.5.1) is used. Step 8 is implemented for Scenario 4, which has supplementary criteria that have not been evaluated by the DMs previously. The example of the survey is presented in Appendix C. The process in this part is pictured in Figure 6.

Step 8. The DMs evaluate the projects for each criterion with the ER approach.

Step 9. Calculate projects' scores with the ER approach by following Equation (34) to Equation (45).

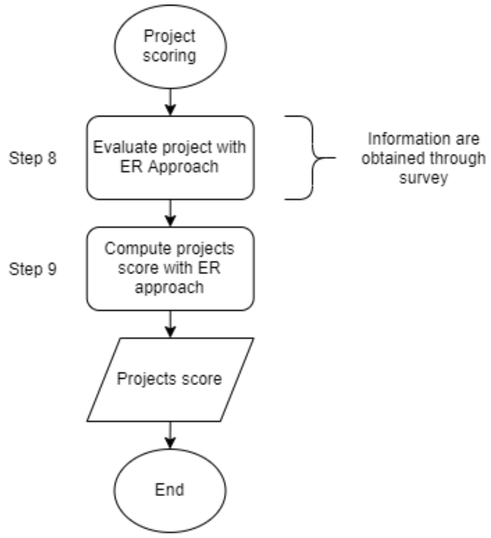

Figure 6. The procedure of project scoring with ER approach.

Chapter IV Case Study

This chapter consists of three sections. First, Section 6 discusses the general information of KPPIP and analyses the information provided by KPPIP regarding the decision-making process that has been implemented in the current assessment. Following this, Section 7 provides data collection and analysis. Section 8 discusses the result.

"The quality of a decision cannot be solely judged based on its outcome "
- Nassim Nicholas Taleb -

6 Large Infrastructure Projects Prioritization of KPPIP in Indonesia

This section presents an overview of the selected case study. It is about the selection of LIPs in Indonesia, in which the process is executed by a government body, KPPIP.

6.1 Background

The Indonesian government perceives that infrastructure provisions often face obstacles due to lack of coordination between various stakeholders of the private and public sectors, or between the governmental bodies itself (KPPIP, 2016). Ziara et al. (2002) stated that prioritizing infrastructure projects should integrate the views of all parties involved. These issues led the infrastructure establishment to grow slowly and affected economic growth due to the misalignment of the views. The government believes that an action must be taken to prevent slower growth in the future.

There are 247 projects proposed in the first selection process. Developing 247 projects at the same time is impossible. Thus, the government decided to select only 37 projects that could match its capability. The projects scattered around the provinces in Indonesia can be seen in Figure 7. The projects selection was implemented by KPPIP, which was established by the central government to develop infrastructure projects in Indonesia

Figure 7. List of 37 KPPIP priority projects (KPPIP, 2016).

6.2 The Organizational Structure of KPPIP

KPPIP is an inter-ministerial/government institutional committee, which focuses on project preparation quality improvement as well as debottlenecking. An implementation team is established with the responsibilities to assist the committee by exercising six main tasks, as presented in Figure 8.

6.3 Decision-Making Process

In the decision-making process, the level of difficulty increases due to many factors such as the involvement of many parties, priorities, and other factors; thus, it needs strategic planning to select the optimal alternatives (Ziara et al., 2002). KPPIP created a mechanism and divided project selection into three stages. The process is presented in Appendix E.

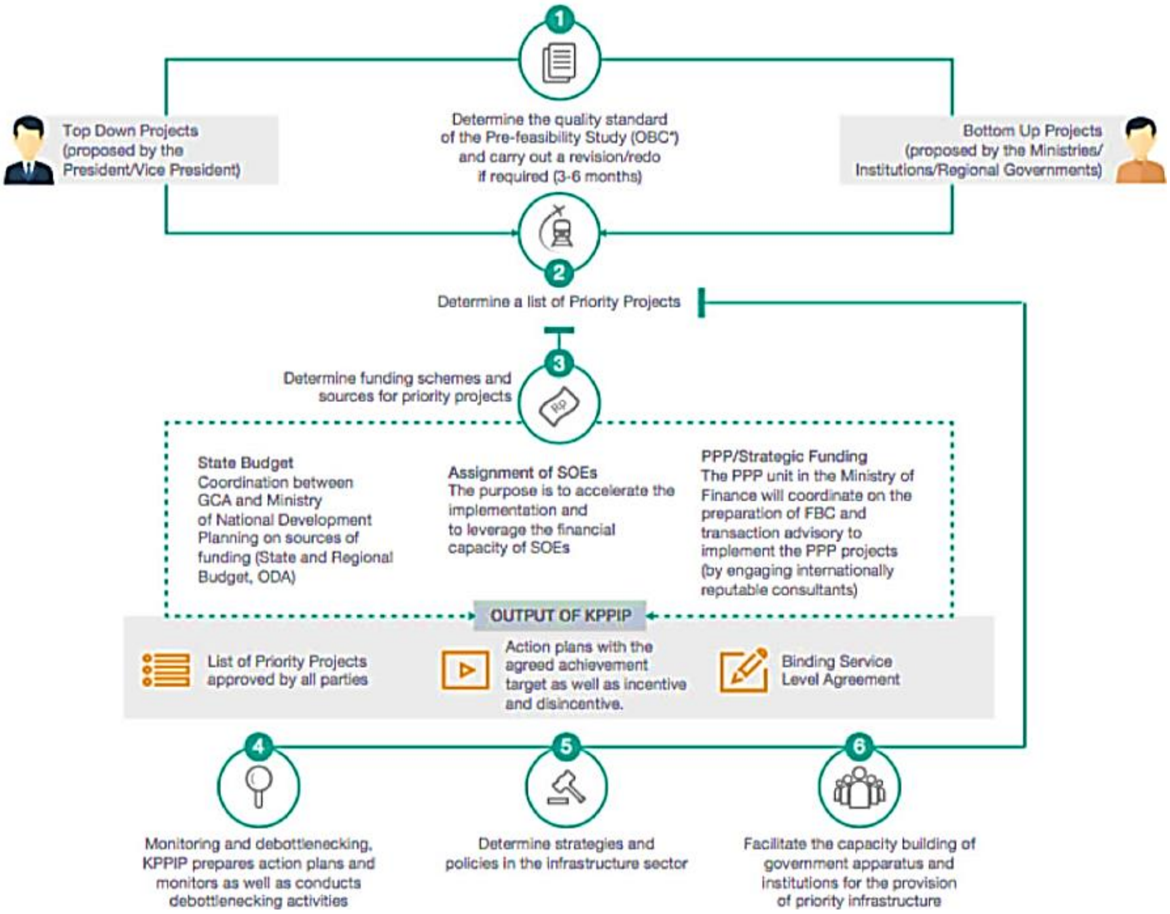

Figure 8. KPPIP's workflow to accelerate project development (KPPIP, 2016).

The last stage qualifies the projects through eliminative criteria that reduce 247 projects to 80. The 80 projects are evaluated with 20 scoring criteria and are reduced to 37 priority projects. The original projects' rankings of the 80 projects are presented in the table in Appendix E. The project evaluation is conducted separately by each sector. However, the evaluation is combined into one list of 80 projects. The definition of the scoring criteria is provided in Appendix F.

KPPIP Current Criteria Set

The 20 KPPIP's criteria are categorized into four main decision criteria. This criteria system is set through discussions among KPPIP internal parties. They assign the level of importance for each of the criterion and sub-criterion. The list of criteria and sub-criteria are presented in Table 6.

The KPPIP criteria set does not consider some criteria, as found in the literature study. It is unknown whether KPPIP considers those criteria unnecessary or they are unaware of them.

The level of importance of the criteria has been provided. All the sub-criteria, except the "executive direction" that stands as a single criterion, weight 4%. The "executive direction" criterion weights 8%, while the criteria "issuance of project permits" and "number of authorities involved" weight 12%. These weights arrangements are intended to provide the simplicity of the process, and it might not reflect their real importance. The weights of each main category are presented in Table 6.

KPPIP has developed some assessment grades to evaluate the projects. However, they consider the grades as deterministic scores, which are better assessed with range scores.

Table 6. KPPIP criteria set and the weights (KPPIP, 2017).

Main category & criteria		Global Weights
1.	Executive Direction	0,08
2.	Project Preparation	
-	Outline Business Case (OBS) comprehensiveness	0,04
-	Economic benefits	0,04
-	Technical planning complexity	0,04
-	Project Development Fund (PDF) support	0,04
-	Infrastructure readiness/requirement surrounding the project	0,04
3.	Funding complexities	
-	Acquisition of interest from the investor(s)	0,04
-	Determination of funding scheme	0,04
-	Funding resources synchronization	0,04
-	Public Service Organization (PSO) structuration	0,04
-	Granting of credit risk	0,04
-	Granting of business feasibility support	0,04
4.	Authorities coordination complexities	
-	Stakeholder Buy-in	0,04
-	Land acquisition coordination	0,04
-	Spatial plan synchronization	0,04
-	Issuance of project permits (contains 3 sub-criteria)	0,12
-	Number of authorities involved (contains 3 sub-criteria)	0,12
-	Publishing of supporting policies (general/sectoral)	0,04
-	Implementation of procurement between government and business entity	0,04
-	Synchronization with other National Strategic Projects	0,04

7 The Application of the Proposed Method

This section comprises of three sections. Section 7.1 starts with presenting the supplementary set of criteria. Section 7.2 provides an analysis of the criteria and how to obtain the weights. Section 7.3 provides the analysis of the project scoring and ranking.

7.1 Supplementary Criteria Determination

In the first survey, the DMs have selected several criteria that they think might be relevant to be added as influencing criteria for the selection of LIPs. The outcome is presented in Table 7. Each sector has a different preference for the complexity criteria.

Table 7. Selection of supplementary criteria in each sector.

Sector			
Energy & Electricity (EE)	Road & Bridge (RB)	Transportation (TT)	Water & Sanitation (WS)
Technical (T) Category			
(T1) High-quality requirements/standards, (T2) Number & variety of technological dependencies, (T3) Schedule and duration of the project, (T4) Number & variety of activities/tasks/process, (T5) Size in Capital Expenditure, (T6) Number & variety of the scope/ components/specifications, and (T7) Dynamic of plan, organization, and components.	(T1) Technological newness/innovation of the project/products, (T2) High-quality requirements/standards, and (T3) Size in Capital Expenditure.	(T1) Technological newness/innovation of the project/products, (T2) Schedule and duration of the project, (T3) Size in Capital Expenditure, and (T4) Dynamic of plan, organization, and components.	(T1) Size in Capital Expenditure, (T2) Number & variety of the scope/components/ specifications, and (T3) Dynamic of plan, organization, and components.
Organizational (O) Category			
(O1) Capability & competencies/skills of the team (knowledge, experience, education, training), (O2) Availability of people, material and of any resources due to sharing, (O3) Team/partner cooperation, coordination, communication, and trust, (O4) Number & variety of interfaces in the project organization, (O5) Number & variety of hierarchical levels, (O6) Number & variety of different occupational specializations/disciplines, (O7) Number & variety of decision to be made, and (O8) Internal politic issues (ambiguity, hidden information, lack of support).	(O1) Capability & competencies/skills of the team (knowledge, experience, education, training), and (O2) Number & variety of hierarchical levels.	(O1) Capability & competencies/skills of the team (knowledge, experience, education, training), (O2) Availability of people, material and of any resources due to sharing, (O3) Number & variety of different occupational specializations/disciplines, and (O4) Internal politic issues (ambiguity, hidden information, lack of support).	(O1) Team/partner cooperation, coordination, communication, and trust, (O2) Number & variety of interfaces in the project organization, (O3) Number & diversity of staff (experience, background, social span), (O4) Number & variety of hierarchical levels, and (O5) Internal politic issues (ambiguity, hidden information, lack of support).
External (E) Category			
(E1) Form of contract, (E2) Level of competition and conflict between stakeholders, (E3) Neighboring environment (including site access/location/difficulty), (E4) Number & variety of the interests/objectives/goals, (E5) Number & variety of stakeholders, (E6) Number & variety of investors/ financial resources, (E7) Site compensation and clearance, and (E8) Social disturbance.	(E1) Level of competition and conflict between stakeholders (E2) Number & variety of the interests/objectives/ goals, and (E3) Number & variety of investors/financial resources.	(E1) Level of competition and conflict between stakeholders, (E2) Number & variety of stakeholders, (E3) Number & variety of investors/financial resources, (E4) Unrealistic demand/ expectation, and (E5) Social disturbance.	(E1) Level of competition and conflict between stakeholders, (E2) Number & variety of the interests/objectives/ goals, (E3) Number & variety of investors/financial resources, and (E4) Social disturbance.

7.2 Obtaining Weights of Criteria by Applying B-BWM

The KPPIP criteria are rearranged after a discussion with experts to represent the project complexity better, as presented in Table 8. The reason behind this was to create the criteria set that could fit with the TOE categories when it is combined with the KPPIP criteria set. As a result, some criteria are shifted to fit with the category.

The "executive direction" criterion is moved into a new category named "policy complexity." Two other criteria previously from "authorities coordination complexity" are moved into "policy complexity" category. "Authorities coordination complexity" is renamed as "coordination complexity." In the end, seven complexity categories are developed: project preparation, funding, coordination, policy, and three new criteria from the literature, i.e., technical, organizational, and external.

Table 8. The reorganized KPPIP criteria.

Complexity Category	Criteria
Project Preparation Complexity (PP)	PP1. Outline Business Case comprehensiveness PP2. Economic benefits PP3. Technical planning complexity PP4.Project Development Fund support PP5. Infrastructure readiness/requirement surrounding the project
Funding Complexity (F)	F1. Acquisition of interest from the investor(s) F2. Determination of funding scheme F3. Funding resources organization F4. Public Service Organization structuration F5. Granting of credit risk F6. Granting of business feasibility support
Coordination Complexity (C)	C1. Stakeholder buy-in C2. Land acquisition coordination C3. Spatial plan synchronization C4. Number of authorities involved C5. Implementation of procurement between government and business entity C6. Synchronization with other National Strategic Project
Policy Complexity (PC)	P1. Issuance of project permits P2. Publishing of supporting policies (general/sectoral) P3. Executive direction

As mentioned in Figure 2, Scenario 2 and Scenario 3 use the set of KPPIP criteria as presented in Table 8 and the criteria's importance is reassessed by DMs through surveys. Scenario 4 uses the KPPIP current set of criteria from Table 8 and the supplementary criteria set from Table 7.

7.2.1 Data Collection

From the survey, the assessment of the criteria's level of importance is collected. There are two parts, first, the KPPIP criteria; second, the supplementary criteria.

The KPPIP Criteria

The first survey is shown in Appendix B, which was taken from the TT sector. DM from each sector followed Step 1 to Step 4 of B-BWM. In Step 5, the assessment from the survey is transformed into BS. The result is presented in Table 9 for the main category, and the table in Appendix G is the criteria within each category. The table shows two pairwise comparisons. The "Best to Others" column is obtained by following Step 3 that compares "Best" criterion to "Other" criteria, while "Others to Worst" column follows Step 4 that compares "Other" criteria to "Worst" criterion.

Table 9. The KPPIP category assessment from four sectors.

Main Category											
Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst
Energy & Electricity			Road & Bridge			Transportation			Water & Sanitation		
PP^B	{(1; 1)}	{(7; 1)}	PP^B	{(1; 1)}	{(7; 0,7), (Ω; 0,3)}	PP^B	{(1; 1)}	{(2; 0,2), (3; 0,8)}	PP^B	{(1; 1)}	{(5; 0,8), (Ω; 0,2)}
F	{(1; 1)}	{(7; 1)}	F	{(3; 0,7), (Ω; 0,3)}	{(3; 0,8), (Ω; 0,2)}	F	{(1; 0,2), (2; 0,8)}	{(2; 0,8), (3; 0,2)}	F	{(2; 1)}	{(4; 0,7), (Ω; 0,3)}
C^W	{(7; 1)}	{(1; 1)}	C	{(5; 0,8), (Ω; 0,2)}	{(1; 0,6), (Ω; 0,4)}	C	{(1; 0,1), (2; 0,9)}	{(2; 0,9), (3; 0,1)}	C^W	{(5; 0,8)}	{(1; 1)}
P	{(1; 1)}	{(7; 1)}	P^W	{(7; 0,7), (Ω; 0,3)}	{(1; 1)}	P^W	{(2; 0,2), (3; 0,8)}	{(1; 1)}	P	{(2; 0,3), (3; 0,7)}	{(5; 0,5), (Ω; 0,5)}

B = Best category, W = Worst category

The Combined Criteria

Again, by following Step 1 to Step 4, the respondents assessed the supplementary criteria from Table 7. In Step 5, the assessment is transformed. The result can be found in Appendix H. The assessment of KPPIP criteria have been conducted, and it is used in the combined criteria set. The assessment for the combined category is presented in Table 10. The survey can be seen in Part III of Appendix B.

Table 10. The combined category assessment from four sectors.

Main Category											
Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst	Category	Best to Others	Others to Worst
Energy & Electricity			Road & Bridge			Transportation			Water & Sanitation		
PP^B	{(1; 1)}	{(5; 1)}	PP^B	{(1; 1)}	{(7; 0,9), (Ω; 0,1)}	PP^B	{(1; 1)}	{(3; 0,2), (4; 0,8)}	PP^B	{(1; 1)}	{(3; 0,2), (4; 0,8)}
F	{(1; 1)}	{(5; 1)}	F	{(2; 0,7), (Ω; 0,3)}	{(5; 0,7), (Ω; 0,3)}	F	{(1; 0,2), (2; 0,8)}	{(1; 0,8), (2; 0,2)}	F	{(1; 0,2), (2; 0,8)}	{(1; 0,8), (2; 0,2)}
C	{(1; 1)}	{(5; 1)}	C	{(3; 0,7), (Ω; 0,3)}	{(2; 0,8), (Ω; 0,2)}	C	{(1; 0,1), (2; 0,9)}	{(1; 0,9), (2; 0,1)}	C	{(1; 0,1), (2; 0,9)}	{(1; 0,9), (2; 0,1)}
P	{(1; 1)}	{(5; 1)}	P	{(2; 0,8), (Ω; 0,2)}	{(5; 0,8), (Ω; 0,2)}	P	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}	P	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}
T	{(1; 1)}	{(5; 1)}	T	{(4; 0,7), (Ω; 0,3)}	{(6; 0,7), (Ω; 0,3)}	T	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}	T	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}
O^W	{(5; 1)}	{(1; 1)}	O^W	{(7; 0,9), (Ω; 0,1)}	{(1; 1)}	O	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}	O	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}
E	{(1; 1)}	{(5; 1)}	E	{(6; 0,8), (Ω; 0,2)}	{(2; 0,7), (Ω; 0,3)}	E^W	{(3; 0,2), (4; 0,8)}	{(1; 1)}	E^W	{(3; 0,2), (4; 0,8)}	{(1; 1)}

B = Best category, W = Worst category

7.2.2 Calculation

The Weights of KPPIP Criteria with B-BWM

After collecting the data, Step 6 is conducted to obtain the criteria weights. The results of the main category in the KPPIP criteria are presented in Figure 9. The figure reveals the range of interval weights that vary in each sector. Interval weights can be seen in RB and WS sectors in each category. As an example, “project preparation” category in the RB sector reveals the broadest range of interval weight with a minimum 0,25 and maximum 0,59, which expresses the uncertainty of the DM. It means that the weights between that interval are possible values in the case when the DM does not properly assess the importance of the criteria.

After obtaining all weights from each sector, data are analyzed and correlated with the reliability measure by following Step 7. The average weights in each sector are taken to compute the group weights. First, find the IR for each respondent by using Equation (25), the AU with Equation (28), and computes the RD with Equation (29). The weights of the DMs are computed with Equation (30), and the collective weight can be obtained from Equation (31). The RD of DMs is presented in Figure 10. This figure shows that EE sector plays the most crucial role in deciding the project because it has the highest RD with a score of 0,04.

As one measure to compute RD, IR shows the inconsistency of the DMs in assessing the importance of the criteria in the survey. As an illustration, an example is given from the "policy" category from TT sector. See Appendix B. In comparing "issuance of project permits" criterion (Best) to "publishing of supporting policies" criterion (Others); it is scored 20 (grade 3, see Table 3) and 80 (grade 4). However, it is not consistent when "publishing of supporting policies" criterion is compared to the worst criterion "executive direction" with scores of 80 (grade 3) and 20 (grade 4). One possible consistent assessment is to have scores 80 (grade 3) and 20 (grade 2). Nonetheless, there are many possible alternatives.

The second measure, AU, shows the uncertainty in the assessment of DMs. As an example, when DMs consider one criterion with score 80 in grade 2, and 20 in grade 3, the uncertainty is 0,23. Another case, a score of 70 in grade 3, has an uncertainty degree of 0,13, meaning a lower uncertainty than the first example. Finally, all the uncertainties are aggregated into AU measure.

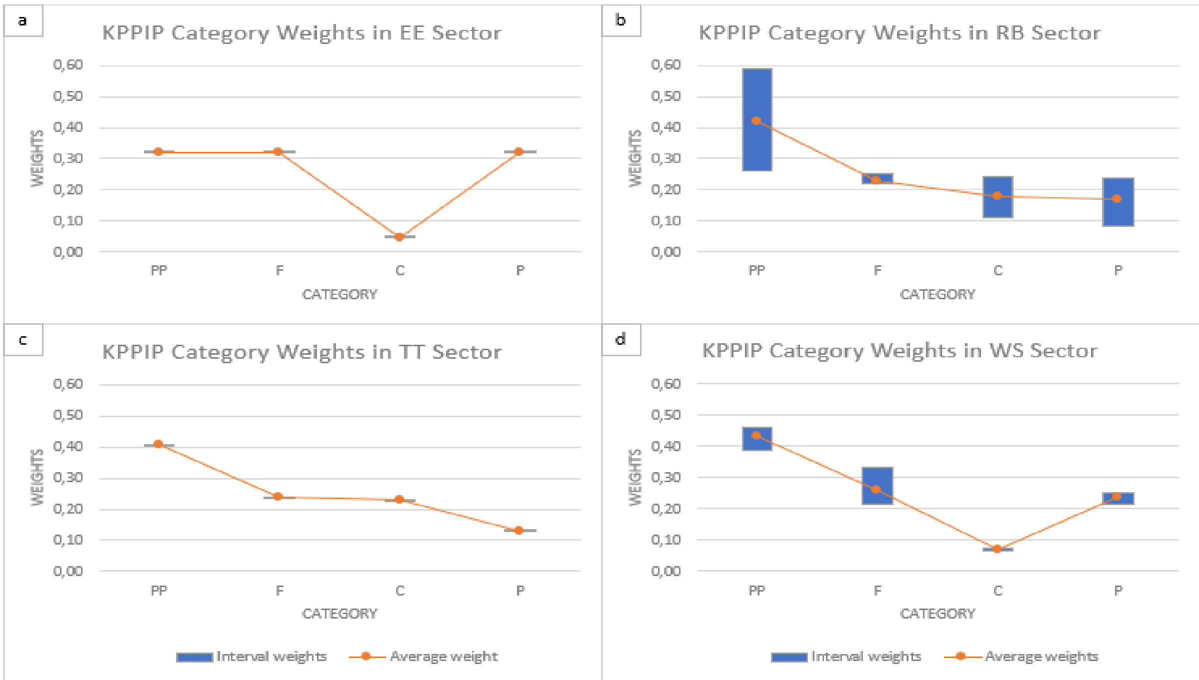

Figure 9. The interval weights for the main categories in KPPIP criteria in each sector.

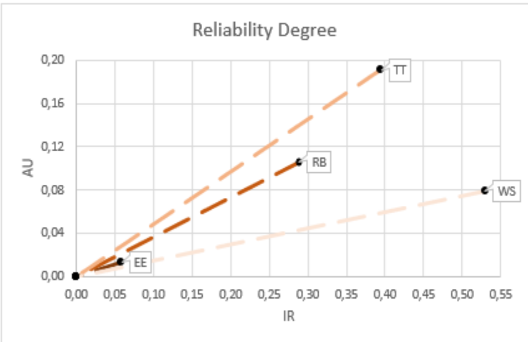

Figure 10. The Reliability Degree of DMs.

The RD of DMs is calculated, and it is presented in Figure 10. The figure shows the highest RD is the DM from TT sector. It means that TT sector is the least reliable DM because it shows high inconsistency and uncertainty. It has scores of 0,39 for IR and 0,19 for AU.

Based on the reliability of DMs, the collective weights of criteria are calculated. For example, the average weights of the "project preparation" category in EE, RB, TT, and WS are 0,32, 0,42, 0,41, and 0,43, respectively, which can be seen in Figure 9. These weights are multiplied with the DMs weights by using Equation (30). The weights for EE, RB, TT, and WS are 0,31, 0,26, 0,23, 0,20, respectively. The weight of the DM from EE sector is multiplied with the weight of "project preparation" category, 0,32, and similarly for all sectors. The total sum represents the average group weight, which is presented in Figure 11.

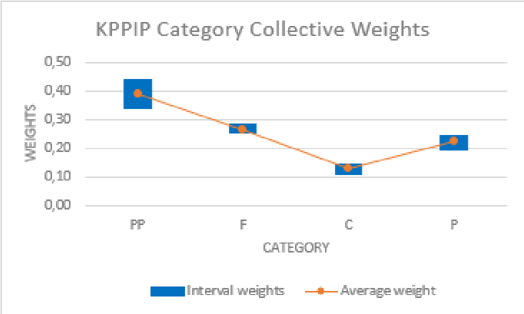

Figure 11. The collective weights for the main categories in KPPIP criteria.

Figure 12 shows the weights for the criteria, which are computed with Step 6. This figure presents only the average weights in Scenario 1, 2, and 3 for simplification purposes.

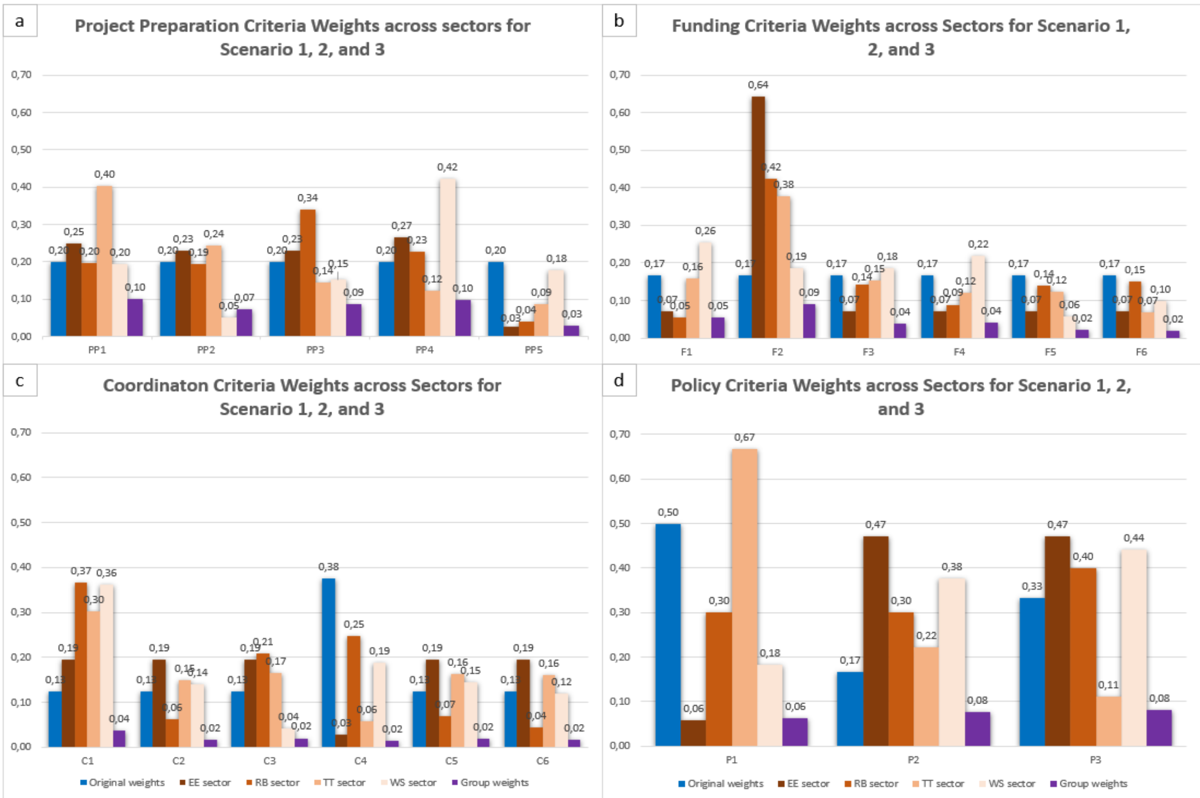

Figure 12. The weights of KPPIP criteria across sectors in Scenario 1, 2, and 3.

The Weights of the Combined Criteria with B-BWM

Also follows Step 6, the weight computation results in the interval weights of the categories in the combined criteria set, which is shown in Figure 13. Again, RB and WS sectors show a broad range of interval weights, while the TT sector shows a slight uncertainty. In sector EE, the DM can be judged as fully consistent.

In Figure 14, the average weights for each criterion from the supplementary categories are presented. These criteria apply only in Scenario 4. The DMs in each sector have selected a different number of criteria. For example, in the technical category, EE sector, RB sector, TT sector, and WS sector have seven, three, four, and three criteria, respectively. The number in TOE notation represents different criteria according to each sector, as provided in Table 7.

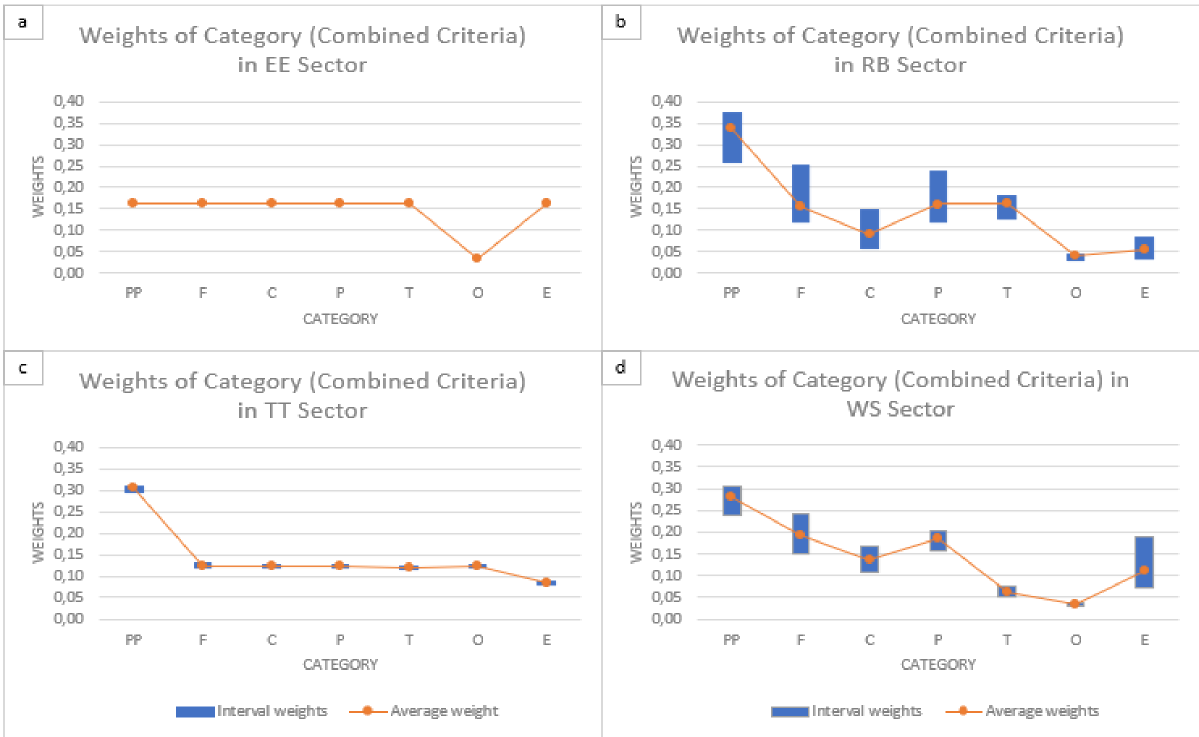

Figure 13. The weights of the combined criteria for the main category in each sector.

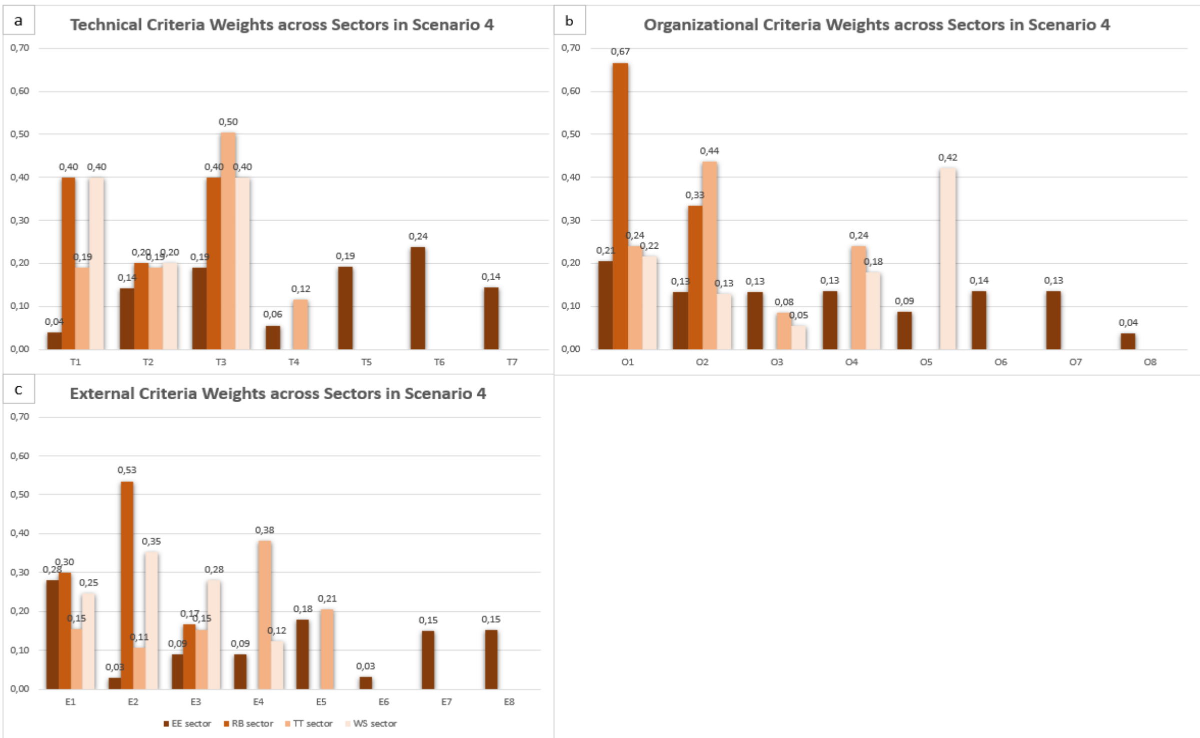

Figure 14. The weights of the combined criteria for TOE categories.

7.2.3 Synthesis of Criteria's Global Weights

The results from the four scenarios are gathered. The previous figures of local weights comprising the categories and criteria are used to compute the global weight. The evaluation of the global weight for the main category and criteria are presented in Table 11 and Table 12. Further discussion is presented in Sub-section 8.2.1.

Table 11. Global weights and the rankings of the main categories in the four scenarios.

Category	Scenario 1		Scenario 2							
	KPPIP		EE		RB		TT		WS	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
Project Preparation	0,20	4	0,32	1	0,42	1	0,41	1	0,43	1
Funding	0,24	2	0,32	1	0,23	2	0,24	2	0,26	2
Coordination	0,32	1	0,05	4	0,18	3	0,23	3	0,07	4
Policy	0,24	2	0,32	1	0,17	4	0,13	4	0,24	3
Category	Scenario 3		Scenario 4							
	Group		EE		RB		TT		WS	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
Project Preparation	0,39	1	0,16	1	0,34	1	0,31	1	0,28	1
Funding	0,27	2	0,16	1	0,16	4	0,12	2	0,19	2
Coordination	0,13	4	0,16	1	0,09	5	0,12	3	0,14	4
Policy	0,22	3	0,16	1	0,16	3	0,12	5	0,19	3
Technical	-	-	0,16	1	0,16	2	0,12	6	0,06	6
Organizational	-	-	0,03	7	0,04	7	0,12	4	0,03	7
External	-	-	0,16	1	0,05	6	0,08	7	0,11	5

Table 12. Global weights and the rankings of the criteria in four scenarios.

Scenario 1			Scenario 2								Scenario 3		Scenario 4							
KPPIP			EE		RB		TT		WS		Group		EE		RB		TT		WS	
C	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
PP1	0,04	4-20	0,08	5	0,08	4	0,16	1	0,08	4	0,10	1	0,04	6	0,14	1	0,12	1	0,05	4
PP2	0,04	4-20	0,07	6	0,08	5	0,10	2	0,02	14	0,07	7	0,04	9	0,08	3	0,07	3	0,01	23
PP3	0,04	4-20	0,07	7	0,14	1	0,06	6	0,07	7	0,09	4	0,04	8	0,05	7	0,04	7	0,04	8
PP4	0,04	4-20	0,08	4	0,10	3	0,05	7	0,18	1	0,10	2	0,04	5	0,04	8	0,04	9	0,12	1
PP5	0,04	4-20	0,01	19	0,02	16	0,04	13	0,08	5	0,03	13	0,00	36	0,03	11	0,03	14	0,05	5
F1	0,04	4-20	0,02	8	0,01	17	0,04	8	0,07	6	0,05	9	0,01	24	0,02	15	0,02	19	0,05	6
F2	0,04	4-20	0,20	1	0,10	2	0,09	3	0,05	9	0,09	3	0,10	1	0,06	6	0,05	6	0,04	11
F3	0,04	4-20	0,02	9	0,03	13	0,04	12	0,05	10	0,04	11	0,01	26	0,02	16	0,02	21	0,04	12
F4	0,04	4-20	0,02	10	0,02	15	0,03	17	0,06	8	0,04	10	0,01	25	0,02	18	0,01	25	0,04	9
F5	0,04	4-20	0,02	11	0,03	14	0,03	15	0,01	15	0,02	14	0,01	27	0,02	17	0,02	24	0,01	27
F6	0,04	4-20	0,02	12	0,04	12	0,02	18	0,03	12	0,02	16	0,01	28	0,01	26	0,01	32	0,02	20
C1	0,04	4-20	0,01	14	0,07	6	0,07	5	0,03	13	0,04	12	0,03	10	0,03	13	0,04	8	0,05	7
C2	0,04	4-20	0,01	15	0,01	19	0,03	14	0,01	18	0,02	18	0,03	13	0,01	24	0,02	22	0,02	21
C3	0,04	4-20	0,01	16	0,04	11	0,04	9	0,003	20	0,02	15	0,03	11	0,01	21	0,02	17	0,01	30
C4	0,12	1-2	0,001	20	0,04	10	0,01	19	0,01	16	0,02	20	0,004	35	0,01	28	0,01	33	0,03	16
C5	0,04	4-20	0,01	17	0,01	18	0,04	10	0,01	17	0,02	17	0,03	12	0,01	22	0,02	18	0,02	19
C6	0,04	4-20	0,01	18	0,01	20	0,04	11	0,01	19	0,02	19	0,03	14	0,01	23	0,02	20	0,02	22
P1	0,12	1-2	0,02	13	0,05	9	0,09	4	0,04	11	0,06	8	0,01	29	0,11	2	0,08	2	0,03	13
P2	0,04	4-20	0,15	2	0,05	8	0,03	16	0,09	3	0,08	6	0,08	3	0,04	9	0,03	13	0,07	3
P3	0,08	3	0,15	3	0,07	7	0,01	19	0,10	2	0,08	5	0,08	2	0,02	19	0,01	27	0,08	2
T1													0,01	32	0,07	5	0,02	15	0,02	18
T2													0,02	21	0,03	10	0,02	16	0,01	26
T3													0,03	16	0,07	4	0,06	4	0,02	17
T4													0,01	30			0,01	26		
T5													0,03	15	-				-	
T6													0,04	7			-			
T7													0,02	20						
O1													0,01	31	0,03	14	0,03	11	0,01	28
O2													0,004	41	0,01	25	0,05	5	0,004	31
O3													0,004	40			0,01	30	0,002	32
O4													0,004	38			0,03	12	0,01	29
O5													0,003	42	-				0,01	24
O6													0,004	37			-			
O7													0,004	39					-	
O8													0,001	43						
E1													0,05	4	0,02	20	0,01	28	0,03	15
E2													0,005	34	0,03	12	0,01	31	0,04	10
E3													0,01	22	0,01	27	0,01	29	0,03	14
E4													0,01	23			0,03	10	0,01	25
E5													0,03	17			0,02	23		
E6	*C = Criteria												0,01	33	-				-	
E7	W = Global weight												0,02	19			-			
E8	R = Ranking												0,02	18						

7.3 Projects Scoring by Applying Belief Structure

The new weights from Scenario 2, 3, 4 are used in the project scoring. In this part, Scenario 4 requires an assessment from survey phase 2.

7.3.1 Project Assessment Regarding the Supplementary Criteria

The assessment of the project scoring uses BS to capture the uncertainty of the DMs. The supplementary criteria are set in the survey form with nine assessment grades that represent the relevance of the criteria to the project complexity factors. The higher the DM assigned the grades, the more the criterion contributes to the complexity of the project.

In Step 8 of the proposed procedure, the respondents in each sector assess five different projects. The five projects are considered sufficient to analyze the result. An example of the assessment is presented in Appendix C. The final assessment is provided in Appendix I.

7.3.2 Calculation

The assessment from the second survey is used in Step 9 to calculate the project's score. The scores of the 20 selected projects for the four sectors are presented in Table 13. The projects' ranking in Scenario 1 is altered into 1 to 5 per sector in this case study. The rankings' order follow the original KPPIP's project ranking, as presented in Appendix E.

Compared with Scenario 1, the highest-ranking identified in Scenario 2 changes only in EE sector. In Scenario 3, changes occur in EE and TT sectors. Lastly, in Scenario 4, only RB sector has a different first-ranking.

Table 13. Project's rankings across scenarios in each sector.

Project	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
EE1	0,580	2	0,611	1	0,511	1	0,557	4
EE2	0,583	1	0,583	2	0,504	2	0,625	1
EE3	0,330	5	0,193	5	0,243	5	0,310	5
EE4	0,520	3	0,425	3	0,498	3	0,609	2
EE5	0,510	4	0,393	4	0,451	4	0,604	3
RB1	0,340	4	0,297	4	0,247	5	0,234	5
RB2	0,510	1	0,451	1	0,461	1	0,397	2
RB3	0,410	2	0,370	2	0,255	4	0,257	4
RB4	0,400	3	0,327	3	0,416	2	0,612	1
RB5	0,330	5	0,189	5	0,367	3	0,309	3
TT1	0,240	4	0,142	4	0,132	5	0,350	3
TT2	0,230	5	0,079	5	0,436	2	0,292	5
TT3	0,460	2	0,155	3	0,275	4	0,348	4
TT4	0,350	3	0,260	2	0,444	1	0,452	2
TT5	0,530	1	0,405	1	0,395	3	0,518	1
WS1	0,510	1	0,633	1	0,589	1	0,520	1
WS2	0,390	3	0,581	2	0,457	2	0,453	2
WS3	0,420	2	0,445	4	0,357	3	0,406	3
WS4	0,320	4	0,448	3	0,287	4	0,348	4
WS5	0,320	4	0,170	5	0,260	5	0,275	5

Graphs in Figure 15 illustrates the final rankings across different scenarios. The data reveal significant changes in rankings in some sectors, especially in TT sector. For example, TT2 project's rankings jump from 5 to 2 and a drop for TT5 project from 1 to 3 in Scenario 3. Still comparing in Scenario 3, RB sector projects' rankings change but with less significant impact, while in the other two sectors, the alteration can be ignored. More discussion is presented in the Sub-section 8.2.2.

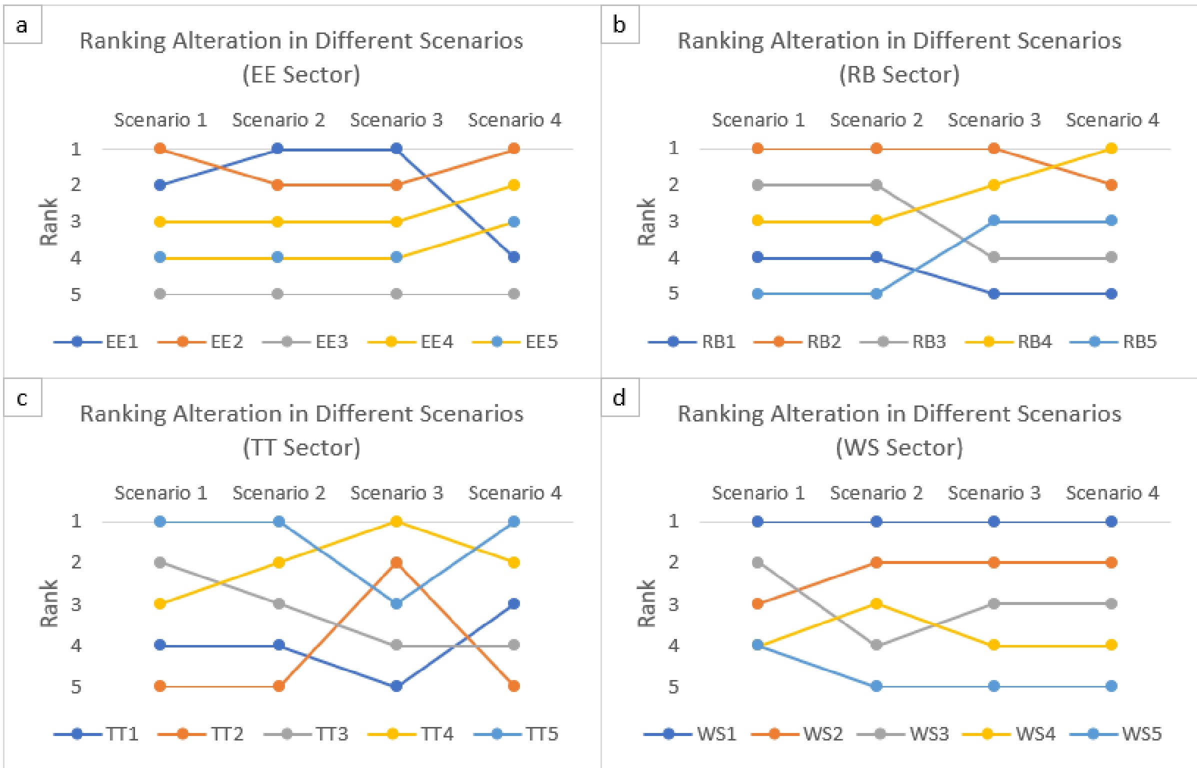

Figure 15. Projects' rankings across scenarios in each sector.

8 Discussion

Section 8.1 starts by presenting the robustness of the analysis. Section 8.2 examines the context and implementation of the approach. Section 8.3 discusses the methodology. Section 8.4 explains the implication of this study.

8.1 Robustness Analysis

The subjectivism problem in the decision-making process leads to the need for a robustness check. The first robustness check is for the survey tool. The tool uses a built-in confirmation tool in Excel sheets to prevent wrong input or error.

A sensitivity analysis is implemented with the aim of checking the robustness of results. It is conducted by changing the weight values of relevant links within the model (Ivanović et al., 2013) and change the highest weight criterion (Mangla et al., 2015). In this case, "project preparation" category is selected for Scenario 2, 3, and 4. Figure 16 presents the sensitivity analysis, which aims to show the difference between Scenario 2, 3, and 4. Two variants are used: weights are reduced and increased by 50%. When the result in the group weights (Scenario 3) is compared to the sectoral weights (Scenario 2), a lower sensitivity can be seen in three sectors: EE, RB, and WS. For example, the sensitivity in project WS4 in Scenario 2 is 0,36 and it decreases into 0,18 in Scenario 3.

The group weights are less sensitive than the sectoral weights.

From the same Figure 16, when comparing Scenario 2 (KPPIP criteria) and 4 (The combined criteria), the result exhibits lower sensitivity in Scenario 4. The more comprehensive the criteria set, the less sensitive the result. For example, EE and WS sectors can represent the decrease of the sensitivity in the figure.

The comprehensiveness of the selection criteria leads to a less sensitive result.

The sensitivity analysis is extended to investigate how it affects the projects' rankings with a focus on the group weights (Scenario 3). It is conducted with nine variants of the weight of "project preparation" category, as presented in Table 14. The weight variations are based on the "project preparation" category from 0,1 to 0,9 with an interval of 0,1. The other criteria's weights change proportionally to the original average group weights.

Table 14. Category weights with the changes in "project preparation" category.

Category	Weights variation									
	1	2	3	*	4	5	6	7	8	9
PP	0,1	0,2	0,3	0,39	0,4	0,5	0,6	0,7	0,8	0,9
F	0,39	0,35	0,30	0,27	0,26	0,22	0,17	0,13	0,09	0,04
C	0,19	0,17	0,14	0,13	0,12	0,10	0,08	0,06	0,04	0,02
P	0,32	0,29	0,25	0,22	0,21	0,18	0,14	0,11	0,07	0,04

*The average group weights

The projects' rankings after applying the different weights are shown in Figure 17. From the figure, extreme changes can happen in EE and RB sectors. For instance, project EE1 can deviate from the first into third ranking in variation 6, and to the fourth-ranking in variation 8. As a result, EE4 is selected as the first ranking.

KPPIP's LIPs selection case is highly sensitive to the change.

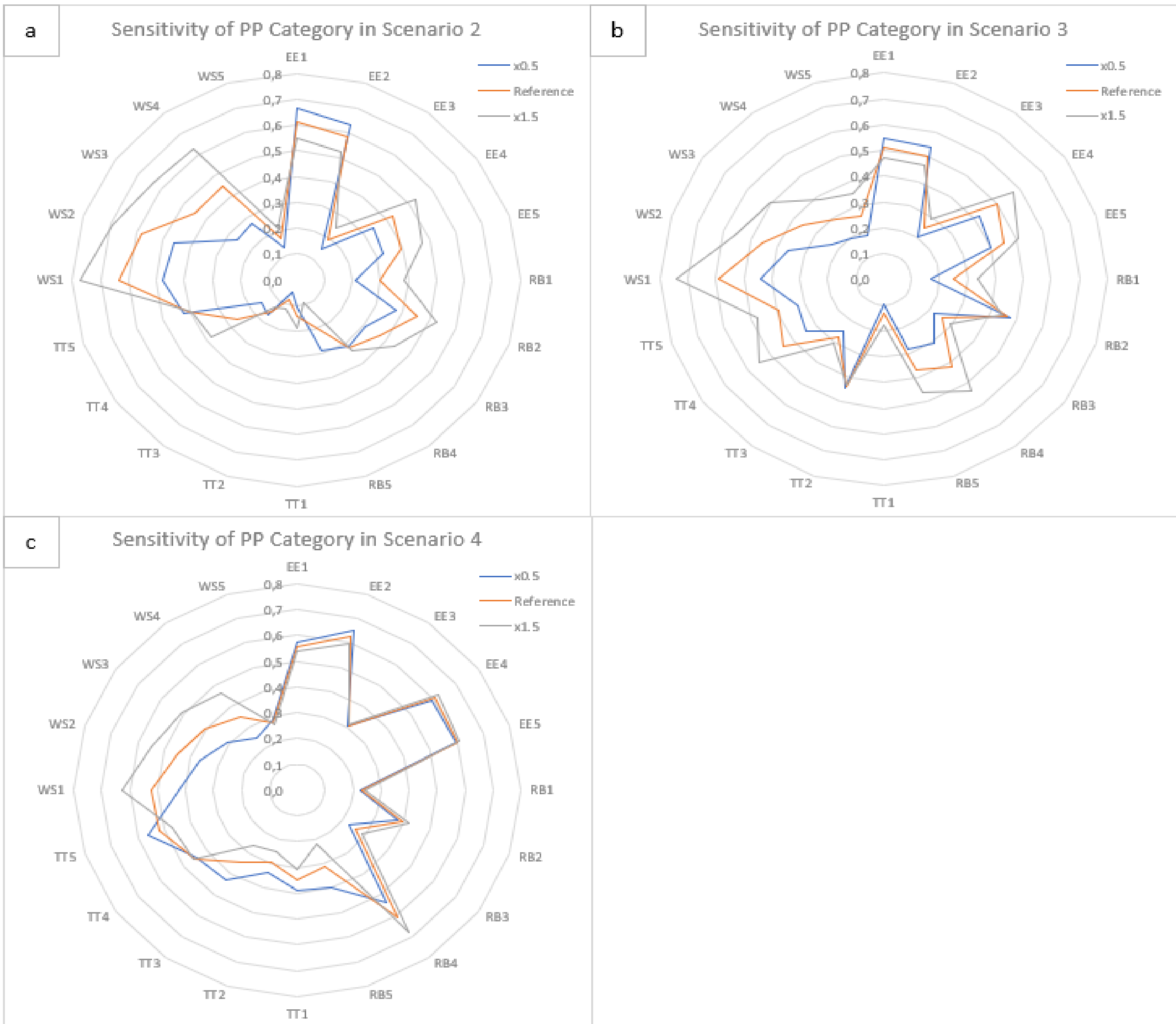

Figure 16. Sensitivity analysis of 2, 3, and 4.

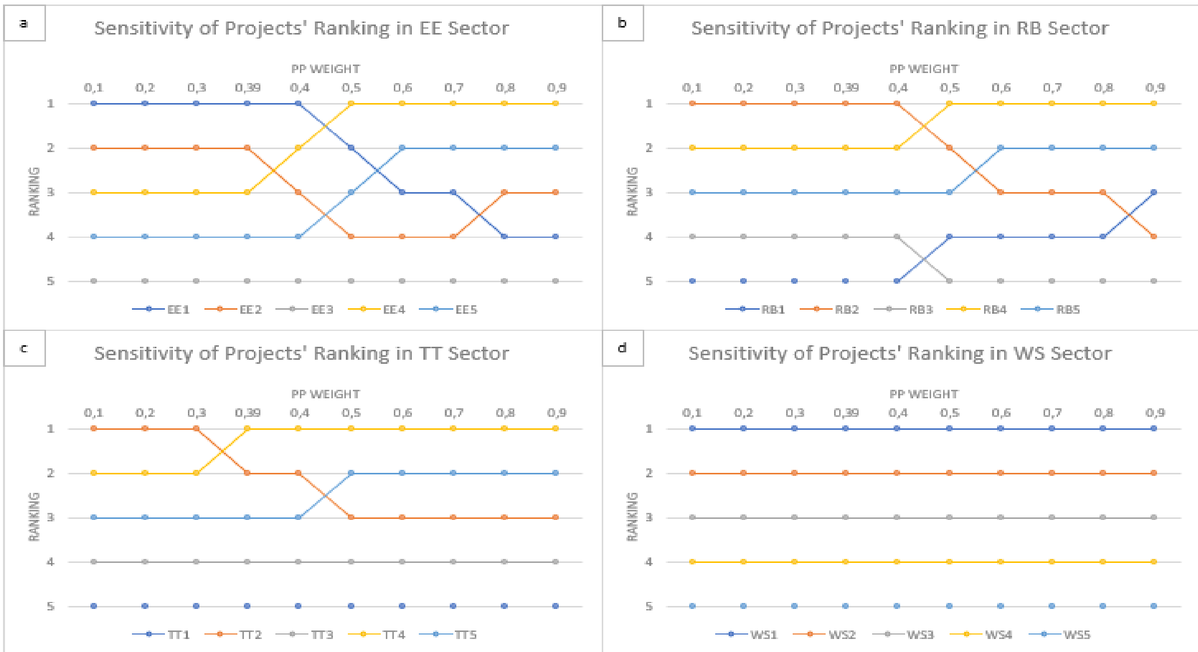

Figure 17. The sensitivity analysis of projects' rankings in the group weights.

The weight variations in Table 14 are standard cases in sensitivity analysis. However, the result from Group B-BWM provides interval weights that consider the uncertainty of the DMs. In Table 15, nine weight variations within the interval group weights are used for the sensitivity analysis. The variations are based on "project preparation" category within the original interval group weights with a minimum and maximum of 0,334 and 0,437. The other weights are provided with a similar interval between the variations. These weights are taken from the Matlab simulation, which is set to generate 100 runs. The sample-set which has a similar weight to the weight variation of "project preparation" category is selected.

Table 15. Weights with the changes in "project preparation" category in the interval group weights.

Category	Weights variation									
	1	2	3	4	5	*	6	7	8	9
PP	0,334	0,345	0,355	0,366	0,376	0,387	0,399	0,412	0,424	0,437
F	0,299	0,292	0,287	0,279	0,272	0,267	0,260	0,254	0,245	0,240
C	0,140	0,137	0,134	0,132	0,129	0,127	0,123	0,120	0,117	0,113
P	0,227	0,226	0,224	0,223	0,222	0,220	0,218	0,215	0,214	0,210

*The average group weights

In Figure 18, fewer deviations present in all sectors (WS sector is not sensitive in both cases). The interval limits the possible deviations that may occur when the weights fluctuate. In RB sector, ranking changes occur in all projects. Nonetheless, only two projects' rankings deviate, and they do not affect the top-three rankings. Previously, the top-three projects' rankings can change, but only two projects must be considered as the top rankings. Similarly, the number of changes in EE sector decreases in this interval weights.

In summary, this finding proves the robustness of Group B-BWM. Our results show that the number of possible options is reduced when the interval weights are applied in the sensitivity analysis. It facilitates the DMs in LIPs selection due to the lessened changes in projects' ranking.

The Group B-BWM provides a more robust analysis in the selection of LIPs.

Figure 18. The sensitivity analysis of projects' rankings in the interval group weights.

8.2 Discussing the Context & Approach

8.2.1 Criteria's Rankings

The Group B-BWM has proved to be a robust method. It considers DM's reliability, as shown in Figure 10. WS sector has the highest RD score, 0,38, which means the least reliable DMs, while TT sector has 0,04 score or the most reliable. This reliability measurement is correlated to the weight of the DMs. These weights affect the interval group weights, as shown in Figure 11. As presented in Figure 18, the narrower the range of interval weights, the less deviation may occur. It shows the superiority of Group B-BWM.

The group weights of the criteria show some significant differences compared to KPPIP's current assessment. In Table 11, KPPIP specified that "coordination" category is the most critical category, and "project preparation" is the least important. The outcome shows a highly contrasting result with "project preparation" category as the most crucial category with a change from 20% to 39% and "coordination" category changing from 32% to 13%. This result is obtained because four DMs have selected "project preparation" category as the most important. It is strengthened by three "project preparation" criteria, which are on the top-five project complexity criteria. "Technical planning complexity" criterion (ranking 4 in the group weight) is seen as highly contributing to project complexity (Bosch-Rekveldt et al., 2011; Nguyen et al., 2015; Vidal et al., 2011a). Similar to the group weights, "project preparation" category also scores the highest in all sectors in Scenario 4. From the short review above, the finding shows that the B-BWM can help the DMs to measure the weights of the criteria with the pairwise comparisons.

The changes happen to the top-three criteria, "issuance of project permits," "number of authorities involved," and "executive direction." In contrast, most of the DMs disagree that "the number of authorities involved" belongs to one of the most important criteria. "The number of authorities" criterion is ranked as less important in the GDM. "Issuance of project permits" criterion is ranked second by KPPIP, while the group weights only ranked 8. In contrast, "executive direction" criterion is ranked almost similar in both scenarios.

According to the GDM, "outline business case comprehensiveness," "project development fund support," and "determination of funding scheme" criteria are the most important criteria. These three criteria are highly important, with a total contribution of 29%. The four DMs selects the top-two criteria as highly to very highly important, while the third criterion is ranked as very highly by three DMs and moderately by one DM. The analysis has suggested several important criteria. However, confirmation is needed for these criteria, which is presented in Sub-section 8.2.3.

A biased understanding of the criteria's importance leads to the wrong determination of the weights, and B-BWM can help DMs to assess the criteria.

The current set of criteria is added with the supplementary criteria from TOE categories. The supplementary criteria in the second scenario affect the decision moderately. The highest impact is in EE sector, with 35%, followed by TT (32%), RB (26%), and WS (21%). The top supplementary criteria (the top 15% from each sector) are "form of contract," "size in capital expenditure," "technological newness/innovation of the projects," "availability of people/material/resources due to sharing," and "number & variety of scope/components/specifications."

At this stage, the analysis demonstrated that the current process did not include a comprehensive list of criteria because some supplementary criteria possess relatively high importance. It might happen because KPPIP tried to avoid some criteria that they do not have available measurable information

(Haryanto, 2019). This may raise concerns about the confirmation of the selected important criteria, which will be addressed in Sub-section 8.2.3.

KPPIP avoids some criteria in the current assessment due to the unavailability of information and non-quantifiable information.

8.2.2 Project's Rankings

Project ranking has changed compared to the original scenario (Scenario 1). The following analysis explains the deviation that occurs between Scenario 1 and each scenario. These ranking changes can be seen in Figure 15.

With KPPIP sectoral weights in Scenario 2, no ranking changes occur in RB sector, while slight changes occur in EE and TT sectors. There is a significant change in WS sector with three projects' rankings deviate from the original one. This deviation might be caused by the proportion of weights in this sector. The weights of KPPIP criteria emphasize "coordination" category, while in contrast, WS sector in Scenario 2 assumes this as extremely low importance.

In Scenario 3 (KPPIP group weights), the rankings of LIPs change in all sectors. The most significant change occurs in TT sector in all projects. Projects' rankings in RB sector also change significantly, while the changes in the other two sectors are relatively small. The main issues are from EE and TT sectors because the top-ranking projects changes.

Scenario 4 (Using the combined criteria) has the biggest impact on the rankings. The significant changes happen in three sectors except for WS sector. This substantial change results from the presence of the supplementary criteria, which influence the weights of the existing categories.

The project rankings in these scenarios do not show a clear pattern, which is caused by different factors, such as the profound change of criteria and category weights, and the dispersion of weights due to the supplementary criteria. Likewise, the characteristic of the project itself also plays a part in this phenomenon. Projects in RB sector from Scenario 3 can illustrate this. Ranking of RB3 project changes from 2 to 4, while RB5 from 5 to 3. It is driven by two criteria that were previously weighted as moderate importance but are now deemed highly crucial. In contrast, one criterion in RB3 project, which previously scores very high, now gives a minimal impact due to the decrease of weight from 0,32 to 0,13. The fluctuation in rankings confirms the high complexity of LIPs selection. KPPIP argued that scoring is better used to filter out the projects based on the high uncertainty of the result (Haryanto, 2019).

The practice of KPPIP applied deterministic scores in their assessment of the criteria. For instance, regarding the "issuance of project permit" criterion, KPPIP assigned three deterministic grades as follows: no issue for project permit (score 0), coordination to prolong the process is needed (score 2), and non-technical & non-administrative issues occurred (score 4). This practice impacts the project scoring. However, with B-BWM, the DMs can obtain a better result. The DMs can assign their uncertainty and assess the criteria more flexibly.

KPPIP's current assessments lead to a higher sensitivity to the projects' rankings, and it is amplified by the deterministic scoring system.

8.2.3 Confirmation

Comparison to the Findings in the Literature

The obtained criteria's rankings are checked, whether they are considered as important or not. The top-rankings criteria (15% best rankings) are compared with the findings on the literature by categorizing the importance level into very low (ranking <20%), low (20% ≤ ranking < 40%), moderate (40% ≤ ranking < 60%), high (60% ≤ ranking < 80%), and very high (ranking > 80%). For instance, when a criterion ranks 3 out of 20 criteria (ranking < 20%), it is considered as very high importance. KPPIP's current criteria are presented in Table 16, and the supplementary criteria are in Table 17.

The validity of the three criteria is confirmed as relatively consistent with the findings in the literature. Those criteria are "Project Development Fund support," "determination of funding scheme," and "executive direction." Various arguments in the literature are consistent for "publishing of supporting policies" criterion while contradicting results are found for "issuance of project permits" criterion. Two other criteria cannot be confirmed through the literature study.

The three KPPIP important criteria are validated, those are "Project Development Fund support," "determination of funding scheme," and "executive direction."

Table 16. KPPIP criteria's weight rankings and confirmation from literature.

Criteria	Ranking in this research	Arguments found in the literature
Outline Business Case comprehensiveness	1 (Group weight)	-
Project Development Fund support	2 (Group weight)	A moderate number of citations (Bakhshi et al., 2016).
Determination of funding scheme	3 (Group weight)	Very high importance (Bosch-Rekveldt et al., 2011) and a moderate number of citations (Bakhshi et al., 2016).
Executive direction	2 (EE & WS sectors) & 5 (Group weight)	Moderate importance (Bosch-Rekveldt et al., 2011).
Publishing of supporting policies	2 (EE & WS sectors) & 6 (Group weight)	High importance (Bosch-Rekveldt et al., 2011), moderate importance He et al. (2015), and a low number of citations (Bakhshi et al., 2016).
Issuance of project permits	2 (RB & TT sectors)	Very low importance (Bosch-Rekveldt et al., 2011; Nguyen et al., 2015), moderate importance (Vidal et al., 2011a), and a moderate number of citations (Bakhshi et al., 2016).
Economic benefits	3 (RB & TT sectors)	A particular case in KPPIP and it does not affect project complexity.

Some intriguing results happen for the three-lowest criteria in Scenario 3. The result of "number of authorities involved" criterion in this study contradicts the literature information, which deemed it highly relevant to project complexity (Vidal et al., 2011a). The contradicting result also occurs for "land acquisition coordination" criterion (Nguyen et al., 2015). Lastly, "Synchronization with other National Strategic Project" criterion was moderately cited in papers (Bakhshi et al., 2016).

Four supplementary criteria are validated from the literature. See Table 17. The importance of "technological newness/innovation of the projects" and "form of contract" criteria are in line with the existing literature. "Availability of people, material, and resources due to sharing" criterion has a wide range of information, which leans towards the high importance. "The size of capital expenditure" criterion is found contrasting with the result. These supplementary criteria are checked further, whether it is relevant in the case of KPPIP's LIPs selection.

Feedback from the Head of Four Sectors

Content validity is conducted to evaluate the relevance and coverage of this research (Anastasi, 1986) in the decision-making of KPPIP. Feedback is asked from the head of four sectors. The questions and answers of the interview can be seen in Appendix D.

The interviewee agreed that the method is outdated in the current decision-making because some other methods can produce a better result. Nevertheless, the unavailability or the difficulty in obtaining the information might limit the implementation. All things considered, B-BWM and ER are confirmed as a solution to deal with this problem.

KPPIP confirms the proposed methods can handle the deficiency of the existing method, and it can be a solution in the future.

The interviewee confirmed some of the top-ranking supplementary criteria, as presented in Table 17. Two out of four criteria are confirmed as important and confirmed through the literature, and they can be used for LIPs selection, while "form of contract" criterion is rejected because of the irrelevance.

Two supplementary criteria are important and relevant for KPPIP LIPs selection, those are: "technological newness/innovation of the projects" and availability of people/material/resources due to sharing."

Table 17. Supplementary criteria's weight rankings, the confirmation from literature, and the feedback from the head of four sectors.

Criteria	Ranking in this research	Arguments found in the literature & feedback from the head of four sectors
Form of contract	4 (EE sector)	Very high importance (Bosch-Rekveldt et al., 2011), moderate importance (Nguyen et al., 2015), a moderate number of citations (Bakhshi et al., 2016), but irrelevance in the case of KPPIP (Haryanto, 2019).
The size of capital expenditure	4 (TT & RB sectors)	Very low importance (Bosch-Rekveldt et al., 2011), moderate importance (Nguyen et al., 2015), low number of citations (Bakhshi et al., 2016), can be used in KPPIP (Haryanto, 2019).
Technological newness/innovation of the project/products	5 (RB sector)	Very high importance (Bosch-Rekveldt et al., 2011; Xia & Chan, 2012), moderate importance (He et al., 2015; Nguyen et al., 2015), very high number of citation (Bakhshi et al., 2016), and can be used in KPPIP (Haryanto, 2019).
Availability of people, material, and resources due to sharing	5 (TT sector)	Very high importance (Bosch-Rekveldt et al., 2011), low importance (Vidal et al., 2011a), a high number of citations (Bakhshi et al., 2016), and can be used in KPPIP (Haryanto, 2019).

When the interviewee was presented with the projects' ranking, he had a hard time to choose which projects are more important without a decision-making tool. He explained how the complexity of each project is distinct. For instance, the interviewee was asked to select the most complex project between EE1, EE2, and EE4 without being informed about the ranking of these projects. EE1 project was technically complex because it was a unique project. EE2 project was a very highly important project, and it was very difficult to get the funding. EE4 project was complex in both technical and funding. In the end, he was still unable to select the project. He argued that MCDM methods are the key to dealing with it.

In summary, the content of this study has covered all the objectives of this thesis. First, the challenges in the decision-making process are identified. Second, the criteria and project scoring are analyzed. Finally, the proposed method has been validated through the interview.

In addition, the tools are checked if it measures the relevant information or what it is supposed to measure. The survey questions are confirmed to gather the required information and are not out of context. It is prepared to prevent a prolix survey. The survey and interview questions are checked by one expert in the committee in the decision-making field.

8.3 Discussing the Method

8.3.1 Survey Tools

Surveys are conducted using Excel sheets. The DMs are provided with several examples. Excel is used because the author could not find other tools that fit the requirement of the method. There are some advantages and disadvantages of using this program.

The first advantage is that the confirmation process can be constructed in the Excel sheets to prevent input mistakes while filling the survey. A wrong input is avoided by some confirmation measures in the sheet. Secondly, it could accommodate how the method worked, which is very complicated when it is applied to other tools. Furthermore, the flexibility of design in Excel made the survey more compact, and the respondent could follow it easily.

On the contrary, the survey did not display a decent survey form. However, the author has provided the survey with a clear visualization of the method to prevent misunderstanding. Besides, because the survey is shaped into a concise form, a clear explanation of criteria is not provided and might cause the respondents to interpret it differently. However, the respondents are assumed to understand the process entirely because they are fully involved in the process.

8.3.2 The Practicality of the Method

BWM is considered as a more practical method when compared to the other pairwise comparisons methods because it requires fewer pairwise comparisons than the most common pairwise comparison method, AHP (Rezaei, 2015). The number of pairwise comparisons evaluated in the survey is only 45 instead of 276 for the AHP method, and even higher in Scenario 4 due to the number of criteria.

The pairwise comparison in BS helps the DMs to compare two criteria. Moreover, Group B-BWM improves the process in case inconsistency, and uncertainties of DMs occur in assessing the criteria's importance.

The unavailability and unquantified information issues can be handled with the application of the BS in ER approach. For instance, "technological newness/innovation in the project" is hard to be measured quantitatively, but the DMs can assign their qualitative measure together with certainty degree flexibly.

The GDM improves the robustness of the decision-making by limiting the possible projects' rankings deviation. The DMs can easily evaluate the project when the sensitivity analysis is limited to the interval group weights.

In summary, the application of the proposed method is recommended. The current information that KPPIP has generated can still be used as a reference point to compare the result of the proposed methods and transform it into BS. The adaptation of the proposed method in KPPIP will require a shorter time during the assessment of criteria weights by using B-BWM. However, project scoring will consume the same amount of time as the existing method.

8.4 Implications

By implementing the proposed method, KPPIP will generate a more comprehensive assessment in terms of establishing the criteria as well as incorporating supplementary criteria that had not been considered previously. Furthermore, the combined set of criteria show lower sensitivity.

Several LIPs selection criteria have not been considered, and it can improve the comprehensiveness of the current KPPIP criteria set.

Some criteria have different importance than the current assessment of KPPIP. The applied BS has resulted in a more comprehensive assessment than the current process. BS let the respondent put certainty degree on the criteria; in other words, it took into account the uncertainty of the respondent. BWM compares pairs of criteria one at a time so that the respondent could place a sharp comparison for the criteria and is able to manage the complexity of the project. As a result, B-BWM captured the needs of this study to manage the complexity of LIPs.

B-BWM can capture the complexity of LIPs, deal with the uncertainty of DMs, and results in suited weights of the criteria.

The result produced collective interval weights by taking into account the reliability of DMs. As a result, the more reliable DM has more influence on the weights and the decision, which leads to more reliable collective weights.

GDM considers the reliability of the DMs and generates collective interval weights.

Both in B-BWM and the project scoring with ER approach, the decision-making has improved by changing the use of deterministic scoring into assigning certainty degrees on the selected grades. Two benefits are identified. First, it could adjust the uncertainty degree of the respondents. Second, it improved the accuracy of the assessment. In qualitative measurement, decision-making involves a large portion of subjective judgments, as we can see in this case study. The ER framework involved in the approach is suitable for the representation and quantification of subjective judgments with uncertainty (Yang & Singh, 1994).

The issues of unavailability of information and non-quantifiable criteria can be managed with the implementation of the B-BWM and ER approach.

Chapter V. Conclusion and Recommendation

This chapter is divided into two sections; the first section will present the conclusion, and the second will provide a recommendation from the author for future improvement.

"One point of view does not provide an understanding of the general picture."

- Oscar Auliq-Ice St. Wirth -

9 Conclusion

In this section, the five sub-questions are answered.

Q1. What are the challenges in the current decision-making process of selecting LIPs?

Generally, the first issue is the intrinsic complexity of LIPs related to the massive size of the project and other complexity criteria. The unstructured approach to decision-making could not result in a good decision. It is showed by the non-comprehensiveness of the current set of criteria. KPPIP's current method has drawbacks, such as the inability to handle unavailability of information and non-quantifiable criteria.

Our results on the criteria weights obtained by the structured method provide evidence that the current evaluations of KPPIP did not reflect the real importance of the criteria and led to different project rankings. The findings confirm that KPPIP does not manage the complexities in the current process and ignored complexity in evaluating LIPs. Another problem is the high uncertainty in the ranking, as shown by the wide range of interval weights. The assessment is always unclear and unknown in many areas because the DMs could not acquire enough information in the early phase of the project. This uncertainty can be seen from the AU measure that is expressed by the DMs during their assessment.

Q2. What are the criteria that must be considered in selecting LIPs based on project complexity?

The findings in Table 16 confirmed three important criteria from the weightings, and those are "Project Development Fund support," "determination of funding scheme," and "executive direction." Another criterion, "Outline Business Case comprehensiveness," is the most important one. Nevertheless, it is not found in the literature probably, because of the uniqueness in this case study.

This research suggests two important supplementary criteria to be added on the list, as presented in Table 17. These criteria are "technological newness/innovation of the project/products," and "availability of people, material, and resources due to sharing."

Q3. How to obtain the weights of the criteria when considering the uncertainty of the DMs and the complexity of LIPs?

This research suggests a procedure to obtain the criteria weights with B-BWM to manage the complexity issue by creating pairwise comparisons in the criteria assessment and generating weightings through six steps. The weights are collected to compute the collective weights by following Step 7 in the procedure. The first four-steps are implemented to gather the required information through the pairwise comparisons approach in the survey. The information is converted into the BS and is computed with the minimax formula. Finally, the collective interval weights can be obtained after taking into account the inconsistency and uncertainty of the DMs.

Q4. How to incorporate the project complexity into the selection of LIPs?

The application of BS in B-BWM provides the DMs with a more flexible assessment to address the complexity. It can be well-judged with the pairwise comparisons approach. Unlike in the KPPIP current method, B-BWM is highly compatible because it can quantify any type of information by assigning the degree of belief, which is a significant advantage when dealing with qualitative criteria and complex information. Furthermore, the RD measurement relieves the bias assessment by allocating all respondents' preferences and converting it into interval collective weights. Besides, the project scoring with ER approach gets the same benefit from the implementation of BS.

Q5. Is the method fit-for-purpose of selecting LIPs based on the complexity and dealing with the uncertainty of DMs?

The results showed that B-BWM is fit for LIPs selection. In terms of criteria assessment, KPPIP current method cannot accommodate the unavailability of information issues and deal with qualitative criteria. B-BWM can generate a satisfying result by creating flexibility during the assessment and accommodating both qualitative and quantitative judgment of the DMs. It can deal with the complexity of LIPs. The top-ranking criteria are confirmed as fit to be used in the case study. Besides, the uncertainty of the decision-making is captured by the reliability measurement featured in Group B-BWM. The ER approach in the project scoring is fit-for-purpose because it can accommodate the process to quantify any types of information effectively with BS form. The interviewee confirms the benefits of the proposed methods in LIPs selection based on project complexity.

10 Recommendation

This section provides recommendations for KPPIP in Section 10.1, for LIPs selection cases in Section 10.2, and future researches in Section 10.3.

10.1 Recommendation for KPPIP

Reestablish the Criteria Set

This research does not conduct Group B-BWM for the combined criteria set. The result from Group B-BWM in the group weights show a good result, and it might provide a better result when it is implemented in more comprehensive criteria set.

Implement Group B-BWM

Group B-BWM should be implemented to improve the reliability of the outcome. The case study has four sectors with highly distinctive characteristics, and Group B-BWM can help to manage the different perspectives from these sectors. The chosen criteria by the four DMs can be combined into one set of criteria. This set of criteria can be reassessed to obtain the new group weights.

Adopt B-BWM and ER Approach

When there are several supplementary criteria that use qualitative assessment or some information are unknown during the selection process, B-BWM and ER approach can manage these issues. The flexibility and compatibility of the methods help KPPIP to include any types of criteria. Also, the application of this method does not require significant changes in the current process. The criteria selection can be conducted by using the proposed list in this research. KPPIP can follow the proposed nine-steps procedure to score the projects.

Have a Discussion before Implementing B-BWM for Criteria Weightings

In the case of KPPIP considers to recalculate the weights, a discussion between the four sectors can help to deal with some issues. As found in this study that each sector values the importance of the criteria quite differently, it might be helpful to discuss why it could happen. It might happen due to the different characteristics of each sector, or misperception of the criteria's importance.

10.2 Recommendation for Complex MCDM Case

Establish a Comprehensive Set of Criteria

The current approach in Scenario 4 is limited to sectoral weights, and Group B-BWM cannot be conducted. A comprehensive set of criteria should be established and must apply for all projects/alternatives in order to implement the proposed methods.

Implement Group B-BWM

Group B-BWM should be implemented to improve the reliability of the outcome. However, even though the reliability of DMs is taken into account in Group B-BWM, the DMs should be an expert in the field.

Implement B-BWM and ER Approach

The implementation of B-BWM and ER approach will provide some advantages. It is highly flexible and compatible to deal with any type of information. The BS helps DMs to manage the uncertainty in the selection process. Lastly, the implementation of B-BWM is faster than the other MCDM methods.

Set the Grades Definition for the Project Scoring

In the future process, the grades' definition could be constructed by the experts to make the evaluation more understandable and to reduce the uncertainty by providing clear information on the grades. It will help DMs when assigning their certainty degree on the selected grades.

10.3 Limitation and Future Research

Use Project Complexity Criteria Framework from Literature

The combined criteria set has several overlapping criteria. For instance, "policy" category used by KPPIP is related to the TOE framework from the literature. "Internal strategic pressure" criterion is part of "external" category on the TOE framework. However, it is taken into account in the "policy" category of the KPPIP criteria set. The complexity framework in the literature can be used to prevent any overlapping criteria in future research and is more effective.

Conduct Group Project Scoring

It might be intriguing to implement the GDM in the selection of similar alternatives. This is very much the critical component in future attempts to overcome the uncertainty in decision-making.

Conduct Multiple Case Studies

This research uses a case study from Indonesia, which has different characteristics if it is compared to other countries. Some criteria that are selected by the DMs might be only relevant to this case study and might be different for other countries. For instance, the level of infrastructure provisions, the geographical condition of a country, the political system, etc. can play a role in project ranking. As a result, different criteria might be selected in other cases. It might be interesting to do research with multiple case studies with different groups. Future studies should aim to replicate the results in a broader context by comparing different groups. For instance, a group of developing and developed countries, South East Asian and European countries, or transportation and energy sectors may provide new insights.

Use More Sample

The number of projects to be assessed by the respondents was only 20 projects, but it was already a time-consuming process. However, five projects in each sector were considered enough to analyze the case. Nonetheless, more projects might provide more insights into this research by analyzing the rankings' deviation.

Conduct Concurrent Validity for Projects' Ranking

This research does not conduct validity measures for the projects' ranking. Concurrent validity can be implemented in future research. It can be conducted by comparing the projects' ranking with the opinion of KPPIP's managers. The managers are asked to rank the projects without using MCDM methods. The validity can be checked by measuring the correlation between the projects' ranking and the opinion of the top managers.

11 Reflection

Section 11.1, which presents the reflection about the research process. Section 11.2 reflects about the context of this research. The reflection about the method is in Section 11.3. The dissemination of this research is presented in Section 11.4. Lastly, the concluding remarks are presented in Section 11.5

11.1 The Research Process

Towards the Kick-off Meeting

Many things happened before I started this topic. In short, I started looking for a company for the thesis graduation since November and had several rejections. In January, one start-up company had a positive discussion with me. However, they canceled it for no reason in the next month. I changed my topic, and I got this research topic and arranged a kick-off meeting in April, but it was canceled because one committee member withdrew. Finally, I could officially start my thesis on 30th April.

Difficulties at the beginning were to find the topic. One day, I could get in touch with KPPIP, which was alumni from my university. We discussed a lot through email, but it took some time because he was the top manager. It was challenging to get enough information to develop the research proposal. I should have called him to understand the problem more and accelerate the process.

I chose the topic and tried to align my idea with my supervisor. It took some time because I still did not have much information. I focused on getting more information about KPPIP and only did research on the more essential things. A lot of time was misused, and I could have searched for more information at that time to investigate the research gap early.

Discussions with the program manager took some time before acquiring the data because he needed proof of doing a thesis, and the response from KPPIP was slow until it was close to the kick-off meeting. I could have been more active and put prioritize on the more essential things.

Towards the Mid-term Meeting

During the literature study, I studied the wrong information. KPPIP's focus was not to choose the most beneficial project but to select the most complex project that needs KPPIP's assistance to accelerate it. I had to restart the literature study. I realized that a case study could be unique, and the information that they gave was vital to be analyzed carefully.

In the process, I was warned by my committee that I put too many subjective judgments in the report. It was true in some cases, and I realized that I sometimes referred from my past practical experience. I learned more about how to write a good scientific report.

I still faced the difficulty of getting the required information. I contacted the respondents through email, and they replied in a week. My friends always told me to be more active, but my excuse was to be polite when dealing with people. Later, I contacted them every week, every 4 days, and finally, I always called them directly. I had a mixed feeling about this. First, I thought that they did not care about my research, or they were really busy with their work due to the transition to the new government this year. In the end, I could get the data with a short delay, and I learned from this.

Getting delayed in collecting the data had a domino effect on other things. I had to change the research framework from three to two stages of surveys. I learned that I had to plan the schedule more realistic and proportionally to the workload.

Towards the Green-light Meeting

About the BWM, I thought that I could do the calculation just with Excel program like many other MCDM methods, but in fact, I must use Matlab, which I never used before. Even though I did not put this into consideration, the delay due to the data collection gave me some time to manage these problems.

Another unexpected matter happened one week before the green-light meeting. I had to go back to Indonesia for a week. Thus I could not focus on working on the report.

In the first interview with KPPIP, the interviewee asked me to change it into a survey because they were swamped with work, and I had to change the framework. In the end, I received the final survey one week before the meeting and the confirmation interview one day before. It caused a reschedule of my green-light meeting. From this, I could learn that we must provide a simple method when dealing with other people because they valued their time differently than we do. Proper planning and mitigation plans must be taken into account.

Towards the Second Green-light Meeting

I received some concerns about my report, mostly in the structure and the writing. It was challenging for me because my English is weak. For instance, I tried to used synonym words, but it was not used properly. I overcomplicated the framework and the methodology by explaining the case study detailly. I should have provided a more general methodology, which can present a bright idea for the readers and could be applied in general cases. Finally, I did several peer-reviews to my friends to get different views on the content.

Towards the Final Defence

The final comments from the committee gave me an insight into how an incomplete explanation can mislead the readers. From this, I learned that I had to be on a reader's point of view and acted if I were unfamiliar with the topic. Thus, I could have provided more detail information in the report and make the process clear for readers.

The peer-reviews from my colleagues really helped me. I got the green-light and proceed to the final defense with minor revisions. I learned that doing peer-reviews was important because I could get more perspectives that may not land in my thought.

The Whole Process

I look positively back on the whole process. The deadlines that were set in the planning turned out to be feasible if I was more active in the process. I thought that I was active enough until the data collection delayed my plan. I need to learn more in every aspect to prevent unnecessary mistakes that delay my work. I would have shortened my time for the literature study and put more time for data collection, or I could use overlapping time.

11.2 The Research Context

The Position of This Research

This thesis was conducted under two faculties: Civil Engineering and Geosciences and Technology, Policy, and Management faculties at the Delft University of Technology. This research relates closely to a novel decision-making method that was developed by my 2nd supervisor, and further improvement was the study focus of my 1st supervisor, under Engineering Systems and Services department. This research closely relates to his focus on improving the GDM with the BWM. This case study was conducted in civil engineering area, which was in line with the focus in this department.

The Outcome

The outcome of this research was satisfying, and the result was in line with the plan. It could have been improved in terms of the framework.

11.3 The Research Methodology

The original plan was to conduct interviews, but it was changed into surveys. It limited this research from using a mix of qualitative and quantitative analysis. In the end, this research focuses more on quantitative research, and it turned out to be more focus on the aim of this research.

The number of surveys was planned to be eight, but again, they refused because they were busy. In my opinion, if I had more time, I could have added more respondents in this case study. This would have removed a bias that could occur in the survey.

11.4 Dissemination

Companies and Organizations

The results of this thesis are relevant to the current process in KPPIP, and it can be improved for supporting future decision-making processes. The benefits have been presented previously, and this method can be applied in many decision-making cases for companies or organizations. Moreover, the application is not limited by the fields of study and types of institutions.

Universities and Researchers

This research will contribute to the available scientific body of knowledge in the decision-making area. Moreover, it can improve the existing research in TU Delft regarding the BWM. The critical parts lay on the different areas of the case study and the practice of GDM with B-BWM.

11.5 Concluding Remarks

I am happy that I can work on this topic and fulfill my ambition. It gives me some insights regarding the decision-making process in one government body in Indonesia. I had a chance to interview the program manager and the experts and discuss a lot about the process. I learn various decision-making methods and follow the development until the most recent one. It is a learning process that I will never forget.

The overall process officially started on 30th April, and I spent six months on this research until the defense of my research, which is considered as on time. However, I had my graduation delayed because I started late. With everything that went up and down, difficult and happy moments, there will always be recommendations for improvement. At the end of the day, it satisfies me.

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Appendix A

Adapted Project Scoring from KPPIP

Table A below presents KPPIP's current assessment on the selected projects. The assessment is transformed into BS.

Table A. BS of KPPIP current project scoring.

Criteria	Energy & Electricity					Road & Bridge				
	EE1	EE2	EE3	EE4	EE5	RB1	RB2	RB3	RB4	RB5
PP1	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(3; 1)}	{(1; 1)}	{(3; 1)}	{(3; 1)}	{(3; 1)}	{(9; 1)}	{(3; 1)}
PP2	{(1; 0,5), (Ω; 0,5)}	{(1; 1)}	{(1; 0,5) , (Ω; 0,5)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}
PP3	{(5; 1}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}
PP4	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}
PP5	{(7; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(7; 1)}	{(7; 1)}	{(5; 1)}	{(1; 1)}
F1	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
F2	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}
F3	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}
F4	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
F5	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}
F6	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}
C1	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
C2	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}
C3	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
C4	{(7; 1)}	{(7; 1)}	{(3; 0,3), (4; 0,7)}	{(3; 0,3), (4; 0,7)}	{(3; 0,3), (4; 0,7)}	{(4; 0,7), (5; 0,3)}	{(5; 0,3), (6; 0,7)}	{(5; 0,3), (6; 0,7)}	{(7; 0,3), (8; 0,7)}	{(5; 0,3), (6; 0,7)}
C5	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
C6	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}
P1	{(6; 0,5), (7; 0,5)}	{(9; 1)}	{(6; 0,5), (7; 0,5)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(3; 0,5), (4; 0,5)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
P2	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}
P3	{(5; 1)}	{(4; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}

Criteria	Transportation					Water & Sanitation				
	TT1	TT2	TT3	TT4	TT5	WS1	WS2	WS3	WS4	WS5
PP1	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(3; 1)}	{(9; 1)}
PP2	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
PP3	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(9; 1)}
PP4	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}
PP5	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(7; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(7; 1)}	{(1; 1)}
F1	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(5; 1)}	{(9; 1)}
F2	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
F3	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}
F4	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
F5	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}
F6	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}
C1	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(5; 1)}
C2	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}
C3	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}
C4	{(5; 0,3), (6; 0,7)}	{(5; 0,3), (6; 0,7)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(5; 0,3), (6; 0,7)}	{(3; 0,7), (4; 0,3)}	{(5; 0,3), (6; 0,7)}	{(3; 0,7), (4; 0,3)}	{(7; 0,3), (8; 0,7)}
C5	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}
C6	{(1; 1)}	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(9; 1)}
P1	{(3; 0,5), (4; 0,5)}	{(1; 1)}	{(3; 0,5), (4; 0,5)}	{(1; 1)}	{(1; 1)}	{(3; 0,5), (4; 0,5)}	{(2; 0,7), (3; 0,3)}	{(6; 0,5), (7; 0,5)}	{(3; 0,5), (4; 0,5)}	{(1; 1)}
P2	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
P3	{(3; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}

Appendix B

Survey Phase 1: Assessing Selection Criteria

Part I Survey: Assessing KPPIP Criteria with B-BWM

Table B1 below shows Part I of Phase 1 Survey. The assessment takes the result from TT Sector. In each of the categories, two tables are presented, which contains a similar set of criteria. The top table refers to the comparison of the "Best" criterion over the "Other" criteria, while the lower table refers to the comparison of the "Other" criteria over the "Worst" criterion. The grades refer to a definition of pairwise comparison between two criteria and are presented in Table 3. The assessment represents the belief degree of the DMs. This first survey is using the same criteria from KPPIP with modified category, and it has four categories of criteria.

Table B1. Survey Phase 1 result of TT sector for KPPIP criteria.

Main Category									
The most important criterion: Project Preparation Complexity	Grade								
	1	2	3	4	5	6	7	8	9
Project Preparation Complexity	100								
Funding Complexity	20	80							
Coordination Complexity	10	90							
Policy Complexity		20	80						
The least important criterion: Policy Complexity	Grade								
	1	2	3	4	5	6	7	8	9
Project Preparation Complexity		20	80						
Funding Complexity		80	20						
Coordination Complexity		90	10						
Policy Complexity	100								
Project Preparation Category									
The most important criterion: Technical planning complexities	Grade								
	1	2	3	4	5	6	7	8	9
Outline Business Case comprehensiveness	100								
Economic benefits	10	90							
Technical planning complexities		20	80						
Project Development Fund Support			20	80					
Infrastructure readiness surrounding the project			10	90					
The least important criterion: Infrastructure readiness surrounding the project	Grade								
	1	2	3	4	5	6	7	8	9
Outline Business Case comprehensiveness			10	90					
Economic benefits			80	20					
Technical planning complexities		80	20						
Project Development Fund Support		90	10						
Infrastructure readiness surrounding the project	100								
Funding Complexity Category									
The most important criterion: Determination of funding scheme	Grade								
	1	2	3	4	5	6	7	8	9
Acquisition of interest from the investor(s)				90	10				
Determination of funding scheme	100								
Funding resources organization			90	10					
Public Service Organization structuration				90	10				
Granting of Credit Risk				90	10				
Granting of Business Feasibility Support					90	10			
The least important criterion: Acquisition of interest from the investor(s)	Grade								
	1	2	3	4	5	6	7	8	9
Acquisition of interest from the investor(s)			10	90					
Determination of funding scheme					90	10			
Funding resources organization		10	90						
Public Service Organization structuration		10	90						
Granting of Credit Risk		10	90						
Granting of Business Feasibility Support	100								

Table B1. Survey Phase I result of TT sector for KPPIP criteria (continue).

Coordination Complexity Category									
The most important criterion: Stakeholder buy-in	Grade								
	1	2	3	4	5	6	7	8	9
Stakeholder buy-in	100								
Land acquisition coordination		80	20						
Spatial plan synchronization		90	10						
Number of authorities involved				70	30				
Implementation procurement between government and business entity			80	10					
Synchronization with other National Strategic Project		90	10						
The least important criterion: Synchronization with other National Strategic Project	Grade								
	1	2	3	4	5	6	7	8	9
Stakeholder buy-in				70	30				
Land acquisition coordination		20	80						
Spatial plan synchronization		10	90						
Number of authorities involved	100								
Implementation procurement between government and business entity			10	80					
Synchronization with other National Strategic Project		10	90						
Policy Complexity Category									
The most important criterion: Executive direction	Grade								
	1	2	3	4	5	6	7	8	9
Issuance of project permits	100								
Publishing of supporting policies			20	80					
Executive direction				20	80				
The least important criterion: Publishing of supporting policies	Grade								
	1	2	3	4	5	6	7	8	9
Issuance of project permits				20	80				
Publishing of supporting policies			80	20					
Executive direction	100								

Part II Survey: Selecting Supplementary Criteria

In this part, the DMs are asked to select criteria from the literature study that is presented in Table 2 The result of the selection is shown in Table 7.

Part III Survey: Assessing the Combined Criteria with B-BWM

This part uses a similar procedure as in the first part, but it is implemented on the criteria that are selected in Part II. The example in Table B2 below is taken from the TT sector.

Table B2. Survey Phase I result of TT sector for supplementary criteria.

Main Category									
The most important criterion: Project Preparation Complexity	Grade								
	1	2	3	4	5	6	7	8	9
Project Preparation Complexity	100								
Funding Complexity	20	80							
Coordination Complexity	10	90							
Policy Complexity		20	80						
Technical Complexity		20	80						
Organizational Complexity		20	80						
External Complexity			20	80					
The least important criterion: Organizational Complexity	Grade								
	1	2	3	4	5	6	7	8	9
Project Preparation Complexity			20	80					
Funding Complexity	80	20							
Coordination Complexity	90	10							
Policy Complexity		80	20						
Technical Complexity		80	20						
Organizational Complexity		80	20						
External Complexity	100								

Table B2. Survey Phase I result of TT sector for supplementary criteria (continue).

Technical Category									
The most important criterion: Size in Capital Expenditure	Grade								
	1	2	3	4	5	6	7	8	9
Technological newness/innovation of the project/products		10	90						
Schedule and duration of the project		10	90						
Size in Capital Expenditure	100								
Dynamic of plan, organization, and components			20	80					
The least important criterion: High-quality requirements/standards	Grade								
	1	2	3	4	5	6	7	8	9
Technological newness/innovation of the project/products		90	10						
Schedule and duration of the project		90	10						
Size in Capital Expenditure			20	80					
Dynamic of plan, organization, and components	100								
Organizational Category									
The most important criterion: Capability & competencies/skills of the team (knowledge, experience, education, training)	Grade								
	1	2	3	4	5	6	7	8	9
Capability & competencies/skills of the team (knowledge, experience, education, training)			90	10					
Availability of people, material, and resources due to sharing	100								
Number & variety of different occupational specialization/discipline				90	10				
Internal politic issue			90	10					
The least important criterion: Number & variety of hierarchical levels	Grade								
	1	2	3	4	5	6	7	8	9
Capability & competencies/skills of the team (knowledge, experience, education, training)			10	90					
Availability of people, material, and resources due to sharing				90	10				
Number & variety of different occupational specialization/discipline	100								
Internal politic issue			10	90					
External Category									
The most important criterion: Number & variety of the interests/objectives/goals	Grade								
	1	2	3	4	5	6	7	8	9
Level of competition and conflict between stakeholders		10	90						
Number & variety of stakeholders		20	80						
Number & variety of investors/financial resources		20	80						
Unrealistic demand/expectation	100								
Social disturbance		80	20						
The least important criterion: Number & variety of investors/financial resources	Grade								
	1	2	3	4	5	6	7	8	9
Level of competition and conflict between stakeholders		90	10						
Number & variety of stakeholders	100								
Number & variety of investors/financial resources		80	20						
Unrealistic demand/expectation		20	80						
Social disturbance		80	20						

Appendix C

Survey Phase 2: Assessing Project

This assessment takes an example from RB Sector, as presented in Table C. The list of criteria is different for each sector. The assessment grades follow the definition of each criterion. In general, grade 9 represents the most substantial influence on project complexity. For instance, for T1 criterion: No new technology/innovation (Grade 1), involve new technology/innovation in medium-scale (Grade 5), and involve highly new technology/innovation on a big scale (grade 9).

Table C. Survey Phase II of RB sector for project scoring.

Code	Criteria	1	2	3	4	5	6	7	8	9
T1	**Technological newness/innovation of the projects/products**									
	RB1		50							
	RB2		50							
	RB3					70				
	RB4				70					
	RB5		50							
T2	**High-quality requirements/standards**									
	RB1					60				
	RB2					60				
	RB3					60				
	RB4					60				
	RB5					60				
T3	**Size in Capital Expenditure**									
	RB1								100	
	RB2									100
	RB3							100		
	RB4									100
	RB5									100
O1	**Capability & competencies/skills of the team (knowledge, experience, education, training)**									
	RB1		90							
	RB2		70							
	RB3		90							
	RB4		70							
	RB5		90							
O2	**Number & variety of hierarchical levels**									
	RB1						80			
	RB2				70					
	RB3			70						
	RB4				60					
	RB5				80					
E1	**Level of competition and conflict between stakeholders**									
	RB1						80			
	RB2							90		
	RB3			80						
	RB4								90	
	RB5						80			
E2	**Number & variety of the interests/objectives/goals**									
	RB1							80		
	RB2								90	
	RB3				80					
	RB4									90
	RB5							80		
E3	**Number & variety of investors/financial resources**									
	RB1		90							
	RB2						50			
	RB3						80			
	RB4						60			
	RB5					80				

Appendix D

Confirmation Interview

1. Are you familiar with the decision-making method that you are using right now?
- Yes. It has been implemented for four years.
2. What do you think about the decision-making method that you are using?
- It was fit-for-purposes when it was implemented for the first time because it was able to assess all the available information. **However, it is not relevant anymore because there are some other methods that might be better than this method. But, it must be remembered that the unavailability of the information during the decision-making might become the hindrance of using the method.**
3. Can you give an example of the methods?
- Two methods that can be considered are the quantitative prioritization from world bank for South America, and the five-case model from the UK government.
4. Is this selection process used as an enclosure for KPPIP accountability in selecting projects to the executives?
- Yes, there are a few rounds. Firstly, it is presented to the first echelon, then to the ministry, and finally, it will be proposed to the president to be approved.
5. What is your opinion about the changes in the criteria's level of importance? Is it picturing the real condition?
- Yes. Because there are many different complexities.
6. In sector EE, three criteria: "form of contract," and "number & variety of the scope/components/specifications" are among the most important criteria. What is your opinion about these criteria?
- For “number & variety of the scope/components/specifications” criterion, it is not that relevant because it is challenging to acquire the information in the early stage, which is still in basic engineering design.
- **For “form of contract,” it is not relevant because basically the government uses almost the same form of contract**.
7. In sector RB, three criteria: "size in capital expenditure,” "technological newness/innovation of the project/products," and "high-quality requirements/standards" are among the most important criteria. What is your opinion about these criteria?
- It is not a problem, and **all these criteria relevant to this sector**.
8. In sector TT, two criteria: "size in capital expenditure,” "availability of people, material, & resources due to sharing," and "unrealistic demand/expectation" are among the most important criteria. What is your opinion about these criteria?
- **“Size in capital expenditure” criterion can be relevant**.
- **"Availability of people, material, & resources due to sharing” criterion is challenging to acquire the information in the early stage**.
- For “Unrealistic demand” criterion, there is little information to have check and balance of the project because most of the new transportation projects are relatively new in Indonesia.
9. In sector WS, criterion "number and variety of interests/objectives/goals" is among the most important criteria. What is your opinion about these criteria?
- This criterion is quite vague because it is difficult to differentiate the standard practice because all projects have many different stakeholders, which is typically balance for LIPs.
10. Four sectors’ representatives agreed that criteria “size of capital expenditure,” “level of competition and conflict between stakeholders,” and “number and variety of investors/financial resources” must be considered. What is your opinion about these criteria?
- **I agree with them**.
11. Is it possible to quantify these three criteria?

- This is a difficult question, but actually **it subject to the methodology**. **As long as it can quantify subjective assessment and valid, it is relevant to add these criteria**.
12. How beneficial is knowing the ranking of projects?
- It is crucial because it helps to prioritize the project. However, the project ranking is developed to filter out the projects, and the prioritized project will be developed altogether. This prioritization will help the development through annual evaluation. By the end of the day, these projects must pass the bottom line, which is beneficial for society and some other measures.
13. Would you say project EE1, or EE2, or EE4, which is more complex? And why?
- This question cannot be answered. All of the projects are complex in different ways, and it is not comparable. For example, EE1 is essential because it is for waste management, and it is complicated from the perspective of the technical complexity. EE2 is purely energy project, and it is to provide reliable energy for the country, thus makes it essential. Moreover, it is also challenging to find lenders for this type of project. The last one has another complexity because the last developed project was 15 years ago. Secondly, this kind of project is not easy to build because of technical complexity. Another complexity is the location and fiscal issues, such as tax holiday to incentivize the investors.
- KPPIP focuses on three complexities, financial, policy, and technical. So, technically, you have to see it as a whole, and this measurement is used only for filtering out the project. But, again, the most important thing is the bottom line to give the benefit to society.
- Another example, if you don't have any political will for the project, in the end, it will not go anywhere.
14. Is it relevant to use the same set of weights for all the sectors?
- Yes, because, in the end, we have to compare the projects in an equal manner. Otherwise, it will not obtain a consistent result. The important thing is to create a guideline, which makes it applicable and equally evaluate the projects.
15. Would you say project RB2 or RB3 or RB4, which is more complex? And why?
- They all have different types of complexity. For example, the primary concern of project RB2 is the location near the volcano and the amount of earthquake that happened in that area. For project RB3, the complexity comes from the requirement to connect the city with Special Economic Zone, and it affects the policy significantly. Next, RB4 is financially sophisticated because it is the first project in that island. As the first project, it is not easy to attract the investor to support the project.
16. Would you say project TT5 or TT2, which is more complex? And why?
- Again, different complexities for both of the projects. However, as an example, in public transportation planning, these two different types of transportation have different uses.
17. Would you say project WS3 or WS2, which is more complex? And why?
- For WS3, It is complicated due to the fact that it is the first KPBU in that city. Moreover, it is complex because there the potential of the project that makes many stakeholders are willing to involve in the project. On the other hand, WS2 is complex because of the policy and coordination complexity. The project must pass several provinces.
18. In your opinion, how beneficial is this method to be implemented?
- **At the end of the day, it is beneficial as long as it is also an economical approach. However, a few notes must be taken into account. First, the use of the ranking is only to filter out the project. Secondly, the complexity must be treated according to the type of available information. Lastly, do not put the weight as sectoral weight, but only one weight that can be implemented in all sectors**.
19. Can you give us some recommendations for future improvements, or maybe for further research?
- It has to be an objective approach instead of a subjective approach. In this way, the assessment cannot be challenged by other people.

Appendix E

The Decision-Making Process of KPPIP

Medium-Term Development Plan is the first stage in the selection process. The projects are proposed by every ministries or institution within the government. This plan is revised once every five years when the new government is elected. Then, the lists are evaluated for the selection of NSP. The government determines several projects as priority projects. Figure E1 illustrates the stages of prioritizing the LIPs. They rely on four principles, which are detailed into two types of criteria with a total of eight, as presented in Figure E2. The first category of the criteria is eliminative criteria, which directly eliminates the project that cannot fulfill the criteria; and scoring criteria that value the project through another four main criteria with further analysis of the project.

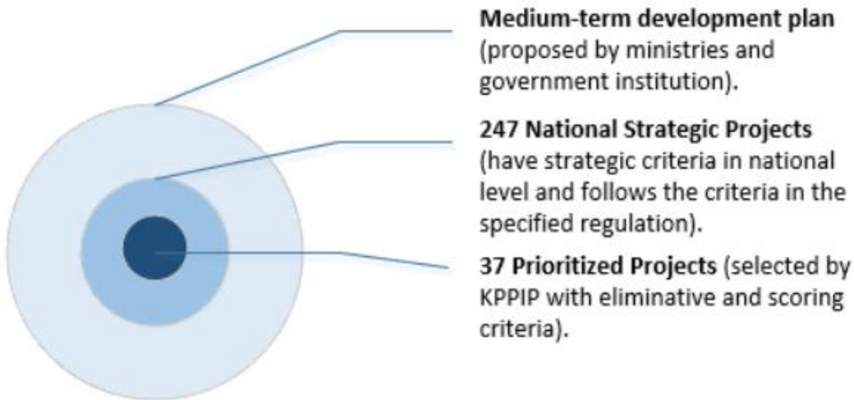

Figure E1. Stages of infrastructure development in Indonesia (KPPIP, 2016).

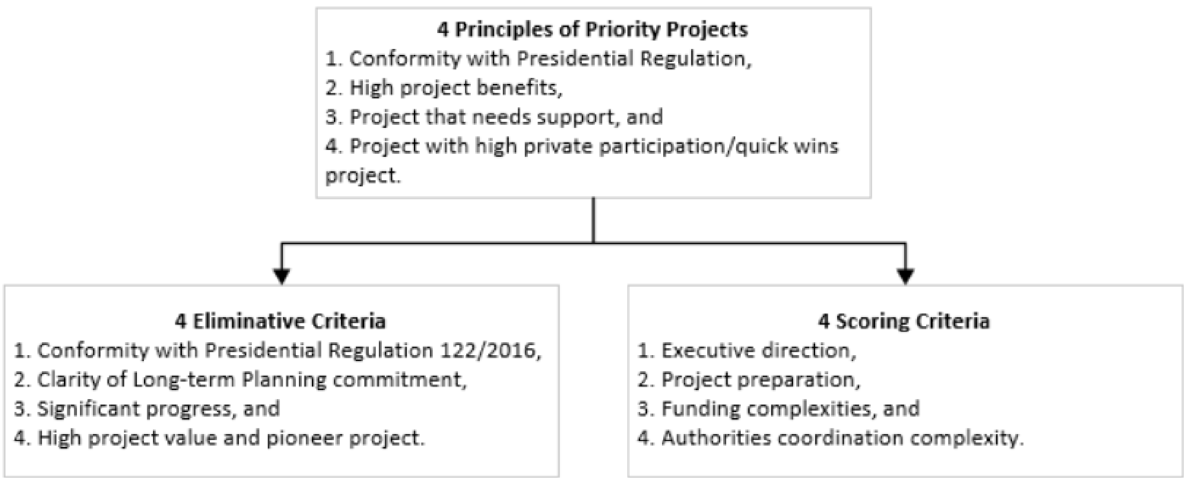

Figure E2. Breakdown of priority project criteria (KPPIP, 2016).

Table E1. Original KPPIP's project ranking within 80 projects.

EE sector		RB sector		TT sector		WS sector	
Project	Ranking	Project	Ranking	Project	Ranking	Project	Ranking
EE1	5	RB1	25	TT1	36	WS1	16
EE2	4	RB2	13	TT2	37	WS2	22
EE3	27	RB3	20	TT3	17	WS3	19
EE4	11	RB4	21	TT4	24	WS4	28
EE5	15	RB5	26	TT5	10	WS5	29

Appendix F

KPPIP's Criteria Definition

Category	Criteria	Definition
Executive Direction	-	The president vision of the country to distribute the wealth to the society, and have national-range impacts.
Project Preparation	Outline Business Case comprehensiveness	Preliminary thoughts, which contains the information, such as outcomes, benefits, and potential risks associated with the proposal.
	Economic benefits	It considers the benefit to the economy, environmental, and also social.
	Technical planning complexity	It considers environments that can bring the project into a complex development, such as land-use plan, environmental dispute, and relocation.
	Project Development Fund support	A programmatic approach to the funding of the cost for early tasks to encourage contracting agencies to use best practice.
	Infrastructure readiness/requirement surrounding the project	The government intends to accelerate the development in the country; it is implemented by integrating infrastructures that can carry out or perform more economic activities in the society surrounding the project.
Funding complexities	Acquisition of interest from the investor(s)	Investors are one of the primary sources of funding for the project that is required to develop multiple projects
	Determination of funding scheme	It shows the scheme of the funding which considers the strategic issue on the availability of the investors' interest.
	Funding resources synchronization	It is a body provided by the central government when it is needed to assist the team in organizing the funding of the project.
	Public Sector Organization structuration	PSO is an entity that is formed to manage the policy and operating requirements that enable a government to achieve its goals of public governance.
	Granting of credit risk	Credit risk is the possibility of a loss resulting from a debtor's failure to meet the obligations. It measures the availability of the assurance of the projects.
	Granting of business feasibility support	The business feasibility support refers to the availability of elements, which support the continuity of the project development.
Authorities coordination complexities	Stakeholder Buy-in	Process of involving all the related stakeholders to reach consensus.
	Land acquisition coordination	Most infrastructure projects mostly involve many areas to be cleared for the project and needs complicated coordination.
	Spatial plan synchronization	Most infrastructure projects involve many areas, and sometimes, it has a different land-use plan that can create some dispute.
	Issuance of project permits	A project permit is a critical milestone of the project, which lets the team continue/start/operate an activity in the project.
	Number of authorities involved	It refers to the complexity that happens due to the administrative and coordination time needed in the project.
	Publishing of supporting policies	The government try to accelerate the development by publishing some sectoral/general policies.
	Implementation of procurement between government and business entity	Some projects involve coordination between private parties or other stakeholders that do not have or little experience in the field or can be due to an innovative project.
	Synchronization with other National Strategic Projects	This criterion intends to synchronize between two or more National Strategic Projects that relate to each other.

Appendix G

KPPIP Criteria Assessment with B-BWM

Table G. KPPIP criteria assessment in each category from four sectors.

Project Preparation (PP)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
PP1	{(1; 1)}	{(9; 1)}
PP2	{(1; 0,2), (2; 0,8)}	{(9; 1)}
PP3	{(1; 0,2), (2; 0,8)}	{(9; 1)}
PP4^{B}	{(1; 1)}	{(9; 1)}
PP5^{W}	{(9; 1)}	{(1; 1)}
Road & Bridge		
PP1	{(2; 0,7), (Ω; 0,3)}	{(5; 0,8), (Ω; 0,2)}
PP2	{(3; 0,8), (Ω; 0,2)}	{(6; 0,8), (Ω; 0,2)}
PP3^{B}	{(1; 100)}	{(7; 0,7), (Ω; 0,3)}
PP4	{(2; 0,7), (Ω; 0,3)}	{(6; 0,7), (Ω; 0,3)}
PP5^{W}	{(7; 0,7), (Ω; 0,3)}	{(1; 1)}
Transportation		
PP1^{B}	{(1; 1)}	{(3; 0,1), (4; 0,9)}
PP2	{(1; 0,1), (2; 0,9)}	{(3; 0,8), (4; 0,2)}
PP3	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}
PP4	{(3; 0,2), (4; 0,8)}	{(2; 0,9), (3; 0,1)}
PP5^{W}	{(4; 0,1), (5; 0,9)}	{(1; 1)}
Water & Sanitation		
PP1	{(2; 0,7), (Ω; 0,3)}	{(4; 0,8), (Ω; 0,2)}
PP2^{W}	{(6; 0,7), (Ω; 0,3)}	{(1; 1)}
PP3	{(2; 0,8), (Ω; 0,2)}	{(3; 0,8), (Ω; 0,2)}
PP4^{B}	{(1; 1)}	{(6; 0,7), (Ω; 0,3)}
PP5	{(4; 0,9), (Ω; 0,1)}	{(5; 0,9), (Ω; 0,1)}

B = Best Criterion, W = Worst Criterion

Funding (F)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
F1	{(9; 1)}	{(1; 1)}
F2^{B}	{(1; 1)}	{(9; 1)}
F3^{W}	{(9; 1)}	{(1; 1)}
F4	{(9; 1)}	{(1; 1)}
F5	{(9; 1)}	{(1; 1)}
F6	{(9; 1)}	{(1; 1)}
Road & Bridge		
F1^{W}	{(6; 0,8), (Ω; 0,2)}	{(1; 1)}
F2^{B}	{(1; 1)}	{(6; 0,8), (Ω; 0,2)}
F3	{(2; 0,6), (Ω; 0,4)}	{(3; 0,6), (Ω; 0,4)}
F4	{(5; 0,7), (Ω; 0,3)}	{(2; 0,6), (Ω; 0,4)}
F5	{(3; 0,6), (Ω; 0,4)}	{(3; 0,6), (Ω; 0,4)}
F6	{(5; 0,7), (Ω; 0,3)}	{(5; 0,7), (Ω; 0,3)}
Transportation		
F1	{(4; 0,9), (5; 0,1)}	{(3; 0,1), (4; 0,9)}
F2^{B}	{(1; 1)}	{(5; 0,9), (6; 0,1)}
F3	{(3; 0,9), (4; 0,1)}	{(2; 0,1), (3; 0,9)}
F4	{(4; 0,9), (5; 0,1)}	{(2; 0,1), (3; 0,9)}
F5	{(4; 0,9), (5; 0,1)}	{(2; 0,1), (3; 0,9)}
F6^{W}	{(5; 0,9), (6; 0,1)}	{(1; 1)}
Water & Sanitation		
F1	{(1; 1)}	{(5; 1)}
F2	{(1; 1)}	{(5; 0,7), (Ω; 0,3)}
F3^{B}	{(1; 1)}	{(6; 0,8), (Ω; 0,2)}
F4	{(2; 0,7), (Ω; 0,3)}	{(5; 0,8), (Ω; 0,2)}
F5^{W}	{(6; 0,8), (Ω; 0,2)}	{(1; 1)}
F6	{(3; 0,8), (Ω; 0,2)}	{(2; 0,8), (Ω; 0,2)}

Coordination (C)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
C1^{B}	{(1; 1)}	{(7; 1)}
C2	{(1; 1)}	{(7; 1)}
C3	{(1; 1)}	{(7; 1)}
C4^{W}	{(7; 1)}	{(1; 1)}
C5	{(1; 1)}	{(7; 1)}
C6	{(1; 1)}	{(7; 1)}
Road & Bridge		
C1^{B}	{(1; 1)}	{(7; 0,9), (Ω; 0,1)}
C2	{(7; 0,9), (Ω; 0,1)}	{(3; 0,7), (Ω; 0,3)}
C3	{(2; 0,8), (Ω; 0,2)}	{(5; 0,8), (Ω; 0,2)}
C4	{(2; 0,8), (Ω; 0,2)}	{(6; 0,8), (Ω; 0,2)}
C5	{(5; 0,7), (Ω; 0,3)}	{(2; 0,7), (Ω; 0,3)}
C6^{W}	{(7; 0,9), (Ω; 0,1)}	{(1; 1)}
Transportation		
C1^{B}	{(1; 1)}	{(4; 0,7), (5; 0,3)}
C2	{(2; 0,8), (3; 0,2)}	{(2; 0,2), (3; 0,8)}
C3	{(2; 0,9), (3; 0,1)}	{(2; 0,1), (3; 0,9)}
C4^{W}	{(4; 0,7), (5; 0,3)}	{(1; 1)}
C5	{(3; 0,8), (4; 0,1), (Ω; 0,1)}	{(3; 0,1), (4; 0,8), (Ω; 0,1)}
C6	{(2; 0,9), (3; 0,1)}	{(2; 0,1), (3; 0,9)}
Water & Sanitation		
C1^{B}	{(1; 1)}	{(6; 0,4), (Ω; 0,6)}
C2	{(4; 0,6), (Ω; 0,4)}	{(4; 0,9), (Ω; 0,1)}
C3^{W}	{(6; 0,4), (Ω; 0,6)}	{(1; 1)}
C4	{(1; 0,8), (Ω; 0,2)}	{(4; 0,8), (Ω; 0,2)}
C5	{(4; 0,7), (Ω; 0,3)}	{(5; 0,7), (Ω; 0,3)}
C6	{(3; 0,8), (Ω; 0,2)}	{(3; 0,8), (Ω; 0,2)}

Policy (P)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
P1^{W}	{(8; 1)}	{(1; 1)}
P2^{B}	{(1; 1)}	{(8; 1)}
P3	{(1; 1)}	{(8; 1)}
Road & Bridge		
P1	{(1; 0,8), (Ω; 0,2)}	{(2; 0,8), (Ω; 0,2)}
P2^{W}	{(2; 0,8), (Ω; 0,2)}	{(1; 1)}
P3^{B}	{(1; 1)}	{(2; 0,8), (Ω; 0,2)}
Transportation		
P1^{B}	{(1; 1)}	{(4; 0,2), (5; 0,8)}
P2	{(3; 0,2), (4; 0,8)}	{(3; 80), (4; 0,2)}
P3^{W}	{(4; 0,2), (5; 0,8)}	{(1; 1)}
Water & Sanitation		
P1^{W}	{(2; 0,7), (Ω; 0,3)}	{(1; 1)}
P2	{(1; 0,9), (Ω; 0,1)}	{(2; 0,9), (Ω; 0,1)}
P3^{B}	{(1; 1)}	{(2; 1)}

B = Best Criterion, W = Worst Criterion

Appendix H

Supplementary Criteria Assessment with B-BWM

Table H. Supplementary criteria assessment in each category from four sectors.

Technical (T)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
$T1^{W}$	{(5; 1)}	{(1; 1)}
T2	{(1; 0,2), (2; 0,8)}	{(4; 0,8), (5; 0,2)}
T3	{(2; 1)}	{(5; 1)}
T4	{(4; 1)}	{(1; 0,8), (2; 0,2)}
T5	{(1; 1)}	{(5; 1)}
$T6^{B}$	{(1; 1)}	{(5; 1)}
T7	{(3; 0,8), (4; 0,2)}	{(4; 0,2), (5; 0,8)}
Road & Bridge		
T1	{(1; 0,8), (Ω; 0,2)}	{(2; 0,8), (Ω; 0,2)}
$T2^{W}$	{(2; 0,8), (Ω; 0,2)}	{(1; 1)}
$T3^{B}$	{(1; 1)}	{(2; 0,8), (Ω; 0,2)}
Transportation		
T1	{(2; 0,1), (3; 0,9)}	{(2; 0,9), (3; 0,1)}
T2	{(2; 0,1), (3; 0,9)}	{(2; 0,9), (3; 0,1)}
$T3^{B}$	{(1; 1)}	{(3; 0,2), (4; 0,8)}
$T4^{W}$	{(3; 0,2), (4; 0,8)}	{(1; 1)}
Water & Sanitation		
T1	{(1; 0,8), (Ω; 0,2)}	{(1; 1)}
$T2^{W}$	{(2; 0,9), (Ω; 0,1)}	{(2; 0,9), (Ω; 0,1)}
$T3^{B}$	{(1; 1)}	{(1; 1)}

Organizational (O)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
$O1^{B}$	{(1; 1)}	{(5; 1)}
O2	{(2; 1)}	{(4; 1)}
O3	{(2; 1)}	{(4; 1)}
O4	{(2; 1)}	{(4; 1)}
O5	{(3; 1)}	{(3; 1)}
O6	{(2; 1)}	{(4; 1)}
O7	{(2; 1)}	{(4; 1)}
$O8^{W}$	{(5; 1)}	{(1; 1)}
Road & Bridge		
$O1^{B}$	{(1; 1)}	{(2; 0,8), (Ω; 0,2)}
$O2^{W}$	{(2; 0,8), (Ω; 0,2)}	{(1; 1)}
Transportation		
O1	{(3; 0,9), (4; 0,1)}	{(3; 0,1), (4; 0,9)}
$O2^{B}$	{(1; 1)}	{(4; 0,9), (5; 0,1)}
$O3^{W}$	{(4; 0,9), (5; 0,1)}	{(1; 1)}
O4	{(3; 0,9), (4; 0,1)}	{(3; 0,1), (4; 0,9)}
Water & Sanitation		
O1	{(2; 0,9), (Ω; 0,1)}	{(4; 0,8), (Ω; 0,2)}
O2	{(4; 0,8), (Ω; 0,2)}	{(3; 0,9), (Ω; 0,1)}
$O3^{W}$	{(7; 0,9), (Ω; 0,1)}	{(1; 1)}
O4	{(3; 0,9), (Ω; 0,1)}	{(4; 0,8), (Ω; 0,2)}
$O5^{B}$	{(1; 1)}	{(7; 0,9), (Ω; 0,1)}

External (E)		
Criteria	Best to Others	Others to Worst
Energy & Electricity		
$E1^{B}$	{(1; 1)}	{(8; 1)}
$E2^{W}$	{(8; 1)}	{(1; 1)}
E3	{(5; 1)}	{(5; 1)}
E4	{(5; 1)}	{(5; 1)}
E5	{(2; 1)}	{(7; 1)}
E6	{(8; 1)}	{(1; 1)}
E7	{(3; 1)}	{(6; 1)}
E8	{(3; 1)}	{(6; 1)}
Road & Bridge		
E1	{(2; 0,8), (Ω; 0,2)}	{(2; 0,8), (Ω; 0,2)}
$E2^{B}$	{(1; 1)}	{(3; 0,8), (Ω; 0,2)}
$E3^{W}$	{(3; 0,8), (Ω; 0,2)}	{(1; 1)}
Transportation		
E1	{(2; 0,1), (3; 0,9)}	{(2; 0,9), (3; 0,1)}
$E2^{W}$	{(2; 0,2), (3; 0,8)}	{(1; 1)}
E3	{(2; 0,2), (3; 0,8)}	{(2; 0,8), (3; 0,2)}
$E4^{B}$	{(1; 1)}	{(2; 0,2), (3; 0,8)}
E5	{(2; 0,8), (3; 0,2)}	{(2; 0,8), (3; 0,2)}
Water & Sanitation		
E1	{(1; 0,9), (2; 0,1)}	{(2; 0,8), (3; 0,2)}
$E2^{B}$	{(1; 100)}	{(1; 0,3), (2; 0,7)}
E3	{(1; 0,2), (2; 0,8)}	{(3; 0,8), (Ω; 0,2)}
$E4^{W}$	{(2; 0,3), (3; 0,7)}	{(1; 1)}

B = Best Criterion, W = Worst Criterion

Appendix I

Table I. Project assessment from four sectors.

Criteria	Energy & Electricity				
	EE1	EE2	EE3	EE4	EE5
T1	{(1; 1)}	{(3; 0,2), (4; 0,8)}	{(5; 1)}	{(3; 0,2), (4; 0,8)}	{(3; 0,2), (4; 0,8)}
T2	{(1; 1)}	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(1; 1)}
T3	{(5; 1)}	{(4; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
T4	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
T5	{(8; 1)}	{(8; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}
T6	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
T7	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
O1	{(1; 1)}	{(9; 1)}	{(1; 1)}	{(5; 1)}	{(5; 1)}
O2	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}	{(5; 1)}
O3	{(3; 1)}	{(9; 1)}	{(3; 1)}	{(9; 1)}	{(9; 1)}
O4	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
O5	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(8; 1)}	{(8; 1)}
O6	{(3; 1)}	{(9; 1)}	{(3; 1)}	{(8; 1)}	{(8; 1)}
O7	{(5; 1)}	{(9; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
O8	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(9; 1)}	{(9; 1)}
E1	{(7; 1)}	{(9; 1)}	{(7; 1)}	{(9; 1)}	{(9; 1)}
E2	{(1; 1)}	{(5; 1)}	{(7; 1)}	{(7; 1)}	{(7; 1)}
E3	{(3; 1)}	{(3; 1)}	{(3; 1)}	{(3; 1)}	{(3; 1)}
E4	{(1; 1)}	{(5; 1)}	{(1; 1)}	{(4; 1)}	{(4; 1)}
E5	{(3; 1)}	{(9; 1)}	{(3; 1)}	{(9; 1)}	{(9; 1)}
E6	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}	{(1; 1)}
E7	{(5; 1)}	{(2; 1)}	{(5; 1)}	{(9; 1)}	{(9; 1)}
E8	{(1; 1)}	{(1; 1)}	{(5; 1)}	{(7; 1)}	{(9; 1)}

Criteria	Transportation				
	TT1	TT2	TT3	TT4	TT5
T1	{(4; 0,6), (5; 0,4)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}
T2	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}	{(8; 0,8), (9; 0,2)}
T3	{(9; 1)}	{(9; 1)}	{(8; 1)}	{(9; 1)}	{(9; 1)}
T4	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}	{(9; 1)}
O1	{(6; 0,7), (7; 0,3)}	{(3; 0,8), (4; 0,2)}	{(4; 0,8), (5; 0,2)}	{(6; 0,7), (7; 0,3)}	{(4; 0,8), (5; 0,2)}
O2	{(7; 1)}	{(7; 1)}	{(7; 1)}	{(7; 1)}	{(7; 1)}
O3	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}
O4	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}
E1	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}	{(8; 1)}
E2	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}
E3	{(2; 1)}	{(2; 1)}	{(2; 1)}	{(8; 1)}	{(5; 1)}
E4	{(5; 0,7), (6; 0,3)}	{(9; 1)}	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}	{(7; 0,2), (8; 0,8)}
E5	{(7; 0,3), (8; 0,7)}	{(7; 0,3), (8; 0,7)}	{(7; 0,3), (8; 0,7)}	{(7; 0,3), (8; 0,7)}	{(7; 0,3), (8; 0,7)}

Criteria	Water & Sanitation				
	WS1	WS2	WS3	WS4	WS5
T1	{(9; 0,7), (Ω; 0,3)}	{(6; 1)}	{(6; 1)}	{(6; 1)}	{(7; 0,4), (Ω; 0,6)}
T2	{(5; 0,5), (Ω; 0,5)}	{(2; 0,2), (3; 0,6), (Ω; 0,2)}	{(2; 0,1), (3; 08), (Ω; 0,1)}	{(2; 0,1), (3; 0,8), (Ω; 0,1)}	{(7; 0,4), (8; 0,4), (Ω; 0,2)}
T3	{(5; 0,5), (Ω; 0,5)}	{(5; 0,6), (Ω; 0,4)}	{(5; 0,5), (Ω; 0,5)}	{(5; 0,4), (Ω; 0,6)}	{(9; 0,7), (Ω; 0,3)}
O1	{(5; 0,5), (Ω; 0,5)}	{(3; 0,6), (Ω; 0,4)}	{(9; 0,7), (Ω; 0,3)}	{(3; 0,6), (4; 0,2), (Ω; 0,2)}	{(9; 0,9), (Ω; 0,1)}
O2	{(6; 0,3), (7; 0,2), (Ω; 0,5)}	{(3; 0,6), (Ω; 0,4)}	{(3; 0,4), (4; 0,1), (Ω; 0,5)}	{(5; 0,5), (Ω; 0,5)}	{(9; 0,8), (Ω; 0,2)}
O3	{(3; 0,6), (4; 0,2), {Ω; 0,2)}	{(5; 0,5), {Ω; 0,5)}	{(1; 0,6), {Ω; 0,4)}	{(7; 0,4), (8; 0,2), {Ω; 0,4)}	{(7; 0,8), (8; 0,1), {Ω; 0,1)}
O4	{(3; 1)}	{(1; 0,5), (Ω; 0,5)}	{(9; 0,8), (Ω; 0,2)}	{(2; 0,3), (3; 0,4), (Ω; 0,3)}	{(7; 0,4), (8; 0,4), (Ω; 0,2)}
O5	{(7; 0,8), (8; 0,2)}	{(5; 0,3), (Ω; 0,7)}	{(9; 0,9), (Ω; 0,1)}	{(5; 0,2), (Ω; 0,8)}	{(9; 0,9), (Ω; 0,1)}
E1	{(1; 0,3), (Ω; 0,7)}	{(1; 0,5), (Ω; 0,5)}	{(6; 0,7), (7; 0,2), (Ω; 0,1)}	{(1; 0,5), (Ω; 0,5)}	{(9; 0,8), (Ω; 0,2)}
E2	{(2; 0,3), (3; 0,2), (Ω; 0,5)}	{(2; 0,4), (3; 0,4), (Ω; 0,2)}	{(7; 0,2), (8; 0,7), (Ω; 0,1)}	{(2; 0,1), (3; 0,4), (Ω; 0,5)}	{(9; 0,7), (Ω; 0,3)}
E3	{(1; 0,4), (Ω; 0,6)}	{(3; 0,6), (Ω; 0,4)}	{(3; 0,6), (Ω; 0,4)}	{(3; 0,6), (Ω; 0,4)}	{(1; 0,5), (Ω; 0,5)}
E4	{(5; 0,5), (Ω; 0,5)}	{(1; 0,5), (Ω; 0,5)}	{(1; 0,3), (Ω; 0,7)}	{(5; 0,6), (Ω; 0,4)}	{(9; 0,6), (Ω; 0,4)}

Criteria	Road & Bridge				
	RB1	RB2	RB3	RB4	RB5
T1	{(2; 0,5), (Ω; 0,5)}	{(2; 0,5), (Ω; 0,5)}	{(5; 0,7), (Ω; 0,3)}	{(4; 0,7), (Ω; 0,3)}	{(3; 0,5), (Ω; 0,5)}
T2	{(5; 0,6), (Ω; 0,4)}	{(5; 0,6), (Ω; 0,4)}	{(5; 0,6), (Ω; 0,4)}	{(5; 0,6), (Ω; 0,4)}	{(5; 0,6), (Ω; 0,4)}
T3	{(8; 1)}	{(9; 1)}	{(7; 1)}	{(9; 1)}	{(9; 1)}
O1	{(2; 0,9), (Ω; 0,1)}	{(2; 0,7), (Ω; 0,3)}	{(2; 0,9), (Ω; 0,1)}	{(3; 0,7), (Ω; 0,3)}	{(3; 0,9), (Ω; 0,1)}
O2	{(6; 0,8), (Ω; 0,2)}	{(4; 0,7), (Ω; 0,3)}	{(3; 0,7), (Ω; 0,3)}	{(4; 0,6), (Ω; 0,4)}	{(4; 0,8), (Ω; 0,2)}
E1	{(6; 0,8), (Ω; 0,2)}	{(7; 0,9), (Ω; 0,1)}	{(3; 0,8), (Ω; 0,2)}	{(8; 0,9), (Ω; 0,1)}	{(6; 0,8), (Ω; 0,2)}
E2	{(7; 0,8), (Ω; 0,2)}	{(8; 0,9), (Ω; 0,1)}	{(4; 0,8), (Ω; 0,2)}	{(9; 0,9), (Ω; 0,1)}	{(7; 0,8), (Ω; 0,2)}
E3	{(2; 0,9), (Ω; 0,1)}	{(6; 0,5), (Ω; 0,5)}	{(6; 0,8), (Ω; 0,2)}	{(6; 0,6), (Ω; 0,4)}	{(5; 0,8), (Ω; 0,2)}