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A FRAMEWORK FOR STRATEGIC PROJECT ANALYSIS AND PRIORITIZATION

BY

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ABSTRACT

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Title: A Framework for Strategic Project Analysis and Prioritization

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Projects that support the long-term strategic intent and alignment are considered strategic projects. Therefore, these projects must consider their alignment with the organization's current strategy and focus on the risk, organizational capability, resources availability, political influence, and socio-cultural factors. Quantitative and qualitative methods prioritize the projects; however, they are usually suitable for specific industries. Although prioritization models are used in the private sector, the same in the public sector is not widely seen in the literature. The lack of models in the public sector has happened because of the projects' social implications, the value perception of different projects in the public sector, and potentially differing value perceptions attached to the types of projects in different decision-making environments in the public sector.

The thesis proposes a generic framework to develop a priority list of the available basket of projects and decide on projects for the next undertaking. The focus of the thesis is on public projects. The analysis in the framework considers the critical factors for prioritization obtained from the literature clustered through the agglomerative text clustering technique. In the proposed framework, 13 critical clusters are identified and weighted using the Criteria Importance Through Intercriteria Correlation (CRITIC) method to develop their ranking using the Technique for Order of Preference Similarity Ideal Solution (TOPSIS) method. In addition, the proposed framework uses vector weighting to prioritize projects across industries.

The applicability of the framework is demonstrated through Qatar's real estate and transportation projects. The outcome obtained from the framework is compared with those obtained through the experts using the System Usability Scale (SUS). The comparison shows that the framework provides good predictability of the projects for implementation.

DEDICATION

I dedicate this thesis to all decision-makers in Qatar to support their project selection process. In addition, I would like to thank my parents, wife, sons, daughters, and my extended family for their sincere love, confidence, and generous support.

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ACRONYMS

Acronym	Full form
AHP	Analytical hierarchical process
ANN	Artificial neural network
ANP	Analytical network process
AP	Affinity propagation
ARRA	American recovery and reinvestment act
CRITIC	Criteria importance through inter-criteria correlation
DEA	Data envelopment analysis
DEMATEL	Decision-making trial and evaluation laboratory
DOR	Department of revenue
ELECTRE	Elimination and choice translating reality
ERP	Enterprise resource planning
IRM	Integrated risk management
IT	Information technology
MCDM	Multi-criteria decision-making
NIH	National Institute of Health
PCA-DP	Principal component-dynamic programming
PMP	Project management professional
PROMETHEE	Preference ranking organization for enrichment evaluation
QFD	Quality function deployment
SAW	Simple additive weighting
SUS	System usability score
TOPSIS	Technique for order of preference by similarity to the ideal solution
USE	Universal sentence encoder

CHAPTER 1: INTRODUCTION

Strategic projects are expected to create a long-term competitive advantage for a particular organization, and they are prioritized based on their importance and the degree of potential risk. Strategic projects usually require significant investments, resources, and the organization's project environment.

Strategic projects are also categorized based on their duration, investment requirements, and business or social impacts (Mahdavi *et al.*, 2021). Therefore, these projects are analyzed for immediate take-up, holding, or cancellation (Jafarzadeh *et al.*, 2018), which necessitates understanding a project portfolio suitable for an organization becomes important in the organization (Martinsuo, 2013). The type of projects in the portfolio can differ from one to another, thus providing a challenge for their selection, and this situation is more complex in the public sector. For example, such projects can be from different sectors such as construction (Karamoozian *et al.*, 2019), transportation (Li *et al.*, 2019), R&D (Cook and Green, 2000), information technology (Ligardo-Herrera *et al.*, 2019), or real estate (Pain *et al.*, 2020).

Studies have addressed the importance of strategic projects. A study by Kopmann *et al.* (2017) that examined projects in 182 firms mentions that organizations focus on tactical strategies, deliberate and emerging strategies, and the business environment becomes important considerations for project decision-making.

Different authors categorize strategic projects considering various factors. For example, strategic projects are categorized based on organizational strategic objectives (Crawford *et al.*, 2004a). In addition, multiple stakeholders in projects have different priorities, often conflicting, requiring a thorough analysis of the projects.

Strategic projects are also categorized based on estimated development time, investments, sustainability, or business and social impacts. However, strategic project prioritization becomes challenging (Toor and Ogunlana, 2010), especially in the public sector (Abbasi and Al-Mharmah, 2000) due to dynamic changes in the environment (Cooper *et al.*, 2001) or the government priorities.

Strategic projects should also consider organizational capabilities through managerial aspects such as resource capabilities management (Villafáñez *et al.*, 2020), value management (Martinsuo and Killen, 2014), governance (Müller *et al.*, 2017), risk management (Karamoozian *et al.*, 2019), and stakeholder management (Ligardo-Herrera *et al.*, 2019). These considerations help optimize resource use for competitive value generation (Cook and Green, 2000). Sufficient capacity and capability management also help balance organizational potential with achieving organizational goals (Wang *et al.*, 2016). The project value management ensures planned returns with potential returns from the project and contributes to sustainability (El-Halwagi, 2017). Dynamic governance harmonizes many factors such as the organizational structure, stakeholder role with communication mechanism, coordination mechanism to ensure organizational growth (Li *et al.*, 2019). Incorporating uncertainty ensures value and sustainability in decision-making. Therefore, risk management should optimize project selection (Dixit and Tiwari, 2019). Competing stakeholders' priorities must also be balanced to identify the best project that provides a tradeoff between organization project selection sustainability and stakeholder value (Read *et al.*, 2017a; Kudratova *et al.*, 2019).

Strategic project prioritization is critical, but factors used for prioritization could affect the overall cost of projects (Al-Sobai *et al.*, 2020). These factors can be classified as quantitative and qualitative. The qualitative factors focus on the qualitative aspects such as stakeholder commitment and political acceptance, and the quantitative factors focus on the measurable and quantifiable values such as finance or the project's productivity. These factors also depend on the decision-making environment; for example, evaluating geometrical, ownership/social, environmental, erosion, and morphology factors can be important for land-related projects (Muchová and Petrovič, 2019), whereas financial factors may be necessary for other projects. In addition, evaluation criteria are often organization-specific (Nowak, 2013), although they might be impacted by the stakeholder priorities (Ligardo-Herrera *et al.*, 2019).

1.1 Motivation

The motivation for this work follows:

1. Multiple projects need to be implemented for socio-economic development in the public sector. However, the number and type of projects are limited due to investment capability, organizational capability, and the risk associated with the projects. Therefore, it is difficult for the decision-makers to choose a particular

project or a particular portfolio of projects for implementation. As these projects are long-term oriented in terms of their benefits and require significant investments, resources, and capability, the priority for investments in projects should be analyzed. The review shows no comprehensive models and frameworks that capture factors related to the public sector and the available organizational inventory of management capability. Therefore, the primary motivation for developing this thesis is to explore the factors, use quantitative analysis, and develop a basis for prioritizing and selecting strategic projects.

2. The literature review shows that the decision-makers adopt methods to select projects based on the need at the time of decision-making; they often consider a small number of factors in selecting a project portfolio, which could be due to the difficulties in comprehending a large number of factors. While there are some common weighting techniques to decide on the ranking of the projects (Tavana *et al.*, 2015; Oztaysi, 2015; Elbok and Berrado, 2018), most of these techniques are limited to a small set of projects (Bryce *et al.*, 2014) or specific business sector (Yang *et al.*, 2017), or has a small collection of factors that do not cover project diversity. Consequently, strategic project prioritization criteria are limited to a particular project type of business sector.

3. The competition for resources and the need for the development of projects brings the need to provide a common platform to compare one project to decide on project tradeoffs. A common platform can lead to informed decisions. Therefore, the framework proposed in this thesis provides an opportunity to assess the impact of different projects based on their inherent criteria and support decision-making. The analysis can be refined with additional data obtained in each decision-making cycle.

1.2 Problem Statement

Strategic project execution depends on many factors that affect cross-sections in large-scale organizations or government sectors (Pain *et al.*, 2020). Several issues such as financial capabilities, social and political concerns, technology fit, legal and policy concerns, strategic alignment, risk, and organizational capabilities hinge on such projects' execution.

The decision-makers who rank strategic projects face challenges, such as handling many criteria, measuring each criterion concerning each strategic project, finding weights between conflicting criteria, and handing quantitative and qualitative factors together. Moreover, the diversity of project factors results in factors' weights that are not easily comparable across the industry. For example, the real estate and manufacturing projects focus more on financial factors health-related, and transportation projects focus on social impacts. Therefore, the challenge is portfolio decision when such a difference in the implication of the factors arises.

Prioritization models try to leverage the efforts carried out by the decision-makers across different managerial levels. Although, the review shows that researchers have used specific strategic project prioritization that targets specific industries such as construction (Karamoozian *et al.*, 2019; Khadija and Laila, 2014), Energy (Wu *et al.*, 2019a), environmental (Di Ludovico and Fabietti, 2018a), and oil and gas (Rebeeh *et al.*, 2019), decision-makers have a more significant challenge of how to rank different types of projects.

Therefore, the challenge lies in how different project types could be integrated to fulfil the socio-economic agenda. Unfortunately, the current prioritization methods do not consider heterogeneous public projects that span different sectors. Therefore, this thesis aims to achieve this gap by providing a generic framework to assist the decision-makers.

1.3 Research Questions

The primary research questions to be explored in this thesis are given below.

RQ 1: What factors are important for strategic project selection?

RQ 2: What methods can be used to reduce the factors?

RQ 3: What type of generic framework is most suitable for strategic project prioritization?

1.4 Objectives

The following are the research objectives of the thesis, which address the above-mentioned research questions.

1. Identify the dominant strategic project selection factors (related to RQ1);
2. Analyze project selection factors as applicable for an industry (related to RQ2);

3. Develop a generic framework for project prioritization and selection (related to RQ3).

1.5 Research Methodology

Johnson *et al.* (2019) mentioned that adopting a multi-phase sequential approach can help obtain outcomes through progressive analysis. Therefore, a multi-phase sequential approach is used in this research. The method starts from the literature review to identify the criteria for project selection, reduce and cluster the criteria, and apply it through a particular framework for a specific industry. Saunders *et al.* (2019) also recommend the sequential multi-phase method for exploratory-based research.

As shown in Figure 1.1, the research method in this paper starts with identifying criteria for project selection, followed by criteria grouping (clustering) to reduce the number of factors required for decisions. Some of these factors may not be related to a particular type of industry. Therefore, screeing factors specific to the industry is done. The research method then focuses on criteria weighting, ranking of projects by industry and across the industry. Finally, a method to decide on a project is presented. The thesis uses a number of projects in Qatar to demonstrate

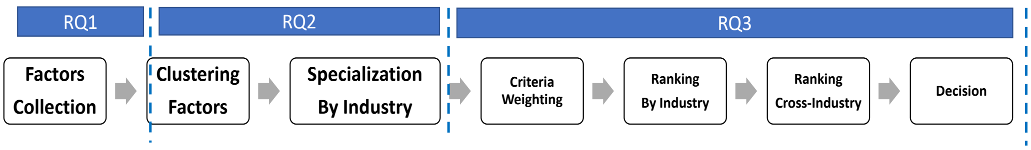

Figure 1.1 The Research Method

the implementation of the framework. The outcomes of the analysis are validated with a system usability scale (SUS), as suggested by Brooke (1996).

1.6 Organization of the Thesis

The rest of the thesis is organized as follows. In Chapter 2, the most important success factors, criteria, and project knowledge areas that contribute to the success of construction projects as obtained from the literature are provided. In Chapter 3, the framework adopted in this research and the questionnaire development is discussed. The data analysis, sampling method, and statistical methods are provided in Chapter 4. The chapter also provides discussions on the implications of the results from the analysis. Finally, in Chapter 5, conclusions, limitations, and future research directions are presented.

CHAPTER 2: LITERATURE REVIEW

Since the list of strategic project selection criteria depends on the industry, this research opts to adhere to the literature's criteria. Moreover, eliciting criteria from decision-makers is infeasible and time-consuming. Therefore, this chapter follows the systematic framework for literature analysis (Al-Sobai *et al.*, 2020). Content analysis is used to extract the knowledge from the literature to highlight different aspects of the strategic project selection process. This type of content analysis of the selected literature was also used in (Pokharel and Mutha, 2009; Caunnhye *et al.*, 2012; Xu *et al.*, 2019; Rebeeh *et al.*, 2019).

2.1. Literature Review Methodology

Figure 2.1 shows the steps for the systematic review method (Tranfield *et al.*, 2003) and data extraction and synthesis. As suggested by Klein and Müller (2020), research questions are developed first, and the framework is developed later. The framework is analyzed for

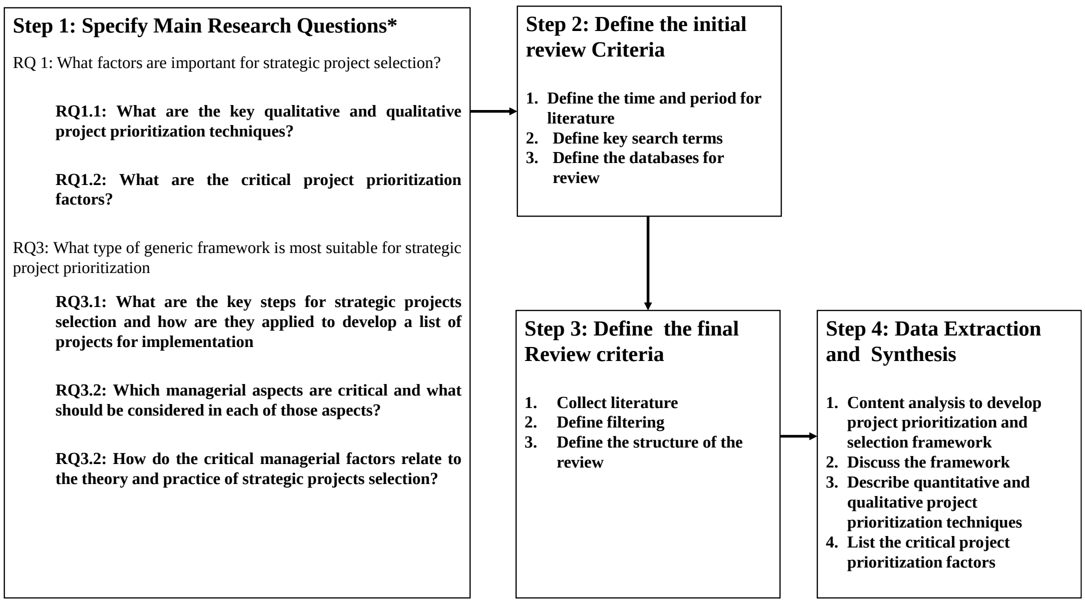

Figure 2.1 Literature Review Research Methodology (adapted from Tranfield et al. (2003))

opportunities and the gaps in current knowledge in strategic project selection. Note that RQ1.1 and RQ1.2 relate to RQ1, discussing strategic project selection factors and methods.

For step 2, the literature published mainly during 2008-2021 is considered as most of the recent papers have been found to extend the methodology, if any, published in the previous literature. The research focused on the 'selection' and 'prioritization' of strategic projects. Literature was primarily searched from the Google Scholar database, IEEE Xplore, ScienceDirect, Emerald Insight, Springer, Taylor and Francis, and Wiley.

For step 3, 300 literature were obtained, filtered for the content that discusses identification, categorization, evaluation, and selection for further analysis, prioritization, balancing, and decision-making.

For step 4, the guidelines by Farrington (Farrington, 2003), as shown in Table 2.1 was used for filtering. This resulted in a list of 155 pieces of literature used for content analysis. Finally, the analysis followed the method (Mihas, 2019) and yielded four significant steps and six main managerial aspects.

Table 2.1 Screening criteria of collected articles

#	Criteria	Description	Criteria Checking Example
1	Descriptive validity	In terms of how accurate and objective is the collected information	Adequacy of result description
2	Statistical conclusion validity	In terms of inferences drawn and logic is presented in the literature	Fitness of the statistical tool and sample size.
3	Construct validity	In terms of literature referring to the strategic projects and their characteristics	Provision of validation of the results
4	External validity	In terms of results containing factors that can lead to the development of generic understanding in different application areas.	Comparison of cases from different industries for generalizability of the results.

2.1.1. Strategic Project Selection Frameworks

Data extraction and analysis explained in Step 4 of Figure 2.1 are used in this research. Therefore, the framework presented in Al-Sobai *et al.* (2020) and given in Figure 2.2 is adopted for this purpose. The review summary will answer these research questions

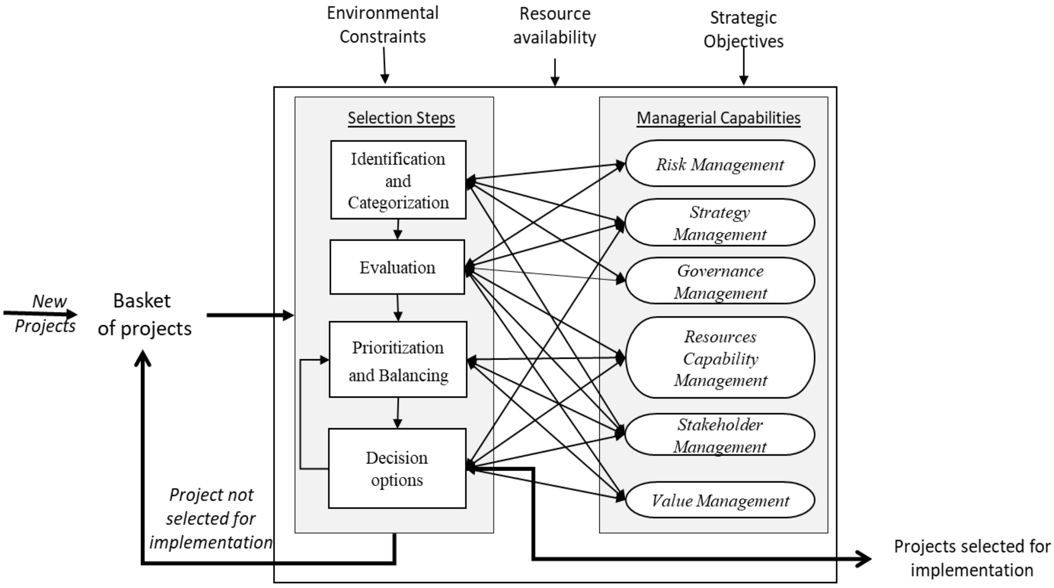

Figure 2.2 Framework for literature analysis for strategic project selection.

based on the literature review at the end of this chapter. Figure 2.2 follows the systematic process based on the BLOC-ICE approach mentioned in Pokharel (2022).

Figure 2.2 shows the strategic project selection containing inputs, as the basket of projects, either newly identified through business case analysis or rejected in the earlier cycle of decision-making. Projects' prioritization in the current decision-making cycle is subject to change in strategic objectives; therefore, the environment must consider decisions. In addition, the BLOC-ICE approach mentions that decisions have to consider limitations, called constraints. The resources, environment, or strategic guidelines may provide the limitations. Therefore, understanding and managing constraints are important in the decision-making process (Steyn and Viljoen, 2007). The importance of the constraints in projects is also mentioned in (Di Ludovico and Fabietti, 2018b; Wang and Wu, 2019; Aarseth *et al.*, 2017).

The process (inside the rectangle boundary) given in Figure 2.2 considers two parts, analytical and managerial. The figure shows that both quantitative methods and managerial capabilities are considered for decision-making. The output of this process is a list of the selected project for immediate take up or the rejected projects that can be considered at a later decision-making period. In this thesis, based on the literature review, it is assumed that Figure 2.2 provides the comprehensiveness of the project selection process, and it is guided by the strategic objectives so that only strategic projects are considered for the analysis. Therefore, the review will focus on the literature which considers the elements (inputs, outputs, constraints, and processes) mentioned in Figure 2.2.

2.1.2. Analysis of the Project Selection Process

The project selection process requires evaluating and selecting a single project or a set of projects to meet organizational goals(Costantino *et al.*, 2015a). Multiple criteria are also recommended for the selection (Nowak, 2013). A list of 48 criteria is given in (Wu *et al.*, 2019b) to evaluate and select projects. These methods and criteria can be used in different steps (Figure 2.2). Figure 2.2 shows that any project not selected for implementation in a cycle is collected in a basket for possible consideration in the next decision-making cycle. A list of papers that consider different application areas as presented in Thonemann *et al.* (Thonemann *et al.*, 2020) is given in Table 2.2. Further details on the papers are given in Appendix A.

Table 2.2 Identified literature (some studies are also mentioned in (Al-Sobai *et al.*, 2020)).

Sector	Author (n=120)
Construction (n=15)	(Issa *et al.*, 2020) (Feyzi and Badrgermi, 2020) (Bektur, 2021) (Maceika *et al.*, 2021) (Zarjou and Khalilzadeh, 2021) (Taylan *et al.*, 2014a) (Karamoozian *et al.*, 2019) (Mahdavi *et al.*, 2021) (Nguyen *et al.*, 2019) (Han *et al.*, 2019) (Pangsri, 2015)

Sector	Author (n=120)
	(Taylan *et al.*, 2014b)
	(Kaiser *et al.*, 2015)
	(Mohagheghi *et al.*, 2015)
Real Estate (n=5)	(Ginevičius and Zubrecovas, 2009)
	(Di, 2021)
	(Dobrovolskienė *et al.*, 2021)
	(Song *et al.*, 2021)
	(Sánchez-Garrido *et al.*, 2021)
Energy (n=10)	(Rezaei *et al.*, 2021)
	(Elkadeem *et al.*, 2020)
	(Zolfaghari and Mousavi, 2021)
	(Wu *et al.*, 2020)
	(Yi *et al.*, 2021)
	(Xu *et al.*, 2020)
	(Davoudabadi *et al.*, 2021)
	(Kudratova *et al.*, 2019)
	(Wu *et al.*, 2019b)
	(Al-Saleh and Taleb, 2010)
Environmental and Healthcare (n=8)	(Adalı and Tuş, 2021)
	(Alao *et al.*, 2021)
	(Aryanfar *et al.*, 2020)
	(Kalian, 2021)
	(Abad *et al.*, 2021)
	(Di Ludovico and Fabietti, 2018b)
	(Wang and Wu, 2019)
	(Hesarsorkh *et al.*, 2021)
Infrastructure (n=10)	(Genger *et al.*, 2021)
	(Alves *et al.*, 2020)
	(Anderluh *et al.*, 2020)
	(Yang *et al.*, 2017)
	(Daryani *et al.*, 2020)
	(Mokhtari and Imamzadeh, 2021)
	(Mohagheghi *et al.*, 2020)
	(Lehtinen and Aaltonen, 2020)
	(Bryce *et al.*, 2014)
	(Ahern and Anandarajah, 2007)
	(Aladağ. H and Işik, 2020)
Information Technology (n=11)	(Davoudabadi *et al.*, 2021)
	(Şahin Zorluoğlu and Kabak, 2020)
	(Pramanik *et al.*, 2020)
	(Roy and Shaw, 2021)
	(Mahmoudi *et al.*, 2020)
	(Ligardo-Herrera *et al.*, 2019)
	(Oztaysi, 2014)
	(Machado *et al.*, 2015)
	(Jafarzadeh *et al.*, 2015)
	(Oztaysi, 2015)
	(Jafarzadeh *et al.*, 2018)
Manufacturing (n=9)	(Pirasteh Fard and Abtahi, 2021)
	(Biscaia *et al.*, 2021)
	(James *et al.*, 2021)
	(Ghannadpour *et al.*, 2021)

Sector	Author (n=120)
	(Harrison, Elsayed, Sarker, *et al.*, 2021)
	(Ma *et al.*, 2020)
	(Kovach and Ingle, 2020)
	(Ma *et al.*, 2020)
	(Järvenpää *et al.*, 2018)
Military (n=3)	(Simplício *et al.*, 2017)
	(Puthamont and Charoenngam, 2007)
	(Harrison, Elsayed, Garanovich, *et al.*, 2021)
Oil and gas (n=6)	(Mohammed, 2021)
	(Delouyi *et al.*, 2021)
	(Zhang *et al.*, 2021)
	(Rebeeh *et al.*, 2019)
	(Asrilhant *et al.*, 2006)
	(Xue *et al.*, 2014)
Renewable energy (n=8)	(Davoudabadi *et al.*, 2021)
	(Rios and Duarte, 2021)
	(Elkadeem *et al.*, 2020)
	(Umer *et al.*, 2021)
	(Ahmad and Tahar, 2014)
	(Büyüközkan and Güleryüz, 2016)
	(Ritter and Deckert, 2017)
	(Saili and Balimu, 2018)
Transportation (n=8)	(Kaewfak *et al.*, 2020)
	(Li *et al.*, 2019)
	(Ivanović *et al.*, 2013)
	(Dot *et al.*, 2018)
	(Elbok and Berrado, 2018)
	(Dadashi and Mirbaha, 2019)
	(Dong *et al.*, 2019)
	(Novak *et al.*, 2015)
Research and Development (n=8)	(Mavrotas and Makryvelios, 2021)
	(Hesarsorkh *et al.*, 2021)
	(Souza *et al.*, 2020)
	(Hummel *et al.*, 2017)
	(Wang *et al.*, 2016)
	(Thamhain, 2014)
	(Rafiee *et al.*, 2014)
	(Tavana *et al.*, 2015)
General or mixed (n=19)	(RezaHoseini *et al.*, 2020)
	(Nowak and Trzaskalik, 2021)
	(Costantino *et al.*, 2015b)
	(Dutra *et al.*, 2014)
	(Crawford *et al.*, 2006)
	(Villafáñez *et al.*, 2020)
	(Dixit and Tiwari, 2019)
	(Benaija and Kjiri, 2015)
	(Muchová and Petrovič, 2019)
	(Moustafaev, 2010)
	(Müller *et al.*, 2008)
	(Steyn and Viljoen, 2007)
	(Nowak, 2013)
	(Atal *et al.*, 2016)

Sector	Author (n=120)
	(Kaveh Khalili-Damghani and Tavana, 2014) (da Silva *et al.*, 2017) (de Carvalho *et al.*, 2015) (Ding *et al.*, 2014) (Esfahani *et al.*, 2016)

Identification and Categorization

Misidentified or misclassified projects may cause a loss of opportunities, cost overruns, or improper social impact. Moreover, project categories vary across organizations (Crawford *et al.*, 2004b); therefore, the categorization rules may differ.

Screening criteria considered for the selection are based on economic impact, quality, risk (Mahdavi *et al.*, 2021), and potential for subsequent opportunities (Benaija and Kjiri, 2015; Overhage and Suico, 2001; Eken *et al.*, 2020; Atal *et al.*, 2016) due to strategic nature of the project. The project identification should focus on the goals, client, sponsor, key stakeholders, required resources, schedule, project interactions, key deliverables, budget requirements, business unit, market size, risk level estimates, market designation, and short- and long-term impact. Recognizing commonalities and differences between project types helps identify their potential role for project portfolio management. For example, a business project provides strategic integration, market projects that enhance corporate competition and profitability, while public projects that aim to provide positive social impact and welfare. Project categorization is an essential step towards better resource and capabilities management. Project identification and categorization often lead to the assignment of a project manager internally (Lo *et al.*, 2019).

Literature shows that during preliminary assessment for screening, stakeholders' requirements, resources, schedule, budget, market size, and the long-term impact should be considered (PMI, 2018). The screened projects can be categorized in ownership, project characteristics, application area or product, timing, strategic importance, geography, risk, scope, uncertainty, customer complexity, and contracting (Crawford *et al.*, 2004b). Other criteria, such as profitability, risk reduction, competence improvement, legal compliance, increased market share, process improvement, and business requirements, have also been proposed in the literature (Crawford *et al.*, 2006; Crawford *et al.*, 2004b). Literature analysis reveals that qualitative factors such as stakeholder's relationship, trust, the obedience of policies, response, and attitude are not explicitly considered during identification and categorization (Lehtinen and Aaltonen, 2020; Nguyen *et al.,* 2019) mention that identification and categorization should involve both the internal and external stakeholders.

Project Evaluation

Once projects have been categorized, it is essential to know the urgency of their implementation. Usually, a set of criteria is used to score the value of each project. However, researchers have no consensus on the best collection of criteria for each project category. For example, evaluating geometrical, ownership/social, environmental, erosion, and morphology factors for land-related projects (Muchová and Petrovič, 2019), whereas financial factors, may be necessary for other projects. In addition, evaluation criteria are often organization-specific (Nowak, 2013), although they might be impacted by the stakeholder priorities (Ligardo-Herrera *et al.*, 2019).

In project evaluation, scoring methods are not less important than the criteria itself. However, these methods shall consider risk, capabilities, governance, stakeholder management, and value management, along with the alignment of organizational strategic objectives. Although there are many methods, the consistency of these methods across project categories becomes important (Ishizaka and Siraj, 2018). Therefore, it might be worthwhile to develop a range of scores based on project categories.

Different techniques are used for project evaluation. For example, the tradeoff method (Focacci, 2017), DEA based (Wu *et al.*, 2019b), cost-benefit analysis and risk analysis (K Khalili-Damghani and Tavana, 2014), risk analysis and scenario analysis (Asrilhant *et al.*, 2006), and Delphi with MICMAC analysis method (Han *et al.*, 2019) are proposed in the literature. In general, regardless of the application area, the criteria to evaluate projects are grouped in four different factors (Arlt, 2010) and are shown in

Figure 2.3.. This compilation is also shown in Al-Sobai *et al.* (2020). For each of these factors, techniques for analysis can also be different. The list of techniques is also proposed in the literature (Archer and Ghasemzadeh, 1999; Hall and Nauda, 1990; Cooper *et al.*, 1997; Crossan and Apaydin, 2010; Ceria *et al.*, 2012; Hutzschenreuter and Horstkotte, 2013), some of them are listed in Table 2.4.

Table 2.3 Criteria for project categorization adapted from Al-Sobai *et al.* (2020)

Factors	Criteria	Authors
Business	Alignment with country policy Alignment with the sector policy Alignment with strategy and objectives Priorities mentioned Ratios of cost/benefit	(Dutra *et al.*, 2014) (Ahmad and Tahar, 2014) (Bachtler *et al.*, 2014) (Bryce *et al.*, 2014) (Chaouachi *et al.*, 2017), (de Carvalho *et al.*, 2015), (Dobrovolskienė and Tamošiūnienė, 2016) (Pangsri, 2015), (Puri and Tiwari, 2014)
Market	Capacity Growth rate Competition Profitability	(Brook and Pagnanelli, 2014), (Ding *et al.*, 2014), (Dutra *et al.*, 2014), (Sokmen, 2014), (Taylan *et al.*, 2014b), (Thamhain, 2014)
Resource availability	Required funds and budget Skills required Supply chains External technical support	(Costantino *et al.*, 2015a), (Kaiser *et al.*, 2015), (Thamhain, 2014), (Chemweno *et al.*, 2015), (Tavana *et al.*, 2014), (Koulinas *et al.*, 2014), (Van Peteghem and Vanhoucke, 2014), (Büyüközkan and Güleryüz, 2016)
Risk	Balance organization growth and minimal risk.	(Kaiser *et al.*, 2015), (Wu *et al.*, 2019b), (Mohagheghi *et al.*, 2015), (Khandekar *et al.*, 2015), (Hall *et al.*, 2015)

Table 2.4 Approaches used in project selection are also given in Al-Sobai *et al.* (2020)

Technique	Description	Techniques used	Authors
Benefits Measurement	Metrics proposed for ranking. These metrics provide opportunities for sorting, providing weights, and selecting projects.	Economic approaches Risk analysis approaches Productivity measurement Comparison methods Multiple criteria based approaches	(Costantino *et al.*, 2015a), (Dutra *et al.*, 2014), (Kaiser *et al.*, 2015), (Dobrovolskienė and Tamošiūnienė, 2016), (Oztaysi, 2014), (Bhattacharyya, 2015), (Stanujkic *et al.*, 2014), (Jafarzadeh *et al.*, 2015),

Technique	Description	Techniques used	Authors
			(Ouenniche *et al.*, 2016), (Xue *et al.*, 2014), (Nyborg, 2014)
Knowledge-based model	Using prior information and tools for scoring and screening	Top-down approaches Systems based approaches	(Taylan *et al.*, 2014b), (Machado *et al.*, 2015)
Strategic Planning	Using bubble charts for potential projects helps classify, cluster, reorganize, and analyze them according to priorities to balance the type of projects based on the decision-makers' criteria.	Graphical methods and analytical methods like regression and expert systems and clustering algorithms	(Oztaysi, 2014), (Maghsoodi *et al.*, 2018), (Da Silva *et al.*, 2017), (Müller Meier, C., Kundisch, D. & Zimmermann, S., 2015)
Marketing Research	Developing an understanding of the current opportunities and difficulties, information of the type, and prices or other factors as covered in the market research plan.	Consumer panels Focus groups Perceptual maps Preference mapping	(King *et al.*, 2015), (Gantman and Fedorowicz, 2016), (Oztaysi, 2015)
Mathematical and Programming	Consideration of the objectives and current constraints faced in the project. The focus could prioritize the objectives, reflecting cost, efficiency, environment, and labor involvement. The focus is on obtaining the best solution for the given decision-making environment.	Economic and econometric approaches Single/multiple objectives and linear/nonlinear approaches Static/dynamic programming based approaches	(Dutra *et al.*, 2014), (Thamhain, 2014), (Rafiee *et al.*, 2014), (Sahebi *et al.*, 2014), (Tavana *et al.*, 2015), (Ritter and Deckert, 2017)

Prioritization and Balancing

Projects should be prioritized based on resources available and long-term organizational benefits (Adler *et al.*, 1996; Mikkola, 2001; Järvenpää *et al.*, 2018). Management of resource capability refers to allocating the right resources at the right time to the right projects and an ability to preschedule the resource requirement. The management may face risks due to the market and changes in the project scope. Therefore, management capability would mean an ability to develop a dynamic mechanism to consider tradeoffs on allocation and urgency or allocation versus return from the project (Patanakul, 2015).

Projects are ranked within predetermined categories (Mavrotas *et al.*, 2007). Then projects should be prioritized to maximize the selected projects' combined outcomes by balancing organizational capacities (Meskendahl, 2010).

Quantitative methods used for prioritization are goal programming (Ahern and Anandarajah, 2007) and (Qiu, 1997). Railway projects prioritization with social and economic alignment, environmental quality, and safety and standards are considered in (Ahern and Anandarajah, 2007), and it is mentioned that project scoring can be higher for qualitative and lower for quantitative goals. In such cases, the judgment of decision-makers becomes essential. In (Qiu, 1997), goal programming is used for the prioritization of new or upgrading projects, but it is also mentioned that process failure modes and effect analysis (PFMEA) might be better for prioritization in upgrading projects (Kovach and Ingle, 2020). The ranking-based method uses a Likert-type scale with criteria weightage for project prioritization in defense construction projects (Puthamont and Charoenngam, 2007). However, assessing criteria used in different project stages becomes essential to prioritize resource use. A Monte-Carlo simulation-based data envelopment analysis method (DEA) is used (Dadashi and Mirbaha, 2019) to prioritize road safety projects by the government. The model can help to analyze uncertainties in investments and benefits for projects. It is mentioned that simulation-based models help visualize projects' outcomes much better than other methods (Dong *et al.*, 2019). A resource-constrained DEA in the mixed-integer binary program is also proposed (Cook and Green, 2000) for project prioritization.

Qualitative methods used to support prioritization are the Delphi method or a decision tree method (Simplício *et al.*, 2017), focusing on the value of investments and risks. These methods can also support prioritizing projects based on political priorities (Novak *et al.*, 2015). Another method is a fuzzy quality function deployment (QFD), and the DEA mentioned in (Jafarzadeh *et al.*, 2015) for project comparison and a harmony search algorithm (Esfahani *et al.*, 2016) for analyzing the return optimality of projects.

Decision Options

The most difficult option is to choose a set of projects based on different situations faced by the decision-makers. There may be two main approaches for decision, either solely based on internal (organizational) opportunities and requirements (such as legal and dynamics in the market), external opportunities and requirements, or a mix of the both. Authors have also proposed emerging criteria such as sustainability and environmental aspects (Puthamont and Charoenngam, 2007). Different methods have also been recommended, such as a game-based model (Atal *et al.*, 2016), fuzzy logic model (Ma *et al.*, 2020), qualitative criteria (Jafarzadeh *et al.*, 2018), and group decision-making (Archer and Ghasemzadeh, 1999)(Ghasemzadeh and Archer, 2000).

The selected projects are continuously monitored (Bunch, 2003) for developing time-bound reports (Management, 2011) that can be used for project evaluation so that needed managerial interactions can be provided as fast as possible (Archer and Ghasemzadeh, 1999).

2.1.3. Qualitative and Quantitative Approaches

This section classifies the prioritization techniques into two approaches: qualitative and quantitative (Dutra *et al.*, 2014; Brook and Pagnanelli, 2014; Thakurta, 2013). Qualitative approaches are based on observation and interviews, while quantitative methods require extensive past data for analysis. The qualitative and quantitative approaches can be further classified in sub-classifications that can be seen in

2.2. Surveyed Project Prioritization Approaches

Project prioritization and project selection are the essential steps before project execution and control. In this research, top project management journals have been selected, and many relevant papers published from 2008 to 2021 have been found. The advanced search method and Web of Science analytics are used to count journal papers for the selected keywords.

2.2.1. Qualitative Approaches

The qualitative approaches are classified into five types: ethnography approaches, phenomenological approaches, grounded theory, case studies, and narrative approaches. According to the Web of Science advance search feature, it has been estimated that 37 papers have been published in the project prioritization domain from 2008 to 2021.

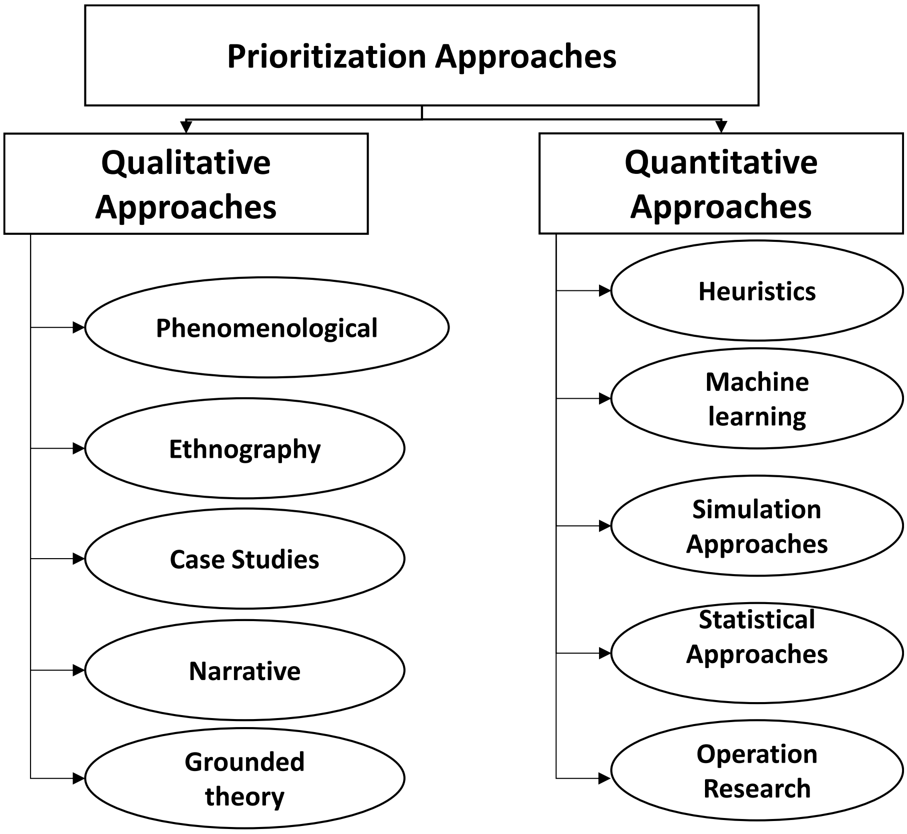

Figure 2.3 Classification of Project Prioritization Techniques.

Ethnography Approaches

These qualitative approaches provide insight into project culture and its impact on the stakeholders on social norms (Hanington and Martin, 2012). The behavior variability of stockholders changes the project prioritization and project selection. Therefore, organizational behavior in project management is an essential element that may affect project prioritization decisions. The ethnography approaches address stakeholders (mainly decision-makers) and project data issues. Seboni and Tutesigensi (2015) addressed a conceptual ethnography model for the project manager allocation to different projects based on various factors such as project workload, competency, availability, decision making, and project location. Vignehsa (2015) presented a hypothetical case of an ethnographical model for project data collection, reporting style, and problematizing confessional tales. They provided an ethnographical qualitative model for project evaluation and prioritization.

Project prioritization or project selection has been adopted for diverse approaches in the literature. Vignehsa (2015) addressed an elicitation in requirement engineering (RE) for software engineering projects. They adopted the ethnography methodology to identify the factors contributing to RE techniques selection. In Project Management, Packendorff (2014) focused on the ethnography case for project leadership in dealing with multiple projects based on past project activities, events, positions, and areas of responsibility. The selection of projects has been well addressed using ethnographical approaches, but still, the corporate level needs to be focused on (Watson, 2011; Kunda, 2009). These approaches focus more on the project manager’s behavior and competency and stockholders involved in projects.

Phenomenological Approaches

The empirical relationship describes project prioritization based on the principle theories that assume that the relationship between project criteria extends past the measured values. Most phenomenological approaches are based on the experienced decision-makers who rank projects. Lundy and Morin (2013) developed a phenomenological model to assess the leadership resistance to project nature change over time. They presented a Canadian Public Service case study by considering leadership style, training, and acceptance of the change. On the other hand, Millhollan (2015) conducted phenomenological research to identify the project manager efficiency determined by the IT leaders and project management professionals (PMP) for multi-projects.

The influence of interpersonal diversity, uncertain project tasks, organizational diversity, and behavior must be direct factors for project prioritization (Huo *et al.*, 2016).

Therefore, the manager's decision-making process could be interpreted differently by stakeholders. Bredillet (2010) analyzed the manager's decision-making practices for the project prioritization by identifying four factors: supplementing, substituting, interpreting, and reframing available evidence. Therefore, Phenomenological approaches are applicable while developing an empirical relationship among various factors affecting the project prioritization.

Grounded Theory

Grounded theory is a systematic method for developing theory or rules defining project prioritization through regular gathering and data analysis (Glaser *et al.*, 2013). This theory has been adopted in multiple disciplines. In IT project selection, (van Rensburg and Pretorius, 2014) proposed a new theory with exploratory research to assess the impact of volatility and resilience response for IT project selection. Daneva *et al.* (2013) addressed the large-scale outsourced system projects for the IT industry. They focused on the underlying requirements, business value, software organization, vendor's domain knowledge, and agile organization. In construction projects, Cardenas *et al.* (2017) proposed a theoretical model for predicting and diagnosing capabilities in projects in the construction domain. However, each project's nature requires different theories and approaches for project prioritization, which might not apply to multi-sector projects. Therefore, the ground theories are valid before imitating a project for a domain, scope, identification of the project.

Case Studies

Several case studies are discussed in the literature. For example, Tavana (2013) presented a case study of NASA to assess and select high technology projects, while (Jayant *et al.*, 2014) presented a case study of mobile phone industry selection. In healthcare, (Ortíz *et al.*, 2015) provided a case study of the healthcare industry at the organizational level using an analytical network process for project selection. Different methods are being used in various application areas.

Hsu *et al.* (2015) focused on project selection and their evaluation in audit selection for the Minnesota Department of Revenue (DOR). They considered the organizational costs, such as personnel expenditure, standardization cost.

Knowledge gained by case studies could directly imply managerial and project management aspects (Trigueros, 2008). Lappe and Spang (2014) provided a case study for developing an empirical relationship between project management and its associated costs. Murdiyarso *et al.* (2008) narrated a case study of district-scale project prioritization to identify the population density between lower and upper limits and the risk of incidences from a social-economic perspective.

Table 2.5 shows the literature of case studies based on historical events in project management; therefore, the lesson learned from the case studies can be used for project prioritization, especially finance and social aspects.

Table 2.5 Case studies for project prioritizations.

Factors	Industry/Case Study	Author
Strategic-agile implementation Agile implementation impact Organizational roles Project initiation Agile project organizations	Information Technology, Software engineering	(Hobbs and Petit, 2017)
Megaproject stockholder values Value opportunities Benefits	Construction, Astonia Bridge in the United States	(Eskerod and Ang, 2017)
Size of project Size of subsidiary firms Project duration A leverage ratio of firms	Generic, Supplier Selection	(Deng *et al.*, 2014)
Project demand Finance distribution of authority	IT, Partner Selection	(Roumboutsos and Anagnostopoulos, 2008)
Economic Vitality Safety and security Environment Energy Efficient system management	Transportation, Vermont Agency of Transportation, USA	(Novak *et al.*, 2015)
Quality program Project characteristics Organizational structure	Market, project-based organization, located in an emerging market	(Kwak *et al.*, 2015)
Time Quality Scope Quality Safety Satisfaction	Construction, Project management	(Almahmoud *et al.*, 2012)
Economic Social	Transportation, urban prosperity	(Jones *et al.*, 2015)

Factors	Industry/Case Study	Author
Environmental Incremental innovation Platforms Breakthrough	Oil and Gas, Partner selection	(Garcez *et al.*, 2014)
Gap value Degree of completion Level of political ambition Political priority	Military, Portuguese Navy	(Simplício *et al.*, 2017)

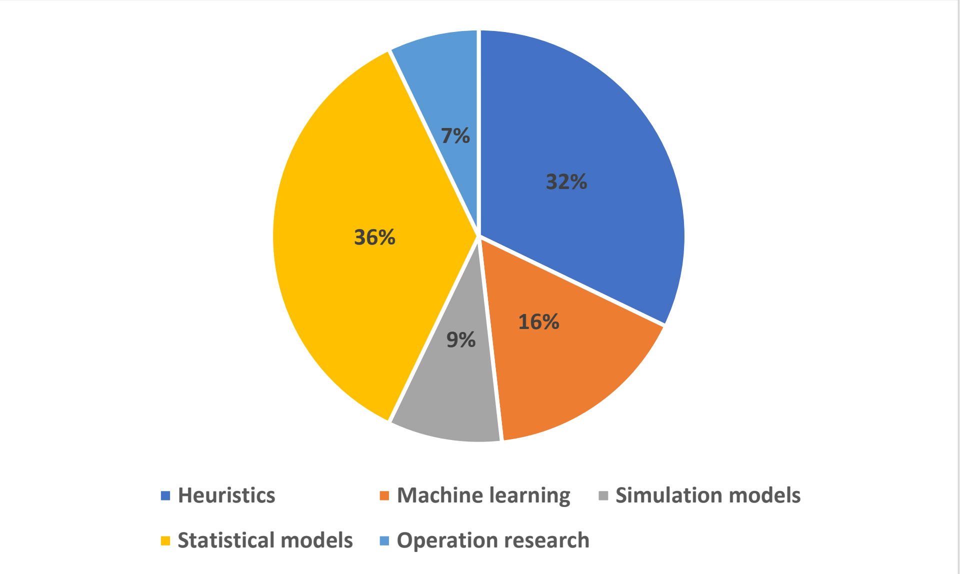

Figure 2.4 Review of qualitative models in project prioritization in the last ten years

Narrative Approaches

Narrative approaches are concerned with finding the facts and laws from the expert's experience (Andrews *et al.*, 2013). However, in selection and project prioritization literature, narrative approaches are scarce. Direct studies of project selection or prioritization have not been well focused because these approaches do not have any strong justification and truth for future projects. Marshall and Bresnen (2013) presented a narrative model with an example of the Thames Tunnel projects in 1843 and executed the projects with alternatives such as technical-rational, practice, a network of people, things, ideas, politics, and society. Goh and Ubeynarayana (2017) evaluated the accidents with narrative approaches and classified construction projects' accidents. Similarly, Leong and Tan (2013) reported the narrative interviews of project managers for the preferences for adopting information systems for managing the projects.

While the literature on project prioritization using narrative approaches is rare, inter-project process prioritization has been addressed. The narrative approaches have more significance than other approaches because of their legal perspective. Strategic projects have variable rules and regulations that affect project prioritization and management. Therefore, consideration of narrative aspects in project prioritization results in project stability.

Limitations of Qualitative Approaches

Qualitative approaches are conceptual approaches based on qualitative data collection methods such as interviews, focus groups, brainstorming, and Delphi methods.

Figure 2.3 shows the percentage of several papers published in the last ten years in all categories of qualitative approaches incorporating project selection or project prioritization. The researcher noted that the case studies are addressed adequately compared to the grounded theories. The high percentage of case studies is related to the massive number of projects executed worldwide. Also, case studies are based on actual data, so the number of publications is very high compared to the other qualitative methods. While the qualitative approaches are built on past data, experiences of experts, feedback, and respondents' interviews, they have certain limitations outlined below.

Qualitative methods do not consider future uncertainty based on experience or data (Ellison, 1998) and are deemed time-consuming (Berkowitz, 2013). That means that the qualitative project prioritization techniques used in past scenarios might not be applicable in upcoming future projects. Furthermore, since the collected data might be inaccurate -because of human ignorance and negligence or when sample size and classes are abundant (Higginbottom, 2004), setting the hypothesis or rules from data analysis is not the right approach (Braun *et al.*, 2017). Moreover, qualitative research produces contextual sensitivities (Kitzinger, 1995), which implies the inapplicability of the project selection methods in a similar situation.

2.2.2. Quantitative Approaches

The quantitative approaches refer to the analysis in business, economic, production, services, or projects with the assistance of mathematics, statistics, and simulations

(Dutra *et al.*, 2014). In quantitative approaches, the set of input variables (criteria) is used to achieve the set of responses or objectives (i.e., prioritization).

Statistical Approaches

The statistical techniques involve analyzing processes with statistical methods such as probabilities, statistical theorem, and statistical inferences. Aguacil *et al.* (2017) provided a statistical tool for project renewals and prioritization from lower strategic levels (building scale) to the national level. Their mechanism adopted helps develop the business plan with economic, energy, emissions, and profit factors. Statistical approaches range from approaches that target financial criteria to multicriteria. Economic approaches harvest a set of criteria for project selection based on project value. Dutra *et al.* (2014) presented an economic-probabilistic model for project selection and prioritization. Rezvani *et al.* (2015) focused on the safety project identification and their prioritization for the North Carolina Department of transportation with probabilistic cost-benefit analysis. Tang *et al.* (2017) explained an integrated network for the project section to view the budget and capacity of projects. Materia *et al.* (2015) analyzed the agriculture research project selection by the Emilia Romagna regional government in Italy. They considered the experience of proposal evaluators.

However, other approaches employ various criteria for project selection, such as the work of Pujadas *et al.* (2017), who developed a multi-criteria mechanism for prioritization index for heterogeneous urban investments and addressed the economic, environmental, and social factors. Also, Jeng and Huang (2015) presented a decision model of project selection and evaluation at the early initiation phase of the project with a multi-criteria statistical model.

Statistical approaches depend on statistical analysis approaches such as ANOVA, regression, or hypothesis testing and could be applied in projects at the managerial level (corporate) or strategic projects (organization to country level). For example, Hadjinicolaou and Dumrak (2017) addressed the corporate-level project prioritization and alignments for strategic and organizational risk decision-making. On the other hand, Park *et al.* (2015) examined the preferences of the national institute of Health (NIH) for project selection under the guidelines of the American recovery and reinvestment act

(ARRA). They employed the ANOVA for the derivation of the results of their problem. Table 2.6 shows a sample of the prioritization factors of statistical approaches.

Table 2.6 factors in statistical approaches for project prioritization

Factors	Author
Economic, energy, emission, cost	(Aguacil *et al.*, 2017)
Investment in infrastructure, human resource, suppliers, logistics, marketing, environmental, social, intangible, and extended	(Dutra *et al.*, 2014)
Cost and hazards	(Rezvani *et al.*, 2015)
Investment, financing, environment, service change, surrounding the impact	(Pujadas *et al.*, 2017)
A business strategy, organizational risks, resource utilization	(Hadjinicolaou and Dumrak, 2017)
Project impact, project quality	(Park *et al.*, 2015)
Need, solution, differentiation, benefits	(Jeng and Huang, 2015)
Risk, budget, project efficiency	(Tang *et al.*, 2017)
Scientific knowledge, the experience of the project manager, and gender	(Boehm and Turner, 2005)
Payments, flexibility, economics, project agreement	(Iftekhar and Tisdell, 2014)

Machine Learning Approaches

Machine learning techniques are advanced statistical techniques with computational and iterative procedures. Neural networks, decision trees, Bayesian networks, linear regression, and support vectors are standard machine learning algorithms used in project prioritization. However, machine-learning application in the project management domain has not been well addressed, especially in project prioritization or portfolio management. Since neural networks balance different inputs, they are often used in project selection. Costantino *et al.* (2015b) proposed a generic artificial neural network (ANN) model for project assessment and project selection, which has the flexibility of implementation on various projects type. Bagloee and Asadi (2015) derived a tractable objective function for prioritizing the road extension projects using the neural network model in conjunction with the Genetic algorithm and ant colony algorithm.

The decision tree is an essential application for the selection and prioritization process. Boskovic *et al.* (2015) adopted a decision tree analysis for the Enterprise Resource Planning (ERP) project assessment considering business process engineering, legacy system, system configuration, alignment, and project synergy. The Bayesian network is another valuable tool for project evaluation and selection because of its dependency and conditional probability variables. Sierra *et al.* (2018) evaluated the infrastructure projects for social sustainability using the Bayesian networks and harmony search method. They considered accessibility, health, education, law, traffic, accident rates, employment, and community integration as evaluation criteria. Islam and Nepal (2016) developed a fuzzy-Bayesian model for assessing power plant projects in terms of risk management in light of economics, managing skills of the manager, bank interest, and multiple stockholders.

The complexity of project activities and resources is one of the biggest challenges for project prioritization; however, machine learning approaches attempted to overcome these issues. Xu and Lin (2016) selected the public transit projects using an approach of Principal Component and Dynamic Programming (PCA-DP), considering the level of service, income, cost, and external influence. Chiang and Che (2010) employed the Bayesian belief network and data envelopment analysis and AHP to rank new product development projects with the criterion of manufacturing risk, ability, degree of difficulty, production facility, and complexity of product design.

However, machine-learning approaches depend on correct samples of data to be trained adequately, which might not suit every project sector.

Simulation Approaches

A simulation model is an intangible equivalent model of an entire project prioritization system that provides real-time operating conditions in a computer-programming environment to check the unforeseen future scenarios of project orders. In addition, simulation approaches incorporate district performance indicators such as cost, emission, and benefits factors for project evaluation and selection (Hernández *et al.*, 2017).

Simulation approaches have been primarily used to evaluate manufacturing systems; however, very few simulation studies in project prioritization have been found. Often in the literature, project simulation approaches are combined with machine learning, multi-objective methods, or multicriteria selection methods to classify and evaluate projects. For example, in machine learning, Alfian *et al.* (2014) developed a simulation model and fuzzy classification to assess the performance of service approaches in car-sharing system projects based on profit, utilization ratio, and reservation acceptance ratio. In complex situations where criteria are competing, simulations are combined with multi-objective or multi-criteria methods. For example, in multicriteria systems, Ahn and Choi (2008) presented a simulation-based analytical hierarchal process (AHP) method for ERP system selection for "homes hoping" companies in Korea. Also, Chung and Lee (2009) used a hydrological simulation program and multicriteria techniques for an alternative evaluation index for determining the priorities of a range of water management sustainability projects.

However, simulation approaches in project selection are not well focused because of their stochastic and random nature. Also, simulation approaches require too much time during the model development phase.

Heuristic Approaches

The heuristics are trial and error methods for solving daily problems, usually consisting of steps with a specific procedure. In the modern era, these techniques are widely used in operation management and computer engineering and are widely adopted by decision-makers of megaprojects to solve project problems. Evolutionary algorithms such as genetic algorithms (GA), particle swarm algorithms (PSO), and ant colony algorithms (ACO) are the widely used heuristic for operation and project management (Polat *et al.*, 2015).

Fernandez *et al.*(2013) adopted the non-outranked sorting genetic algorithm (NO-SGA-II) for multi-criteria decision-making for public project portfolio selection based on cost, benefits, and profit factors. Similarly, Yu *et al.* (2012) presented a multi-criteria nonlinear programming-based genetic algorithm for portfolio selection problems that incorporated decision-makers' preferences.

However, the heuristics are population-based and may follow the random search in a feasible solution space; therefore, heuristic methods are often combined with other methods. For example, Krummel *et al.* (2011) proposed selecting the software projects based on a multi-objective heuristic model and adopting a COCOMO II costing algorithm. Similarly, two heuristic approaches were adopted in Gutjahr *et al.* (2010), who used NSGA -II in conjunction with ACO for R&D project selection. However, Khalili-Damghani *et al.* (2014) used the genetic-based machine learning model for sustainable project portfolio selection to consider economic, social, and environmental factors.

Therefore, with multi-objective functions and heuristics, decision-makers bridge project prioritization and project selection to view the factors of rehabilitation, scour needs, seismic retrofit needs, and mobility needs (Johnson, 2008). Moreover, with multi-objective genetic algorithms (MOGA), project dependency could be evaluated based on effect, outcome, technical, and risk interdependency (Bhattacharyya *et al.*, 2011).

Much literature incorporates the heuristic methods for project selection, project prioritization, and project portfolio management. Table 2.7 classifies project prioritization literature based on the heuristic method, the scope of projects, and the factors addressed.

Table 2.7 Summary of heuristic methods adopted for project prioritization or selection

Factors	Heuristic	Author
Construction strategies, operation management	GA	(Polat *et al.*, 2015)
Cost, benefit, and profit		(Fernandez *et al.*, 2013)
Return, risk, and feasibility		(Yu *et al.*, 2012)
Economic, social, and environmental		(Khalili-Damghani, Sadi-Nezhad and Tavana, 2013)
Effect, outcome, technical, and risk interdependency		(Bhattacharyya *et al.*, 2011)
Benefit, cost, risk	PSO	(Rabbani *et al.*, 2010)
Budget, human resources		(Liu *et al.*, 2014)
Risk, cost	NSGA	(Ghorbani and Rabbani, 2009)
Budget, net present value, and cost	Heuristic	(Ghorbani and Rabbani, 2009)
Cost, benefit, Expansion, and growth	Real option analysis	(Angelou and Economides, 2008)
Project return, project time, profit, and resources	Implicit enumeration algorithm	(Chen and Askin, 2009)

Operation Research Approaches

The operation research approaches (also called optimization methods) consist of analytical methods to solve real-life problems systematically. The optimization problems are classified into two types depending on the function and degree:

linear/nonlinear approaches and multi-criteria decision approaches. The project selection, portfolio management, and project prioritization that adopts operation research approaches are well addressed in the literature.

Linear/Non-Linear Programming Approaches

The linear programming approaches use linear functions to solve real-life problems subjected to obstacles, constraints, and bounds. In addition, the linear approaches employ various objectives such as cost, time, and quality for project prioritization. Linear approaches are used in many areas such as new product screening in product-based project management organizations (Wang and Chin, 2008), network selection for IT projects (Pirmez *et al.*, 2010), transportation project selection (Sefair *et al.*, 2017), and for R& D projects based on profit and risk (Fang *et al.*, 2008; Schaeffer and Cruz-Reyes, 2016).

However, linear programming approaches for project selection or prioritization are binary; therefore, the integer binary linear programming approaches are employed for project selection. The binary linear programming model has been used in many areas; it has been used for resource selection in construction projects (Liu and Wang, 2007) and software project selection to view the objectives of profit and efforts (Zaraket *et al.*, 2014).

Non-linear programming approaches use the non-linear function for problem-solving. Tari and Hashemi (2016) used a nonlinear mathematical programming model for transportation project selection at the country level for cost minimization.

Multi-Criteria Decision-Making Approaches

Multi-criteria decision-making (MCDM) helps make decisions based on multiple criteria. In MCDM approaches, various alternatives are evaluated based on multiple factors. The most common methods used in MCDM are goal programming, analytical hierarchal process (AHP), analytical network process (ANP), data envelopment analysis (DEA), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), The elimination and choice translating reality (ELECTRE) and the preference ranking organization for enrichment evaluation (PROMETHEE).

Goal Programming

Goal programming is a particular case of linear programming in which multiple objectives are optimized simultaneously, given the objective preferences and weights. The goal programming approaches have been used for project prioritization. For example, with goal programming, conflicting factors such as occupational safety, process safety, environmental and operational indicators were used to assess chemical industries' efficiency and sustainability (Barbosa and Gomes, 2015). Also, the goal programming was adopted for six sigma project selection based on business, technological, and financial criteria (Saghaei and Didehkhani, 2011). Other examples for the use of goal programming are urban road selection and construction projects (Dehnavi *et al.*, 2013), defense projects' weapon selection (Lee *et al.*, 2010), and end-of-life computers selection (Ravi *et al.*, 2008). Authors have also used fuzzy goal programming models for portfolio selection for the maximum profit, rate of return, and minimum unused resources (Khalili-Damghani, Sadi-Nezhad, Lotfi, *et al.*, 2013; Daim *et al.*, 2010).

Analytical Hierarchal Process

The analytical hierarchal process (AHP) is a systematic process of deciding based on multi-criteria and multi-objective, which is considered the most straightforward method for analyzing complex decision-making problems. The AHP has been employed for project selection, prioritization, and portfolio management problems. Kundu *et al.* (2017) used AHP for land use prediction and sub-water heads prioritization for environmental stability, while (da Silva Neves and Camanho (2015) prioritize IT projects using AHP in oil and gas companies by considering the factors of innovation, growth productivity, and continuity. The AHP could be integrated with other methods such as TOPSIS; Taylan *et al.* (2014b) studied construction projects and their associated risk, project time, cost, quality, safety, and environmental stability construction project selection at King Abdul-Aziz University. Table 2.8 shows a sample of the relevant literature of AHP.

Table 2.8 Project prioritization literature with the use of AHP

Factors	Author
Environmental safety	(Kundu *et al.*, 2017)
Innovation, Growth productivity, and Continuity	(da Silva Neves and Camanho, 2015)

Project complexity, cost, project scope, duration, technology, and project location	(Amiri, 2010)
Project time, cost, quality, safety, and environmental stability	(Taylan *et al.*, 2014b)
Risk, cost, and opportunity	(Aragonés-Beltrán *et al.*, 2014)
Project size, variety, interdependence, elements of context,	(Vidal *et al.*, 2011)
Financial, risk, urgency, stockholder commitment, and technical knowledge	(Vargas, 2010)
Capacity, system and connection, equipment, staff, and time	(Shaygan and Testik, 2019)
Project risk, project execution, project benefits, and technology	(Huang *et al.*, 2008)
Benefit, process capability, customer satisfaction, cost, time, and risk	(Kahraman and Büyüközkan, 2008)

Similar to AHP, which is also used for criteria weighting, the CRiteria Importance Through Intercriteria Correlation (CRITIC) method (Diakoulaki *et al.*, 1995). The CRITIC method is used for determining the criteria' objective weights in the multiple-criteria decision-making (MCDM) problems by incorporating both contrast intensity of each criterion and contradictory conflict between criteria. The contrast between criteria is determined by correlation analysis, while the criteria conflict is determined by summing up the noncorrelation between a normalized criterion and all others.

Analytical Network Process

Analytical network process (ANP) is a decision-making process based on multi-criteria with dependency and feedback in processes. The goal is divided into the criteria in this process, and the sub-criteria is further subdivided into different alternatives for evaluations. This approach is a helpful tool for project prioritization that has strong interdependencies. Often the ANP is applied in construction and manufacturing. Vinodh and Swarnakar (2015) proposed a hybrid Fuzzy ANP method for lean six sigma projects based on manufacturing lead time, cost, effectiveness, changeover, cycle time, and per day production. Similarly, Ebrahimnejad *et al.* (2012) considered the construction projects in an uncertain environment and prioritized them for the best project section keeping in view the operational, financial, legal, managerial, environmental, and technological factors. The case study of undershirt manufacturer selection gets a tremendous benefit, more opportunities, less cost, and less risk (Liang and Li, 2008).

Similar to other approaches, ANP is combined with other methods for better project selection; Cheng *et al.* (2010) used the ANP along with the decision-making trial and evaluation laboratory (DEMATEL) for research and development project selection and prioritized the projects based on the factors of finance, marketing, and manufacturing.

The ANP approaches can tackle subdomains of the problem up to many levels and can be employed from the operational to the project level in the organization or the corporate level. For example, Ivanović *et al.* (2013) adopted the ANP to select transport infrastructure projects and developed a network from activity level to zone level based on travel time, traffic, cost, benefits, and exterior projects. Therefore, with ANP, it is possible to achieve organizational performance benefits in cost, befit, risk, and opportunity (Grady *et al.*, 2015).

Data Envelopment Analysis

Data envelopment analysis (DEA) is a technique based on linear programming used to evaluate organizations or projects' relative performance. DEA's objective is efficiency, which varies from project to project close to each other, and hence projects can be prioritized. The DEA is also a multi-criteria decision-making technique that uses various criteria for the efficient evaluation of each project. Chang and Lee (2012) discussed mechanical project selection using data envelopment analysis (DEA) in a fuzzy environment; they take the input data of the R&D workforce, mechanical design, and electrical design. On the other hand, Karasakal and Aker (Karasakal and Aker, 2017) employed DEA to analyze R&D projects based on technology, project output, project approach, project resources, finance, and benefits. Table 2.9 summarizes the DEA for project prioritization.

Table 2.9 Data envelopment Analysis (DEA) for project prioritization

Factors	Author
Workforce, design	(Chang and Lee, 2012)
Resource, Finance, Benefits	(Karasakal and Aker, 2017)
Finance, learning growth	(Eilat *et al.*, 2008)
Operations, inventory management, production system	(Yousefi *et al.*, 2018)
Cost, benefit, and safety	(Sadeghi and Moghaddam, 2016)
Opportunity, risks, technology, Finance, and employment	(Tavana *et al.*, 2015)
Human resource, Budget, facilities	(Jahantighi, 2015)
Cost, risk, time, accuracy, and capability	(Mahmudi *et al.*, 2009)
Quality, culture, IT, sustainability, cost,	(Yin *et al.*, 2009)
Technology, time, cost, satisfaction, flexibility, service, and maintenance	(Sheikhrabori *et al.*, 2012)

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is more practical with many alternatives and few attributes, which is the case in this study. Moreover, TOPSIS is widely acceptable in many project prioritization applications. In TOPSIS, each project is evaluated based on a set of clusters for each industry. Finding the worst and best projects is associated with the criteria having a positive and negative impact. It is assumed that the existence of valid weights for each factor is used from the previous step.

TOPSIS and Simple Additive Weighting (SAW) were employed to examine watershed morphological characteristics to identify critical watersheds, thereby achieving successful watershed zone management strategies (Meshram *et al.*, 2020). Moreover, the fuzzy TOPSIS technique was used to evaluate and rank an organization's maturity based on a set of knowledge management (Peyman *et al.*, 2019). TOPSIS was integrated with ANP to prioritize materials based on its activity criticality, where ANP was used for weighting, and TOPSIS was used to calculate materials' criticality (Kar and Jha, 2020). Fuzzy TOPSIS was employed to identify the critical success factors responsible for implementing Six-Sigma to tank Indian Manufacturing (Narwal and Sonipat, 2019). TOPSIS was also used to prioritize transportation projects using economic, social, transportation, and environmental criteria (Hamurcu and Eren, 2020).

2.2.3. Selection of an Effective Prioritization Model

Projects are designed to achieve the strategic vision, including service and profitability (Roberts, 2003). Regardless of the objective, there must be practical methods that suit the nature of the projects and be general so that the concerned parties do not waste time seeking proper techniques (Redick *et al.*, 2014). Consequently, there must be a unified model or one-box solution that allows customization of the criteria flexibly (Sokmen, 2014). Based on these differences, the selection process and priorities will differ depending on the scope and outcome (Novak *et al.*, 2015).

By reviewing the literature on approaches for prioritizing projects within a single portfolio, it can be concluded that they lack the extent to which they suit different industries and intended outcomes. However, this task has been left to the project manager to determine the appropriate model for the prioritization process (Patanakul, 2015). Therefore, a research gap can be addressed as the literature lacks a precise mechanism to indicate a particular model's effectiveness in the scope or intended outcome. Thus, the objective is to identify the approaches of prioritization that are more appropriate for different projects of different sizes and purposes. A possible solution is to integrate approaches, considering their complexity and ability to be managed through a computer application and addressing all qualitative and quantitative aspects of projects (Brook and Pagnanelli, 2014). Therefore, this research provides a holistic view of quantitative and qualitative approaches regarding their advantages and disadvantages.

The qualitative approach depends on experience in the project selection process and priority settings. While a qualitative approach can be positive by discovering new criteria through their experiences, it suffers from many challenges. First, qualitative approaches cannot be generalized as they assume expert data contextualized understanding of project prioritization (Polit and Beck, 2010). Second, qualitative approaches suffer from finding the correct way to apply statistical methods as they are influenced by specific organizational cultures and managerial skills (Thamhain, 2014). Moreover, assessing relations between criteria (Pujadas *et al.*, 2017) is not trivial.

In project prioritization, the quantitative approach aims at numerically mapping information focused on describing a project across many projects, thereby providing the possibility of summarizing criteria across portfolios or relationships (Purnus and Bodea, 2014). However, the approach requires the following limitations. First, solid mathematical and statistical knowledge may not be available to prioritize potential projects(Senn, 1996; Naderi, 2013). Second, caution in interpretation without an expert group (Tavana *et al.*, 2013). Therefore, they often require experts to determine the criteria' weights, which may cause inaccuracy and unreliability (Porras-Alvarado *et al.*, 2017).

As a result, those involved in project selection and prioritization resort to mixing qualitative and quantitative methods. Consequently, the need to rely on experts in these processes remains high (Asosheh *et al.*, 2010). Given the determinants of both quantitative and qualitative methods, two fundamental problems must be attempted in selecting and prioritizing projects. First, the projects should be classified in such a way as to facilitate the selection of the appropriate criteria for each project. Second, it is vital to use general approaches to rely on experts’ opinions as low as possible.

The selection of a helpful prioritization model relies on both methods applied through machine learning approaches. Machine learning allows training and testing datasets to make decisions based on rules with an acceptable accuracy level. In selecting and prioritizing projects, these datasets can be built through case studies or expert opinions for the first time only and then used to classify projects and prioritize them through classification algorithms such as decision trees or genetic algorithms. It is necessary to point out that integrating a qualitative approach through machine learning with a quantitative method through learning algorithms allows the implementation of this model as a computer application that can be fed with new information as needed.

2.3. Managerial Capabilities and Organizational Linkages in Project Selection

The importance of organizational capabilities has two main aspects. First, the selection process would be limited to an organization's project management capability, thereby reducing the chances of projects failure. Second, it provides a direction that if the current set of capabilities is not enough and if the organization aims to venture on new types and scale of strategic projects, the organization should invest in developing such capabilities. Therefore, the inventory of managerial capabilities and their relation with the selection steps becomes essential. The six managerial aspects of organizational capability are discussed below.

2.3.1 Risk Management

Risk is involved primarily in the identification and evaluation stage of project selection. Projects should consider risk factors such as environmental, human, legislation, and compliance. Risk management involves multiple stakeholders (Forcael *et al.*, 2018) and refers to project complexities and uncertainties (Padalkar and Gopinath, 2016). Risk also cuts across the organization's value, and therefore, an organization's intent and capability for risk management becomes vital in the project's selection process(Meulbroek, 2002). The project should be assessed in terms of risk profile (Saili and Balimu, 2018). It is also found that good risk management positively influences project performance (Demirkesen and Ozorhon, 2017).

Integrated risk management (IRM) is recommended for considering the potential risk and uncertainties influencing business performance (Miller and Waller, 2003). A good IRM can support the project's value generation in both short and long terms (D'arcy and Brogan, 2001). A good understanding of risk management, risk ownership, champions, risk register, and risk management plan is essential for project success (Cooke-Davies, 2002). However, the relationship between risk management and resulting project performance is difficult to quantify (Sirisomboonsuk *et al.*, 2018). Furthermore, project risks vary from one industry to another, and therefore, project complexity may negatively impact project success (Kossova and Sheluntcova, 2016). The introduction of project risk assessment and risk management capability can better analyze the projects' acceptability and success (Pramanik *et al.*, 2020). Therefore, detailed risk analysis must be conducted during the project evaluation.

2.3.2 Strategy Management

The importance of managing strategy on projects is highlighted (Musawir *et al.*, 2017). Proper strategic planning and management can yield better project delivery and support improvements in the organizational processes (Koh and Crawford, 2012) and provide an opportunity to assess lifecycle issues and detailed requirement analysis (Dahmas *et al.*, 2019). Strategy management balances constraints posed by resource allocations (Jiang *et al.*, 2011). Therefore, the organization should assess its strategies for different business environment scenarios (Killen *et al.*, 2012). Strategy management requires decision-makers to use organizational learning techniques, adaptability, and employee development to drive project success (Asrilhant *et al.*, 2006). Strategy management can also help strategize resource allocations when there are changes in the economic, social, political, or environmental situation (Zwikael and Smyrk, 2019a). Specifically, strategic project selection is highly correlated with senior management and stakeholders' expectations (Elonen and Artto, 2003). For private organizations, strategic management could also mean the assessment and utilization of internal project management processes or external factors such as business competition. Therefore, the analysis of an organization's strategic posture to initiate the selection process and to finally choosing projects becomes important.

2.3.3 Governance Management

The organization of the project, implementation of the policies, the framework for engagement and facilitation are covered in governance management. Such a holistic oversight can support the continuation of the project (Pinto, 2014) and organizational accountability on the projects (Crawford and Helm, 2009). Therefore, the organizational governance capability is not only about selecting a project that can be taken up based on resource capability (which is considered as project governance, but it is also the ability to select those projects that create a long term value to the stakeholders (Müller *et al.*, 2014). Therefore, governance management should also focus on investment optimization in projects (Bekker and Styen, 2007).

Governance management is critical in decision-making, financial mechanism benefits management, and transparency (Kossova and Sheluntcova, 2016; Lehtinen and Aaltonen, 2020; Sirisomboonsuk *et al.*, 2018; Bekker and Styen, 2007; Zwikael and Smyrk, 2012; Samset and Volden, 2016). Good governance leads the stakeholders to identify the common interests among fundamental challenges and opportunities leading to selecting and implementing the projects (Liu *et al.*, 2004). Moreover, efficient project governance can lead the stakeholders to identify the common interests among primary challenges and opportunities (Bahariah *et al.*, 2012), leading to selection and implementation.

Governance management practice guides the projects' management activities and provides a strong relationship between good project governance and project success (Sirisomboonsuk *et al.*, 2018). Four key governance factors enhance projects' performance and create organizational value (Too and Weaver, 2014). The factors are i) selecting suitable projects, ii) maintaining a direct relationship between the stakeholders and the project manager, iii) monitoring and strategic reporting of projects, and iv) an effective governance system. Efficient project governance positively impacts project management success (Zwikael and Smyrk, 2012) and reasonable risk and quality management (Haq *et al.*, 2018). However, governance may suffer from common deficiencies in large public projects, lack of opportunities for improvements, and rational information (Sirisomboonsuk *et al.*, 2018). These deficiencies can result in the selection of misaligned projects and the cost and time overrun.

In the proposed content analysis framework, governance management is emphasized in the first two strategic project steps. The selection should consider the crucial aspects such as the potential for project success, project payback, project stakeholder relationship, project sponsorship, the resources and investment availability, and transparent monitoring and project execution project. In the public sector projects, specifically, governance would relate to cost-effectiveness in order prioritize and reduce government funding, supporting public expectations on service to be provided by the project, resilience in terms of organizational take-up of the project, capability to involve multiple stakeholders, ability to understand the change and to adapt to the change becomes important (Crawford and Helm, 2009). Therefore, project identification and evaluation should also be considered regarding organizational capability in governance management (Hummel *et al.*, 2017).

2.3.4 Resources Capability Management

The projects should have adequate resources, and the provision of such adequacy and ability to balance the needs versus supply is the basic part of the organization's capability (Nanthagopan *et al.*, 2016; Schiffels *et al.*, 2018; Martens and Carvalho, 2016; Wang *et al.*, 2016). A productive capacity and capability management also help balance organizational potential to achieve organizational goals (Wang *et al.*, 2016). Resource management needs a proper supporting structure (Belassi *et al.*, 2007) through proper governance management.

The resource capability is shown to directly influence project evaluation, prioritization, and the final decision-making step in the proposed framework. In addition, the ability to respond to project changes (Heckmann *et al.*, 2016) and reorganize resources to obtain project goals through the holistic approach (Ketkar and Workiewicz, 2017) is a critical organizational capability.

Resource allocations have also been studied through large-scale software scheduling (Shen *et al.*, 2020), empirical modeling (Dellestrand and Kappen, 2011); multi-attribute decision making (Markou *et al.*, 2017); and two-criteria modeling (Naldi *et al.*, 2016). These approaches can help assess resource capability scenarios in selecting strategic projects.

2.3.5 Stakeholder Management

The involvement of stakeholders is important to elicit the criteria and strategic vision for different types of projects. Stakeholders are involved in funding, defining broad and detailed requirements, and providing project performance requirements (Toor and Ogunlana, 2010; Sirisomboonsuk *et al.,* 2018; Eskerod and Ang, 2017; Eskerod, Huemann and Savage, 2015). Stakeholders are involved in various phases of the project selection process, and they could be simple as a commitment of the budget to providing inputs in terms of new technology use (Kudratova *et al.*, 2019; Yemini *et al.*, 2018; Cameron *et al.*, 2011). Therefore, a good stakeholder analysis is important for stakeholder management and engagement (Karlsen, 2002; Yalegama *et al.*, 2016; Aladağ. H and Işik, 2020). However, stakeholders can be neutral, sensitive, or influencing types (Worsley, 2017). In complex project situations, the team may need continuous involvement and support from the stakeholders (Turner, 2018; Pilkaitė and Chmieliauskas, 2015; Yalegama *et al.*, 2016; Turner and Lecoeuvre, 2017), specifically those who are sensitive and influencing type. Such involvement will help support projects with concerns about evolving needs and project requirements (Eskerod, Huemann, and Ringhofer, 2015a). As project success is dependent on the stakeholders (Zwikael and Smyrk, 2019b; Zwikael and Meredith, 2019), having a good stakeholder schedule with their degree and impact of influence becomes important (Lehtinen and Aaltonen, 2020).

2.3.6 Value Management

Value in project management focuses on its performance on cost and schedule, project management cost, and completing the project as per its objectives (Ibbs and Reginato, 2002). Value consideration becomes important in project selection (Müller *et al.*, 2008; Shenhar and Dvir, 2007; Dyett, 2011; Kwak *et al.*, 2015; Müller *et al.*, 2017).

An effective project value management ensures planned project return (tangible or intangible). The value analysis of projects should focus on stakeholders’ goals, commercial success, and technological development (Zhai *et al.*, 2009). However, not all projects accrue the same value for different stakeholders. Therefore, stakeholders' involvement can help understand the dynamic nature of value outcomes. Large-scale projects or projects with different lifecycles face changing environments; therefore, project value realization in such projects becomes difficult (Patanakul, 2015). The authors (Zhai *et al.*, 2009) also mention that projects also generate value on project management, such as improving processes, cost savings, and performance improvements. Value management also means developing alternate options, re-arranging project returns with the intended results, and ensuring that the project outputs when required (Sirisomboonsuk *et al.*, 2018).

In the framework used for literature analysis, value management is shown as important in evaluating, prioritizing, and decision making. The involvement of stakeholders also becomes important to interact on the anticipated values; for example, those can be related to economic return, social benefits or environmental benefits, and aesthetical enhancements (Martinsuo, 2020). Stakeholder involvement also provides opportunities to understand the perception of asset returns and project operability (Maniak *et al.*, 2014). Therefore, organizational capability in value management becomes very important, especially in strategic projects.

2.4. Chapter Summary

Strategic projects provide long-term benefits to achieve organizational strategy; therefore, they have to be sustainable, either in their development or operation. Furthermore, strategic public projects are accountable to the public regarding their promises and are linked with long-term plans. Literature analysis in this chapter shows that a holistic framework is important for strategic project selection, and more than one qualitative or quantitative method may have to be used in each step of the project selection framework. Table 2.10 summarizes the discussed literature concerning strategic project selection based on Al-Sobai *et al.*(2020). The table shows that most of the studied articles fall in the project evaluation and prioritization; therefore, this study argues that they are the most dominant strategic project selection phases.

Table 2.10. Literature of strategic project selection (based on Al-Sobai *et al.* (2020))

Project Phase	Author (n=44)
Identification and categorization (n=10)	(Crawford *et al.*, 2004b) (Crawford *et al.*, 2006) (Mahdavi *et al.*, 2021) (Lo *et al.*, 2019) (Nguyen *et al.*, 2019) (Lehtinen and Aaltonen, 2020) (Benaija and Kjiri, 2015) (Overhage and Suico, 2001)

Project Phase	Author (n=44)
Project Evaluation (n=12)	(Eken *et al.*, 2020) (Atal *et al.*, 2016) (Muchová and Petrovič, 2019) (Ligardo-Herrera *et al.*, 2019) (Ishizaka and Siraj, 2018) (Focacci, 2017) (Wu *et al.*, 2019b) (K Khalili-Damghani and Tavana, 2014) (Asrilhant *et al.*, 2006) (Han *et al.*, 2019) (Arlt, 2010) (Crossan and Apaydin, 2010)
Prioritization and Balancing (n=15)	(Ceria *et al.*, 2012) (Hutzschenreuter and Horstkotte, 2013) (Mikkola, 2001) (Järvenpää *et al.*, 2018) (Patanakul, 2015) (Mavrotas *et al.*, 2007) (Meskendahl, 2010) (Ahern and Anandarajah, 2007) (Kovach and Ingle, 2020) (Puthamont and Charoenngam, 2007) (Dadashi and Mirbaha, 2019) (Dong *et al.*, 2019) (Cook and Green, 2000) (Simplício *et al.*, 2017) (Novak *et al.*, 2015)
Decision Options(n=7)	(Jafarzadeh *et al.*, 2015) (Esfahani *et al.*, 2016) (Puthamont and Charoenngam, 2007) (Ma *et al.*, 2020) (Atal *et al.*, 2016) (Jafarzadeh *et al.*, 2018) (Ghasemzadeh and Archer, 2000) (Bunch, 2003) (Management, 2011)

It is clear from the literature analysis that the linkages of organizational capabilities and the selection steps are not a transitive closure but some interrelationship-based digraph. The digraph considers that if a project is important for implementation, the organization's capability is not at par with the project's requirement for implementation and operation. Therefore, it would be necessary to invest in increasing organizational capability. The results of the managerial capabilities are summarized in Table 2.11.

Table 2.11 Literature distribution on managerial capabilities.

Managerial Capability	Author (n=59)*
Generic (n= 14)	(Dyett, 2011)
	(Ibbs and Reginato, 2002)
	(Yalegama *et al.*, 2016)
	(Haq *et al.*, 2018)
	(Koh and Crawford, 2012)
	(Nyborg, 2014)
	(Hutzschenreuter and Horstkotte, 2013)
	(Ceria *et al.*, 2012)
	(Crossan and Apaydin, 2010)
	(Martinsuo and Dietrich, 2002)
	(Caunnhye *et al.*, 2012)
	(Järvenpää *et al.*, 2018)
	(Blichfeldt and Eskerod, 2008)
	(Pokharel and Mutha, 2009)
Stakeholder (n=9)	(Zwikael and Meredith, 2019)
	(Eskerod, Huemann and Ringhofer, 2015b)
	(Turner, 2018)
	(Karlsen, 2002)
	(Belassi *et al.*, 2007)
	(Elonen and Artto, 2003)
	(Read *et al.*, 2017b)
	(Toor and Ogunlana, 2010)
	(Zwikael and Smyrk, 2019a)
Governance (n=10)	(Müller *et al.*, 2017)
	(Sirisomboonsuk *et al.*, 2018)
	(Musawir *et al.*, 2017)
	(Pinto, 2014)
	(Crawford and Helm, 2009)
	(Bekker and Styen, 2007)
	(Too and Weaver, 2014)
	(Liu *et al.*, 2004)
	(Samset and Volden, 2016)
	(Management, 2011)
Resource Capability (n= 5)	(Cook and Green, 2000)
	(Schiffels *et al.*, 2018)
	(Ketkar and Workiewicz, 2017)
	(Markou *et al.*, 2017)
	(Belassi *et al.*, 2007)
Value (n= 9)	(Heckmann *et al.*, 2016)
	(Martens and Carvalho, 2016)
	(Zwikael and Smyrk, 2012)
	(Martinsuo and Killen, 2014)
	(Tranfield *et al.*, 2003)
	(Management, 2011)
	(Zhai *et al.*, 2009)
	(Martinsuo, 2020)
	(Maniak *et al.*, 2014)
Risk (n=6)	(Chemweno *et al.*, 2015)
	(D'arcy and Brogan, 2001)
	(Miller and Waller, 2003)
	(Forcael *et al.*, 2018)

Managerial Capability	Author (n=59)*
Strategic (n=6)	(Nyborg, 2014) (Hall *et al.*, 2015) (Nyborg, 2014) (Maghsoodi *et al.*, 2018) (Meskendahl, 2010) (Naldi *et al.*, 2016) (Bunch, 2003) (Killen *et al.*, 2012)

2.4.1. Literature Review Gaps in Strategic Projects' Selection

The review shows that qualitative and quantitative approaches are used to select the projects. It further indicates a need for a holistic approach for selecting strategic projects in large organizations. The followings are the main gaps identified in this research.

1. The literature emphasizes that the set of factors chosen for each project type varies, which implies that it might be challenging to have separate factors for each project type (e.g., energy, construction). There is hardly any literature identifying dominant selection factors concerning public sector projects.
2. Most of the strategic project selection and decision approaches used in the literature emphasize certain project types and may be suitable for specific project sizes. However, multiple projects are implemented in large organizations like the public sector. In addition, there can be competing strategies, such as sustainability and resource availability, need for services and cost optimization, and social well-being and near-term project outcomes. The review shows no comprehensive model and framework that captures factors related to the public sector and the available inventory of management capability. The review indicates that project selection methods and their associated factors are domain-specific, which keeps the decision-maker looking for a way to harmonize different project types in the project selection process.

CHAPTER 3: RESEARCH DESIGN

In this chapter, the research methodology and proposed project prioritization framework are discussed. This study adopts a multi-phase sequential method approach shown in Figure 1.1. The adopted methodology for data collection and processing is consistent with Gray's empirical research process (Gray, 2014), which recommends a sequence from identifying the data needs to presenting findings. The multiphase approach was used by Chowdhury and Quaddus (2016) to build a quality function deployment (QFD) model for health quality systems. It was also used by Wan *et al.* (2018) for multi-attribute group decision-making fuzzy numbers applied to haze management. Baysal *et al.* (2015) proposed a two-phased methodology for selecting municipal projects based on fuzzy TOPSIS and fuzzy AHP. The research questions are addressed in the proposed methodology (Figure 3.1) as follows:

(1) RQ1: What factors are important for strategic project selection?

- The RQ is addressed by experts' interviews and extracted and analyzed factors from the literature.

(2) RQ2: What methods can be used for the reduction of the factors?

- The RQ is addressed following a grouping technique from machine learning known as text clustering. The experts were employed to verify the outputs and specialize the list of grouped factors for each industry sector under study.

(3) RQ3: What type of generic framework is most suitable for strategic project prioritization?

- The RQ is addressed by developing a framework following the steps of criteria weighting, ranking in individual industries, ranking across industries, and decision-making.

Table 3.1. Summary of the data collection approaches and the description of each approach

Data Collection Technique	Total Participants	RQ	The objective of the Technique	Description	Participant selection strategy	Why it is helpful in this context
Factor Scoring: Initial Structured Interview followed with a questionnaire	12+3 (newly added)	RQ1	Validate output from literature review and discover ways to reduce the number of factors. The interview resulted in the identification of other participants.	Participants were provided with a list of factors collected from the literature. Then, they were interviewed independently and asked to provide how factors can be used in practice. After the interview was completed, they were asked to provide the scores of 118 factors.	Cluster sampling (Latunde, 2017)	The interview output showed that the factors are too much for an expert to use in practice. They also showed that some factors are relative, but it was hard to combine them manually. The output of the scored factors shows how factors are used in practice versus the ideal usage of the factors.
Clusters validation: Unstructured interview (Mixed-Data Collection)	5	RQ2	Validate clustered data output	Five participants were chosen to provide an insight into the naming of the developed machine-learning model. They were also asked to score the separation and cohesion of clusters.	Sampling (private, public, and both)	The interview was qualitative to validate the centroids and quantitative to score separation and cohesion of factors. Furthermore, it ensures that the clustering approach's output is meaningful and user-friendly.

Criteria Specialization: Questionnaire (Quantitative Data)	8	RQ3	Specialize and minimize factors per industry sector.	Experts provide a Likert scale for factors across two industries (transportation and real estate). The objective is to select the factors that are valid for each industry. (Criteria Specialization)	Working on both industries	Experts provide quantitative scores to select which factors apply to which industry.
Framework Application: Case study (Quantitative Data)	Collection: >15, as per the focal point of communication in the government of Qatar Validation: 3 experts	RQ3	Validate model output	With a case study, this research aims to validate the framework's output with real-life scenarios. Experts provided the project ranking (ground truth), which will be used later than the proposed framework.	Those who have access to project data and those who are the most experienced people	With a large number of sectors, a case study is deemed applicable.
Framework Application: SUS Questionnaire (Quantitative Data)	10	RQ3	Validate model usability	SUS measures the usability and the reliability of the developed project prioritization framework	Based on their availability and convenience	In addition to manual project ranking, the provided tool should be easy for experts.

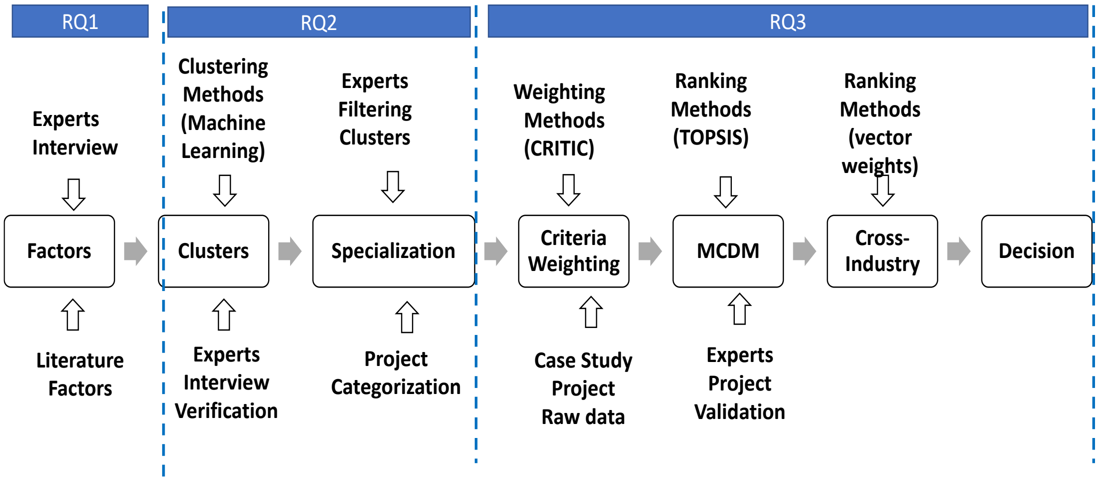

Figure 3.1 Research Methodology

3.1 Proposed Strategic Project Prioritization Framework

This section addresses the research Question RQ3, which is about developing a generic framework. The framework is developed based on the BLOC-ICE systems concept proposed by Pokharel (2022), which requires an understanding and placement of inputs, outputs, constraints, and the processes in a system being examined. In

Figure *3.2*, project prioritization criteria and projects from the baskets of projects are considered the inputs. The framework recognizes three significant constraints to the selection process: environmental constraints, resource constraints, and strategic objectives. The environment constraints may include restrictions to the selection process once the selection is started (Archer and Ghasemzadeh, 1999). The selection process should also consider resource constraints (Costantino *et al.*, 2015b), as resources' availability further limits the prioritization process. Finally, the organizational strategic objectives are often included in the project categorization process (Crawford *et al.*, 2004a). The framework outputs selected projects provided that the selection process gets acceptable projects according to the process along with other needed managerial capabilities as explained in (Al-Sobai *et al.*, 2020). The description of the framework is given in the following sub-sections.

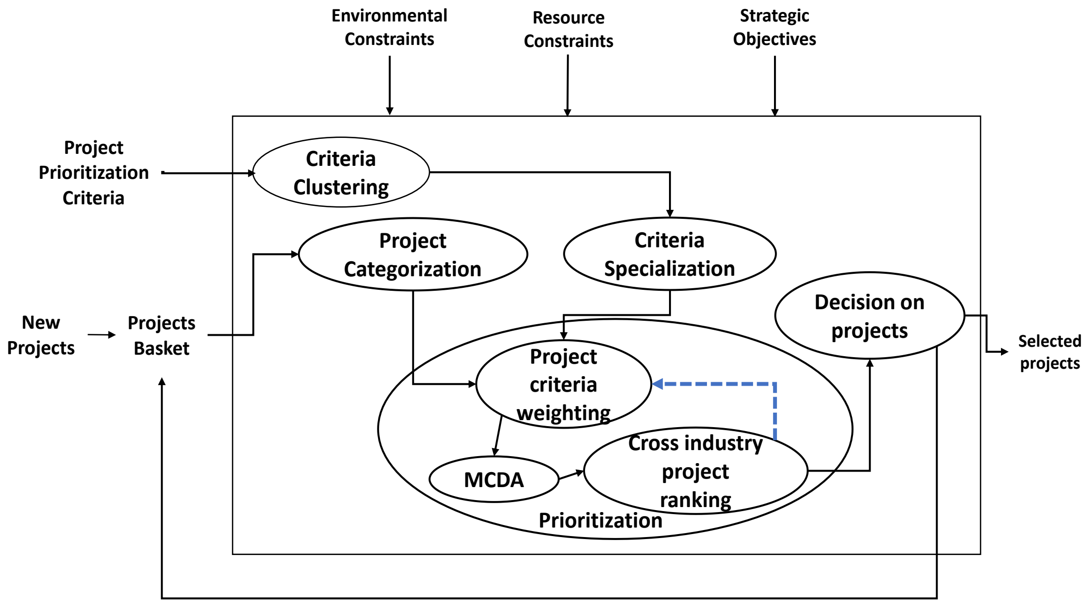

Figure 3.2 : Proposed Framework

Project Prioritization Criteria

Factors that increase project ranking probability are beneficial, such as political acceptance, implementation ability, and productivity. On the contrary, factors that decrease project rank probability are non-beneficial or cost factors, such as investment capital, operating cost, and safety and security. Decision-makers seek to save time and effort to prioritize projects; therefore, reducing the number of criteria used to rank projects under uncertainty and risk conditions. Once the projects are categorized, the next step should be the comparison of factors and reducing them to a smaller number to facilitate decision-making based on Miller (1956).

3.1.1 Project Categorization

It is impractical to test all sectors; therefore, a case study was employed to collect data. Data were collected from strategic project authorities in Qatar as a case study. Considering that projects may have private figures (e.g., costs) that could affect strategic project organization, project names, descriptions, costs, and time was concealed for privacy concerns. A project can be categorized in ownership, application area or product, timing, geography, complexity, contracting, and internal and external stakeholders (Al-Sobai *et al.*, 2020). Other categorization criteria can be competence improvement, increased market share, process improvement, business requirements, capability and controllability, and risk (Elbok and Berrado, 2018; Yang *et al.*, 2017; Jung and Lim, 2007).

3.1.2 Criteria Clustering

To facilitate the decision-making, factors were reduced through clustering:

(1) Miller (1956) mentioned that a human could comprehend only a low number of factors for decision-making at a time. Therefore, clustering was used to group these factors into a set that humans can process efficiently.

(2) As opposed to factor analysis techniques (Rummel, 1988), the clustering considers that the meaning of textual factors could be group-related factors but not share an ordinary meaning. In this study, textual clustering is based on universal sentence encoder semantic space, a vector of 512 entries per word (Cer *et al.*, 2018a); therefore, the issue of small data is not applicable. Moreover, other machine learning methods are not applicable due to the non-availability of training data for projects, and the task was not to detect any project issue but to group textual factors.

(3) The semantic space is a matrix of 512 entries representing the meaning of the factor related to any other word (Cer *et al.*, 2018b). Moreover, factors and descriptions are taken together to provide a better goodness fit of the models. Therefore, the dataset is not considered small.

(4) Clustering is replicable. The clustering techniques are based on state-of-art algorithms, where software codes are available online for the public with rigid libraries such as sci-kit-learn (Pedregosa *et al.*, 2011). The input to these algorithms is just the set of textual entries, and the output will be groups of textual factors.

(5) The other alternative to clustering is the factor analysis family of methods (McDonald, 2014). For example, the principal component factoring is used to extract the maximum possible variance and continues until no meaningful variance is left. The Common factor analysis method reduces variables based on common variance. Factor analysis assumes that variables correlate with any other variable, which is commonly based on linear relationships. However, a linear correlation could not be assured in the given situation as one factor may

be related to a different degree with another one, and such degree of information is expressed in the upcoming framework components (e.g., TOPSIS). Furthermore, for example, the PCA provides several principal components where they could be used to find its correlation with the original set of variables (or factors); however, such correlation is covered in subsequent steps of the proposed framework. Above all, the factor analysis removes the component name, whereas such a common name could be obtained by clustering. Consequently, factor analysis explains correlation in a set of data (simplification and dimensionality reduction), and cluster analysis addresses heterogeneity in each set of data (categorization). Therefore, clustering was chosen.

This section is related to RQ2, which reduces the factors into similar groups. Text clustering applies cluster analysis to text with automatic topic extraction and fast information retrieval or filtering applications. Clustering algorithms can be used for any text regardless of its source. It has been applied to cluster proposals of projects(Ma *et al.*, 2012), process improvement (Khanbabaei *et al.*, 2019), quality models (Sadeghi Moghadam *et al.*, 2021), and categorization of subjects in a questionnaire (Honda *et al.*, 2019; Konok *et al.*, 2019). In the text clustering approach, the text must be converted to a numerical representation of word embeddings, which many machine-learning techniques could accomplish. This research uses The Universal Sentence Encoder (USE by Google). The USE encodes text into high-dimensional vectors used for text classification, semantic similarity, clustering, and other natural language tasks (Cer *et al.*, 2018b). The semantic space is a matrix of 512 entries representing the meaning of the factor related to any other word. Factors, along with descriptions, are taken together to provide a better goodness fit of the models.

Many algorithms can be applied to cluster factors; however, the text must be preprocessed. Accordingly, project factors were converted to semantic space. After analyzing various algorithms, the best-performing clustering algorithms were chosen. Table 3.2 shows a short description of each algorithm.

Table 3.2. Selected Clustering Algorithms

Algorithm	Description	When it is good to be chosen
Agglomerative clustering(Murtagh and Legendre, 2014)	Agglomerative clustering is a hierarchical clustering that merges clusters in a recursive way to minimize a given linkage distance (Euclidian).	Provides better output when results can be grouped hierarchically.
Affinity Propagation(Brusco and Köhn, 2008)	Affinity propagation clustering algorithm based on finding exemplars between data points.	When the number of clusters is unknown.
K-Means (Jain, 2010)	The K-Means algorithm is used in clusters to separae data into n groups of equal variances.	While the algorithm is widely used in many applications, it requires the number of clusters to be specified.

Generating Centroids

A centroid is the cluster's center that could interpret the cluster results (as a cluster does not have a name). The centroid can be seen as a multi-dimensional vector with an almost equal distance to other cluster items. Therefore, cluster centroids could be converted to show the factor that has a relatively similar distance to others. There are two approaches to finding the centroids: the semantic approach embedded in the clustering algorithm and the manual expert judgment approach. The second approach uses the clustering factor with the maximum ideal-factor-weight initially assigned by experts in the previous step, which was chosen to imply high importance as rated by experts.

3.1.3 Criteria Specialization

This section is related to RQ2, which covers how to reduce the factors to satisfy projects from different industries. Experts were chosen to conduct a structured individual interview to facilitate the task of scoring factors for a specific industry (e.g., real estate or transportation sector). Furthermore, it was chosen to ensure interviewees' accountability (Macheridis and Dergård, 2020) and reduce possible social bias, ensuring the same message is delivered clearly to each expert. Since the structured interview involves social interaction, it gathers consistent and comparable results (Bryman, 2016).

The experts could choose between the four options described in Table 3.3. A similar evaluation guideline on the 5-Likert scale was used in Lee *et al.* (2017) to evaluate the automobile industry's R&D project selection. The score descriptions were put in place, and factors that had scores below 50% were excluded from the subsequent steps of project prioritization to make it easier for the experts to evaluate the factors. The 50% ensures no gray area and ensures a valuable factor consistent with the evaluation presented in Lee *et al.* (2017) study.

Table 3.3. The score ranges for factor selection during the interview

Score	Description
0-24%	Negligible effect or not relevant on strategic project selection (must ignore these factors)
25-49%	Low effect on strategic project selection (can ignore these factors)
50-74%	The moderate effect can take into consideration (can consider these factors)
75-100%	The high effect must be taken into consideration (Must consider these factors)

3.1.4 Project Prioritization

The project prioritization process can be divided into three steps: criteria weighting, multi-criteria decision-making, and cross-industry project prioritization.

Criteria Weighting

From the previous step, factors are grouped and reconciled per industry; however, each factor's weighting was based on the Likert style. That means factors do not have relative importance to each other. Therefore, it is critical to get weights of each criterion to know each factor's share to the overall goal of project selection.

Based on experts' feedback and clustering, factors are independent and do not contain extra information. However, the clustered criteria are higher than the AHP method's limits, often used for weighting (Pérez, 1995). Based on the Satty AHP method (Saaty, 2004) and according to Miller's rule, the limits are seven minus plus two according to where a person has a limited capacity of processing information; therefore, AHP and FAHP were not applicable. Investigations on the set of criteria showed that they are highly correlated. For example, Strategic Integration and Develop Long-term business opportunities, Customer point of view of Ease of use, and Operating cost. Therefore, this research adopts the weighting $\boldsymbol{W_c}$ for a cluster, $\boldsymbol{c}$ using the CRiteria Importance Through Intercriteria Correlation (CRITIC) method (Diakoulaki *et al.*, 1995). The CRITIC method is used for determining the criteria' objective weights in the multiple-criteria decision-making (MCDM) problems by incorporating both contrast intensity of each criterion and contradictory conflict between criteria. The contrast between criteria is determined by correlation analysis, while the criteria conflict is determined by summing up the non-correlation between a normalized criterion and all others.

For simplicity, the CRITIC formulas are reported here for a particular industry $\boldsymbol{s} \in \boldsymbol{S}$; however, they could be applied to any industry. To find the weights for each cluster, a decision matrix $\boldsymbol{X_{n \times m}}$ is developed, with $\boldsymbol{m}$ criteria (clusters that belong to industry $\boldsymbol{s}$) and $\boldsymbol{n}$ alternatives (projects in industry $\boldsymbol{s}$) that shows the scores of the criteria against the projects, the normalization of the decision matrix is shown in equation (3.1), where $\boldsymbol{x_{ij}}^*$ is the normalized performance value of the $\boldsymbol{i}^{\text{th}}$ project and $\boldsymbol{j}^{\text{th}}$ criterion, and $\boldsymbol{x_{ij}}$ is the mean criteria score for the project $\boldsymbol{P_i}$ for criteria $\boldsymbol{j}$ as assigned by experts. The CRITIC model divides factors into the beneficial (profit) and non-beneficial (cost) criteria. These criteria types participate positively or negatively in the CRITIC model; beneficial criteria should be maximized while non-beneficial criteria should be minimized. Both criteria types are formulated as $\boldsymbol{x_j}^{\boldsymbol{worst}}$ and $\boldsymbol{x_j}^{\boldsymbol{best}}$ as illustrated in equations (3.2a, 3.2b), which are inputs to equation (3.1). The measure of conflict is shown in equation (3.3a), while the quantity of information is expressed in equation (4.3b), where $\boldsymbol{\sigma_j}$ is the standard deviation of the $\boldsymbol{j}^{\text{th}}$criteria, and $\boldsymbol{r_{jj'}}$ is the correlation between normalized ($\boldsymbol{x_{jj'}}^*$) criteria $\boldsymbol{j}$ and $\boldsymbol{j'}$ criteria as shown in equation (1). A higher quantity of information indicates a higher factor weight. Then the weight for the $\boldsymbol{j}^{\text{th}}$ criteria ($\boldsymbol{W_j}$) is given by equation (3.1), where $\boldsymbol{c_j}$ is determined as in equation (3.3b). The CRITIC equations are shown in Table 3.4.

Table 3.4 CRITIC method equations

Equation	Description	Number
$\boldsymbol{x_{ij}}^* = \frac{x_{ij} - x_j^{worst}}{x_j^{best} - x_j^{worst}}, \boldsymbol{i = 1, 2, .. n, j = 1, 2, .. m;}$	Normalized performance value is a new value that considers	(3.1)

Equation	Description	Number
	the outliers of best and worst scores.	
$x_j^{worst} = \{\max(x_j) \mid x_j \in \text{cost criteria}, \min(x_j) \mid x_j \in \text{profit criteria}\},$ $j = 1, 2, .. m$	The worst value is the maximum cost criteria (non-beneficial) or minimum profit scores. Therefore, higher-cost or lower return projects are not preferable.	(3.2a)
$x_j^{best} = \{\min(x_j) \mid x_j \in \text{cost criteria}, \max(x_j) \mid x_j \in \text{profit criteria}\},$ $j = 1, 2, .. m$	The best value is the minimum cost criteria are the maximum profit criteria. Therefore, lower-cost projects and higher benefit projects are preferable.	(3.2b)
$Conflict_j = \sum_{j'=1}^{m}(1 - r_{jj'}),$ $j = 1, 2, .. m, j' = 1, 2, .. m$	The measure of conflict. As the criteria measure different dimensions of an alternative, the conflict measurement increases, increasing the criteria weight. Note, the correlation is subtracted from the scaler one.	(3.3a)
$C_j = \sigma_j \sum_{j'=1}^{m}(1 - r_{jj'}), j = 1, 2, .. n, j' = 1, 2, .. n$	Quantity of information. Measure how the criteria are weighted when compared across different alternatives.	(3.3b)
$W_j = \frac{C_j}{\sum_{j=1}^{m} C_j}, j = 1, 2, .. m$	Criterion weight, weight between 0-1, represents the final weight for each criterion in the context of other criteria and other alternatives.	(3.4)

Multicriteria Decision Making (MCDM)

There is an extensive list of multi-criteria decisions such as elimination and choice translating reality (ELECTRE), the preference ranking organization for enrichment evaluation (PROMETHEE), analytic hierarchy process (AHP), TOPSIS, and the Simple Multi-Attribute Rating Technique (SMART(Locatelli and Mancini, 2012). According to Roszkowska (2011), selecting a method depends on internal consistency and logical soundness, data transparency, and ease of use. ELECTRE identifies a restricted group of preferable solutions instead of the best one. PROMETHEE uses a higher number of parameters and makes the method more complicated. TOPSIS is more practical with many alternatives and few attributes, which is the case in this study. TOPSIS works for a large number of criteria (clusters) a large number of alternatives (projects) (Guarini *et al.*, 2018). Moreover, TOPSIS is widely acceptable in many project prioritization applications. Therefore, TOPSIS was adopted for project ranking.

In TOPSIS, each project is evaluated based on a set of clusters for each industry (for example, real estate). Finding the worst and best projects is associated with the criteria having a positive and negative impact. The existence of valid weights for each factor (from the previous step-CRITIC) is assumed.

In the TOPSIS method, projects are compared to criteria or factors in a matrix form $\left(\boldsymbol{x_{ij}}\right)_{\boldsymbol{n\times m}}$(Hwang and Yoon, 1981; Yoon, 1987). The equations are formulated for any industry *s*, with different projects ($\boldsymbol{S} = \{\boldsymbol{s_1}, \boldsymbol{s_2}, \dots, \boldsymbol{s_T}\}$). The outputs of individual industry ranks will be merged later in the following subsequent equations. A set of equations are developed, as given in Table 3.5. The value $\boldsymbol{x_{ij}}$ is the mean criteria score for $\boldsymbol{P_i}$ for criteria $\boldsymbol{j}$ as assigned by experts. The normalized matrix ($\boldsymbol{M_{ij}}$) is given in equations (3.5a) and (3.5b), where vector normalization is applied for beneficial and non-beneficial criteria. The weighted normalized values $\boldsymbol{V_{ij}}$ of the matrix is given in equation (3.6), where $\boldsymbol{W_j}$ is obtained from equation (3.4). The project (or solutions) distances to best and worst solutions are shown in equations (3.7a, 3.7b), respectively. Equations (3.8a, 3.8b) are used to calculate the maximum profit criteria and the minimum cost criteria, respectively. The similarity index ($\boldsymbol{R_{is}}$) for a project $\boldsymbol{P_i}$ in industry $\boldsymbol{s}$ is given in equation (3.9), where it could be used to rank projects in any particular industry $\boldsymbol{s} \in \mathbf{S}$. Table 3.5 shows TOPSIS method equations.

Table 3.5. TOPSIS method equations.

Equation	Description	Number
$\boldsymbol{M_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}(x_{ij})^2}}$, $\boldsymbol{i = 1, 2, \ldots n}$, $\boldsymbol{j = 1, 2, .. m}$,	Normalized matrix (Beneficial) uses the principles of matrix eigenvectors weighting projects scores.	(3.5a)
$\boldsymbol{M_{ij}} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}(x_{ij})^2}}$, $\boldsymbol{i = 1, 2, \ldots n}$, $\boldsymbol{j = 1, 2, .. m}$,	Normalize matrix (Non-beneficial) uses the principles of matrix eigenvectors weighting projects scores but considering the non-beneficial aspects of vectors.	(3.5b)
$\boldsymbol{V_{ij} = M_{ij} . W_j, i = 1, 2, \ldots n , j = 1, 2, .. m}$,	Weighted normalized values, multiplies each matrix entry with the factor weight extracted in the previous step.	(3.6)
$\boldsymbol{D_i^+} = \sqrt{\sum_{j=1}^{m}(V_{ij} - V_j^+)^2}$,	Distance to the best solution. The distance of current criteria to the best project.	(3.7a)
$\boldsymbol{D_i^-} = \sqrt{\sum_{j=1}^{m}(V_{ij} - V_j^-)^2}$,	Distance to the worst solution. The distance of current criteria to the worst project.	(3.7b)
$\boldsymbol{V_j^+} = \{\mathbf{max}(V_j) \mid V_j \in \textbf{profit criteria}, \ \mathbf{min}(V_j) \mid V_j \in \textbf{cost criteria}\}$, $\boldsymbol{j = 1, 2, .. m}$	Maximum profit criteria. The criterion maximizes the profit and minimizes the cost.	(3.8a)
$\boldsymbol{V_j^-} = \{\mathbf{min}(V_j) \mid V_j \in \textbf{profit criteria}, \ \mathbf{max}(V_j) \mid V_j \in \textbf{cost criteria}\}$, $\boldsymbol{j = 1, 2, .. m}$	Minimum cost criteria. The criterion maximizes the profit and minimizes the cost.	(3.8b)

$R_{is} = \frac{D_i^-}{D_i^+ + D_i^-}, i = 1,2,\dots n, j = 1,2,..m, s \in S$	Project similarity index for the project P_i in industry s. The values score of a project is based on TOPSIS and CRITIC methods.	(3.9)

Cross-Industry Project Ranking

This step aims to rectify the order of projects across industries in a cross-industry-based project prioritization, where the scores of each project could be compared if they are rescaled. One approach uses vector weights, or linear weights of the new list of projects, as shown in equations (3.10a, 3.10b). These weights showed a minimum error compared to others (Chakraborty and Yeh, 2009). The second approach uses new weight for each industry, as shown in equation (3.10b); however, this approach will require an extra step of an MCDA algorithm to find the new scores assuming projects are pairwise compared. For simplicity, this research adopts the first approach. Finally, the project is re-ranked across industries using the newly generated vector weights, shown in Table 3.6.

Table 3.6. List of cross-industry prioritization equations

Equation	**Description**	**Number**
$Rank_k = \frac{R_{is}}{\sqrt{\sum_k^N R_{ks}^2}}, k = 1,2,..N, N = \sum_s n_i$ where R_{is}, as in equation (9), N is the total number of projects in all industries.	Vector weights based on All projects scores from equation (9)	(3.10a)
$Rank_k = \frac{R_{is}}{\sum_k^N R_{ks}}, i = 1,2,\dots N, N = \sum_s n_i$ where R_{is}, as in equation (9), N is the total number of projects in all industries.	linear weights based on All projects scores from equation (9)	(3.10b)

3.1.5 Decision on Projects

The decision process for project selection is restricted to many managerial capabilities: risk management, strategy management, governance management, resource capabilities management, stakeholder management, and value management (Al-Sobai *et al.*, 2020). Therefore, assuming the inheritance of needed managerial capabilities, a decision-maker should go with the recommended ranks provided by the model. Following the detailed algorithm in Table 3.7, a decision-maker will be given the rank for each project from projects that were part of the decision-making process. Projects ranked on top are amongst the highest priority projects for execution, while projects at the bottom of the list could be executed later.

Table 3.7. Project Prioritization Algorithm.

CRITIC-TOPSIS Cross Industry Project Prioritization

- Define $\boldsymbol{T} = \sum \boldsymbol{S}$ // total number of project sectors, $\boldsymbol{S} = \{\boldsymbol{s_1}, \boldsymbol{s_2}, \dots, \boldsymbol{s_T}\}$,
- Define N= $\sum_{\boldsymbol{s}} \boldsymbol{n_i}$ // total number of strategic projects regardless of their industry
- Define $\boldsymbol{m}$ // number of criteria (factors) in industry $\boldsymbol{s}$
- Define $\boldsymbol{n}$ // number of projects (alternatives) in industry $\boldsymbol{s}$
- Develop the matrix $\boldsymbol{X_{n \times m}}$ from experts' raw data for each industry $\boldsymbol{s}$ of $\boldsymbol{m}$ criteria and $\boldsymbol{n}$ projects

(1) CRITIC Algorithm: Create a Normalized Weighted Matrix for Each Project

- Generate the normalized version of $\boldsymbol{X_{n \times m}}$ using:

For $\boldsymbol{i}$=1,2,…, $\boldsymbol{n}$ do

  For $\boldsymbol{j}$=1,2,…,$\boldsymbol{m}$ do

    If $\boldsymbol{x_j} \in \boldsymbol{beneficial}_{\textbf{criteria}}$ Then

      Let $\boldsymbol{x_j}^{\boldsymbol{worst}} = \mathbf{min}(\boldsymbol{x_j})$

      Let $\boldsymbol{x_j}^{\boldsymbol{best}} = \mathbf{max}(\boldsymbol{x_j})$

    Else

      Let $\boldsymbol{x_j}^{\boldsymbol{worst}} = \mathbf{max}(\boldsymbol{x_j})$

      Let $\boldsymbol{x_j}^{\boldsymbol{best}} = \mathbf{min}(\boldsymbol{x_j})$

    End If

    The normalized performance value, $\boldsymbol{x_{ij}}^*$, is given by equation (1)

$$\boldsymbol{x_{ij}}^* = \frac{x_{ij} - x_j^{worst}}{x_j^{best} - x_j^{worst}},$$

      where $\boldsymbol{x_{ij}}$ is the raw data for $\boldsymbol{i}^{\text{th}}$ project and the $\boldsymbol{j}^{\text{th}}$ criteria

    Compute quantity of information:

$$\boldsymbol{C_j} = \boldsymbol{\sigma_j} \sum_{j'=1}^{m} (\mathbf{1} - \boldsymbol{r_{jj'}})$$, where

      $\boldsymbol{r_{jj'}}$ is the correlation between the $\boldsymbol{j}$ and $\boldsymbol{j'}$ criteria, and $\boldsymbol{\sigma_j}$ is the standard deviation of the **j**th criteria.

    Compute criteria weight $\boldsymbol{W_j} = \frac{C_j}{\sum_{j=1}^{m} C_j}$

  End of the "For" loop

End of the "For" loop

(2) TOPSIS Algorithm: Compute project rank using TOPSIS method:

For $\boldsymbol{i}$=1,2,…, $\boldsymbol{n}$ do

For $\boldsymbol{j}$=1,2,…,$\boldsymbol{m}$ do

If $\boldsymbol{x_j} \in \boldsymbol{beneficial}_{\textbf{criteria}}$ Then

$$\boldsymbol{M_{ij}} = \frac{\boldsymbol{x_{ij}}}{\sqrt{\sum_{i=1}^{n}(\boldsymbol{x_{ij}})^2}}$$

Else

$$\boldsymbol{M_{ij}} = \mathbf{1} - \frac{\boldsymbol{x_{ij}}}{\sqrt{\sum_{i=1}^{n}(\boldsymbol{x_{ij}})^2}}$$

Compute the weighted normalized values:

$\boldsymbol{V_{ij}} = \boldsymbol{M_{ij}} \,.\boldsymbol{W_j}$, where $\boldsymbol{W_j}$ as in equation (4)

Compute the distance to the *best* and *worst* solution (project).

$$\boldsymbol{D_i^+} = \sqrt{\sum_{j=1}^{m}(\boldsymbol{V_{ij}} - \boldsymbol{V_j^+})^2}$$

$$\boldsymbol{D_i^-} = \sqrt{\sum_{j=1}^{m}(\boldsymbol{V_{ij}} - \boldsymbol{V_j^-})^2}$$

If $\boldsymbol{x_j} \in \boldsymbol{beneficial}_{\textbf{criteria}}$ Then

Set maximum cost criteria:

$$\boldsymbol{V_j^+} = \boldsymbol{max}(\boldsymbol{V_{ij}})$$

Else

Set maximum cost criteria:

$$\boldsymbol{V_j^-} = \boldsymbol{min}(\boldsymbol{V_{ij}})$$

End if

Compute the similarity index for each solution (project $\boldsymbol{P_i}$ in industry sector $\boldsymbol{s}$):

$\boldsymbol{R_{is}} = \frac{\boldsymbol{D_i^-}}{\boldsymbol{D_i^+} + \boldsymbol{D_i^-}}$ //project rank

End of the "For" loop

End of the "For" loop

(3) Computing Cross-industry project ranking

For each $\boldsymbol{s} \in \boldsymbol{S}$ do

Compute weights of each criteria $\boldsymbol{j}$ using CRITIC Algorithm // as stated above (1).

Compute $\boldsymbol{R_{is}}$ project $\boldsymbol{P_i}$ rank in the industry using TOPSIS Algorithm // as stated above (2)

End of the "For" loop

For $\boldsymbol{k}$=1,2,…, $\boldsymbol{N}$ do // traverse all projects ranks regardless of their industry

Compute project rank (final rank across industries) :

$\boldsymbol{Rank_k} = \frac{\boldsymbol{R_{ks}}}{\sum_{k}^{N}\boldsymbol{R_k}}$,

where, $\boldsymbol{R_k}$ as in equation (9) for any project $\boldsymbol{P_K}$ in the overall set of projects.

End of the "For" loop

3.2 Chapter Summary

This chapter presents a framework that could be used to prioritize strategic projects across different industries. First, a list of factors collected from the literature is filtered and clustered using a machine learning clustering approach. The project criteria selection is shortened to fewer factors with experts' verification. These factors are then specialized into specific case studies (transportation and real estate in this study). Next, the factors are weighted using the CRITIC method based on two actual project datasets. Then, TOPSIS was used to rank strategic projects per industry. Finally, a new equation was developed to compare and rank projects across industries.

CHAPTER 4: DATA ANALYSIS AND RESULTS

This chapter aims to show the results from the analysis of the proposed research framework. This chapter shows the steps from criteria identification from the literature, clustering, criteria specialization, and project prioritization to a completely validated executable framework.

4.1. Data Collection

This section discusses and analyzes data collection and analyzed by experts.

Criteria Identification

In the first phase, the list of project selection criteria is extracted from the literature, showing more than 527 factors applicable in different industries. Note that some of the factors are repeated due to the terminology used to describe them in various industries. For example, environmental impact (generic factor), air quality factor are combined into one environmental impact. Technology efficiency and technology maturity are combined. Capital cost, construction costs, cost, cost-effectiveness, environmental cost, equipment costs, external costs, fuel costs, implementation cost, improvements in productivity and cost, and others are merged into cost factors. The screening method used a combination of these techniques:

(1) Eliminate duplication.
(2) Find terms that carry similar meaning, such as project cost, capital cost, investment cost
(3) Merge factors with similar abstract meaning such as Political acceptance and government support.
(4) Use excel Functions such as SEARCH and conditional formatting.

After avoiding the duplication, the total number of relevant factors is reduced to 118, as given in Appendix C.

Table 4.1 summarizes the factors and associated subfactors for project selection in all studied qualitative approaches. It is clear from the table that the economic, political, social, and organizational factors are discussed thoroughly, while time and quality factors are limited in the literature.

Table 4.1 Sample of major factors addressed in qualitative project selection methods

Group	Factors
Economics	project location, training, standardization, benefit, project size, leverage ratio firms, financial structure, energy, breakthrough
Politics	resilience, political change, political influence, political risk, political priorities
Organizational	workload, competency, position, resistance to change, diagnostic capabilities, distribution of authority, scope, volatility, agility
Social	behavior, social norms, events, interpersonal diversity, organizational diversity
Time	project estimation completion time
Quality	vender knowledge, safety, project risk

Table 4.2 summarizes the factors used in quantitative approaches for project prioritization. Most of the quantitative approaches are deemed to discuss the organizational factors, followed by the economic factors. This finding is due to the nature of economic and organizational factors that can be quantitatively evaluated. For example, the economic net present value, project capital, resource, risk can be easily quantified. In contrast to qualitative approaches, political factors are loosely addressed due to their nature.

Table 4.2 Sample of major factors addressed in quantitative project prioritization methods

Group	factors
Economics	cost, finance, profit, growth, investment, asset, payments
Politics	opportunity, change, law, legacy, legal
Organizational	risk, technology, resource, safety, design, operation complexity, flexibility, knowledge, marketing, configuration, culture, infrastructure, innovation, outcome, skills, suitability
Social	benefit, employment, social alignment, commitment, culture, health, public, stockholders, suppliers
Time	project time, logistics, urgency
Quality	acceptance, capability, quality risk, service
Environmental	utilization, accidents, accuracy, variety

One primary objective of this study is to identify critical project prioritization factors; therefore, extensive work was carried out to join factors from different sectors. For example, quantitative and qualitative approaches were joined. A sample of those factors is shown in Table 4.3. Note that categories in the table are based on the researcher's experience with more than 15 years in project management, and it does not have any input to the framework. However, it is placed for logical grouping and enhancing readability.

Table 4.3. Sample of factors collected from the literature.

Group	Factor	Description
Capacity	Supplier Capabilities	Performance is defined as a supplier's demonstrated ability to meet a buyer's short-term and long-term requirements regarding cost, quality, service, and other short-term criteria.
Capacity	In-house development	In-house developments allow firms to carry out operations within their premises and use their resources instead of outsourcing.
Economi c impact	Economic Value	The economic value (or maximum payments of goods or services) measures the benefit derived from a good or service to an individual or a company.
Economi c impact	Effect on existing market outlook	The future of market condition or trend could be predicted based upon past performance, prevailing economic factors, consumer demand, and opinion.
Financial impact	Cost-Benefit Analysis	The cost-benefit analysis estimates the value of alternatives used to determine options that achieve benefits and preserve savings
Strategic	Develop Long-term business opportunity	A business opportunity developing or using a new product enables companies to increase their long term investment. Usually, assets are held for a long time of years.
Strategic	Product range growth potential	The potential growth of business in the future providing services and value to services to existing customers quickly

Factor Scoring Analysis

In this study, a face-to-face interview was held between the researcher and each expert to discuss the factors extracted from the literature. The interviews took place between Jan to March 2019. It was assured that the data provided by each expert would remain anonymous. Due to the limitations, the interview was conducted in more than one session in more than one case. The interview focused on providing scores for each factor.

The parametric tests use some extra information about the data, such as data distribution, while non-parametric tests are usually almost as powerful as parametric tests do not mandate that. Although the normality distribution of data is contradictory between researchers (Olvera Astivia *et al.*, 2020), to some extent, the data is considered random. In the context of this experiment, the assumption of normality is hardly violated. The Cronbach alpha measures internal consistency and scale reliability between scores given by experts. It ensures that the selected participants are unbiased and that the data collection is reliable. The data is Likert style ordered from (1-5); however, it forms a scale, from 0-100. There are parametric and non-parametric methods to estimate the variance of Cronbach's (Tsagris *et al.*, 2013); however, the SPSS implementation was used (Marshall and Boggis, 2016).

The rating of scores is critical to the success of the proposed framework, particularly the clustering; it ensures that the ratings by the selected participants are unbiased and that the data provided as the response is reliable. The thesis uses Cronbach alpha to measure internal consistency and scale reliability between scores given by experts. This measure ensures that the selected participants are unbiased and that the data collection is reliable. After the interview sessions, each expert was given one week to finish the factors scoring using the Likert scale (1 lowest, five highest). The Cronbach Alpha between experts was reported to be (Actual=0.952, Ideal=0.851), $\alpha=0.05$, which is acceptable (>0.7) (Tavakol and Dennick, 2011), which measures internal consistency between the experts. It ensures that the selected participants are unbiased and that the data collection is reliable.

Despite the several studies that the Cronbach Alpha may suffer from bias due to the non-normally distribution of factors data (Sheng and Sheng, 2012), this research followed (Shultz, 1993) where they found that sample coefficient Alpha was reasonably acceptable for its normality assumption. In principle, outliers might make lower correlations that one would observe with normal data, but mostly 50% (46/118 factors) of the dataset is normally distributed in the factors dataset using the D'Agostino-Pearson Test (Yap and Sim, 2011) that is based on skewness and kurtosis. Consequently, the Cronbach Alpha scores are acceptable. Therefore, given the error of around 10% introduced due to bias as shown by (Sheng and Sheng, 2012), the reported results are considered acceptable.

Moreover, the Fleiss Kappa statistics, a measure of inter-rater agreement used to determine the level of agreement between two or more raters, reported data in Table 4.4, where the overall Kappa was only 0.107. The low value of Kappa is due to the complexity of the problem, where fifteen experts rating in five category ratings (1-5) are compared. The possibility of high consistency between experts is not apparent; however, such value is considered statistically significant when p-value <0.05.

Moreover, the score is considered a slight agreement according to the interpretation guidelines of Landis and Koch (1977).

Table 4.4. Kappa values for individual categories.

Categ.	Cond. Prob.	Kappa	Asympt. Std Error	Z	P-Value	Lower 95% Asymptotic CI Bound	Upper 95% Asymptotic CI Bound
1	.245	.093	.009	10.368	.000	.076	.111
2	.374	.122	.009	13.600	.000	.105	.140
3	.408	.081	.009	9.032	.000	.064	.099
4	.183	.065	.009	7.288	.000	.048	.083
5	.315	.267	.009	29.759	.000	.250	.285

The insights from these experiments revealed that most experts were satisfied with the collected factors, and they were able to score factors for upcoming phases (ideal and actual scores).

It was expected that experts would provide data that could be used to reduce the number of factors. However, it is found that it was not easily possible due to data was not being normally distributed. Therefore, the D'Agostino-Pearson Test was used to test the normal distribution of each factor among experts. D'Agostino-Pearson Test (Yap and Sim, 2011) is based on skewness and kurtosis. The test is used to test data normality based on the p-value, where the null hypothesis that data is not normally distributed is rejected if the p-value is more than predetermined α =0.05. The D'Agostino-Pearson Alpha was significant for only (46/118) factors. Therefore, another alternative was sought to solve the problem, which results in clustering.

4.2 Criteria Clustering

Selected experts provided a Likert scale (1-5) for each cluster based on cohesion and separation. The list of clusters and subfactors was sent by email to the participants. They score each cluster from 1-5 based on cohesion where current factors are semantically similar and unrelated subfactors are not grouped in the same sector. These are questionnaire questions:

(1) Is the current centroid valuable? If not, suggest another one from the list of factors in the same group.
(2) Rate how good each cluster is separated from others (1-5)
(3) Rate how well the internal cluster factors are related (1-5).

The results were deemed acceptable if the average score of cohesion and separation were above 70%.

The results of clusters are shown in Table 4.5. With cluster names, its descriptions as shared with experts, the average ideal score by experts, and the total number of factors in each cluster.

Table 4.5. Clusters of factors.

Code	Cluster/Factor	Perspective (as shared with experts)	Avg/Ideal	Total factors/Cluster
F1	Strategic Integration	Take advantage and strengthen the project benefits by building horizontal integration (example, acquiring a similar company at the same point of the supply chain) and vertical integration (example, acquiring a company in the supply chain vertical) for the current business or available/completed projects	3.73	3
F2	Develop Long- term business opportunity	Take into consideration the organization long term strategy and potential growth in the business	3.76	15
F3	Political acceptance	political acceptance is the willingness of the governed to endure project acceptance	3.40	5
F4	Social benefits	Benefits received by individuals or the community including health care, unemployment allowance, retirement, housing, and education.	3.80	4
F5	Ease of operation	Keeping projects services or products in safe and reliable functioning conditions based on requirements.	3.65	9
F6	Productivity	Productivity is computed by dividing average output per period by the total	2.93	13

		costs incurred or resources (capital, energy, material, personnel) consumed in that period.		
F7	Project Location	Take into consideration the location importance from strategic, project implementation, and operation perspectives	3.26	10
F8	Ability to implement	Take into consideration the project within project constraints (time, cost, scope, and quality).	3.55	17
F9	Customer point of view Ease of use	Take into consideration from the customer point of view how easily the end-users can use the products or services	3.18	10
F10	Operation Management	Take into consideration the origination readiness in terms of capability and capacity to operate and do the maintenance for the project after its completion	4.01	7
F11	Operating cost	Take into consideration the Operational costs from the operator perspective, which are related to the operation of the output	3.62	4
F12	Investment Capital	Take into consideration the required procurement of money by an organization to further its business goals and objectives.	3.45	9
F13	Safety and Security	Take into consideration the environmental safety & security importance from project implementation and operation perspectives	3.58	12

4.2.1 Criteria Clusters Analysis

The list of subfactors per cluster is shown in Appendix D, while Table 4.6 shows an example for the third cluster (political acceptance) with the highest ideal score. Note that the "Compatibility with the national energy policy" subfactor was grouped in this cluster as it is a kind of national policy that needs political support.

Table 4.6. A cluster sample.

Subfactor	Average Actual Score	Average Ideal Score	Type
Political acceptance	2.87	3.73	Qualitative
Political priority	4.40	3.40	Qualitative
Political support	2.80	3.67	Qualitative
Level of political ambition	4.40	3.33	Qualitative
Compatibility with the national energy policy	2.20	2.87	Qualitative

This research applies three clustering approaches (on factors names and descriptions) and chooses the best one based on its performance. The scores for Silhouette Coefficient and Davies-Bouldin index for the selected algorithms are shown in

Table 4.7. The Silhouette value ranges from −1 to +1, indicating how similar factors are to its cluster (cohesion) compared to other clusters (separation). At the same time, the Davies-Bouldin index is an internal evaluation of clustering defined as the average similarity measure of each cluster with its most similar cluster.

Table 4.7. Criteria clustering validation.

Clustering Method	Number of Clusters	Silhouette Coefficient	Davies-Bouldin index
K-Means	13	0.09	0.38
Affinity Propagation	17	0.12	0.43
Agglomerative Clustering	13	0.24	0.35

The Silhouette Coefficient for the agglomerative clustering algorithm provides the best value based on the above table. Therefore, agglomerative clustering is the best approach for the case data, with sparse semantic vectors (512 entries each). As a comparison, the experts' scorings of clusters are shown in Table 4.8. Most clusters satisfy the experts in separation and cohesion, except the last one (F13). The highest cohesion was F6, indicating that the 13 factors are tightly related. For example, energy consumption and adoption of sustainable material & renewable resources factors increase job creation and employment. However, experts reported a low cohesion and separation for F13. Furthermore, the experts reported that environmental safety, ability to meet likely future regulations, and investment risk were not seen as high separation or cohesion. Further upcoming experiments in the case study result in dropping out of this cluster from comparison.

Table 4.8. Experts scoring of clustering (external validation)

	Cohesion						Separation					
	1	2	3	4	5	AVG	1	2	3	4	5	AVG
F1		1		1	3	84%			2	3		72%
F2	1			4		68%		1			4	88%
F3		1		3	1	76%			1	1	3	88%
F4			2		3	84%			3	2		68%
F5			1	2	2	84%			2	2	1	76%
F6			1		4	92%		1		3	1	76%
F7				3	2	88%			1	4		76%
F8		1		4		72%			1	3	1	80%
F9			1	2	2	84%			2	3		72%
F10				3	2	88%		1	1	2	1	72%
F11			2	2	1	76%			1	2		44%
F12			1	1	3	88%			1	3	1	80%
F13	1	2	1	1		48%	1	1	1	2		56%

4.3 Criteria Specialization

First, the consolidated criteria are used to be specialized for each industry. For example, safety and security criteria seem inadequate for real estate and construction sectors, but they might help IT-related projects. Part of the framework includes quantitative data analysis, where eight experts were chosen to score the importance of each of the consolidated factors in specific industries.

It was impossible to acquire a dataset from many industries due to the privacy issues and difficulty getting a broad set of implemented projects. However, the aim is to prove the developed framework concept; therefore, two sectors were chosen under limited data: transportation and real estate.

All clusters may not be applicable in each project type; therefore, experts ranked each cluster's value regarding its applicability in the transportation and real estate sectors. The average scores for each industry were calculated following the guidelines of Table 3.3. The average score ranges are calculated as follows: first, the range scores were converted to numerical scores (1-4) where the range 0-24% was mapped to zero, and 75-100% was mapped to 4. Next, the processed scores were averaged and rounded up. Then, the numerical scores were converted to the original percentile range scores. As a result, only more than 50% of factors were taken into subsequent steps.

4.4 Participants Selection and Case Study Application

The participants selected in this research are strategic project senior experts, called experts in this thesis. Experts are considered the primary source of ground truth for project factors practicing in their daily activities. The researcher used convenience and cluster sampling (Latunde, 2017) to ease data collection and validation when required. Moreover, in the context of strategic projects, the number of experts is generally low due to the nature of the strategic project selection process with a limited number of decision-makers. Cluster sampling is best used when the clusters (of participants) occur naturally in a population and when the groups are geographically convenient. Therefore, experts were selected to ensure that participants experience various industries.

The use of experts in this study ensures that each step in the framework is validated internally (content validity), with minimum risk of failure that may result due to lack of data, misinterpretation by the researcher due to high dimensional factors involved in the framework—confirming an agreement between the claimed measurement and the real world of ranked projects. Therefore, experts with diverse experience were the ultimate direction for this research, given the limited number of projects and many conflicting elements in the research space.

The number of interviews depends on the availability of experts and their matching criteria; however, the number is consistent with the literature that suggests anywhere between 5 and 50 participants as adequate (Dworkin, 2012).

Invitations were sent to 23 experts who represent various industries and have comprehensive experience of more than ten years in project selection. Twelve of the experts replied to indicate their interest in the interview. The researcher was aware that experts from the real estate sectors might not interpret the strategic project factors differently from other experts. Therefore, an interview with experts was conducted face-to-face and one-to-one based on the experts' free time. Based on the discussion with the 12 experts who replied, three additional experts were approached, which brings the total size of 15 experts that are re-participated in different points according to their availability. The experts have an experience of a mean of 21.5 years and a standard deviation of 7.8 years. Their expertise is on public (three experts), private (four experts), and both (eight experts).

The criteria for selection experts are as follows:

(1) Must have diverse experience with more than ten years in project selection or at the level of CEO
(2) Experience in project selection should be frequent or intermediate.
(3) Preferable to work in more than one industry and an executive level.

Following the suggested participants' selection criteria above, most of them are executive levels, and they have experience working in different industries, as shown in Table 4.9 and following the questions outlined in Appendix B. In addition, open questions are related to any other experience or characteristics that an expert may want to express. The experts mentioned common issues related to project selection, including time and experience needs. They reported that it is hard to compare projects across different industries in many cases. The scores of each factor were carried out in the first interview of 15 experts individually. Scores represent an actual score that an expert thinks the factor has that weight in the Likert scale (1-5), while the idea score represents what should be used in practice. Experts, for example, believe that the “Effect on existing market outlook” factor has an actual score of 2.47, while in practice, the ideal value should be higher (4.27).

Table 4.9. Selected experts in this study.

Expert	Job Title	Job Level	Experience (years)	Public/ Private Experience	Sector Experience	Experience in Project Selection
E1	Head infrastructure and landscaping	Middle	20	Public	infrastructure	Intermediate
E2	CEO	Executive	20	Private	rental, real estate, investment, banking, financing	often, monthly
E3	Adviser	Executive	34	Both (mainly private)	Project management construction and infrastructure, real estate	often
E4	Advisory services director	Executive	20	Private	Oil and gas, industrial, infrastructure	frequently

Expert	Job Title	Job Level	Experience (years)	Public/ Private Experience	Sector Experience	Experience in Project Selection
E5	CEO	Executive	30	Both (mainly Public)	Construction, oil and gas, QF, PEO private engineering office	Often
E6	Adviser	Executive	34	Both sim government	industrial and services	Often
E7	Director strategy Implementation Management	Executive	15	Public and non-profit	QF, education, oil and gas, and government (cross-sectors)	Often
E8	CEO	Executive	29	Both	civil society	every quarter
E9	monitoring and evaluating specialist	Middle	14	Both	social, infrastructure IT, operation heath,	intermediate
E10	Business Transformation Manager	Executive	25	Private		Often
E11	Director of project management and development	Executive	6	Public	transportation	Often
E12	CEO	Executive	15	Private	Banking, rea-estate and financial advisory	Often
E13	CEO	Executive	22	Both (private)	sport, oil and gas	Often
E14	CEO	Executive	21	Both	Army, Ashghal, sport, real estate	Often
E15	Adviser	Executive	18	Both		Often
		Standard Deviation	7.8			
		Average	21.5			

Participants were also part of factor specialization. Participants who helped in specializing in transportation and real estate industries are Real estate (E2, E3, E14, E15), Transportation (E3, E5, E11, E15). The participants E5 and E15 were good choices are they were experts in both industries. Experts were also part of the clustering validation. The experts that were part of this exercise were private (E2, E4), and public (E1, E7), and both (E8).

This study employed interviews, questionnaires, and case studies to collect and validate the output of this research. In addition, various data collection was used to develop the proposed framework.

Case Study Description

The case study projects have the following data, as explained in Table 4.10. Note, not all projects data are revealed due to project sensitivity and the non-disclosure agreement with the Qatar Government representative. Experts were first provided with score guidelines for this exercise, as shown in

Table 4.11. Although four scores could be used, the researcher uses five scores so that experts could rank the project such that the middle score is ranked 3, the lowest and highest are one and five, respectively. A 5-Likert-type scale (As opposed to a 7 and 10 point scale) increases response rate and responses quality (Dawes, 2008). This helps to reduce the effort to differentiate the scale more clearly to have a strategic decision (Bouranta *et al.*, 2009).

This study chooses to validate the framework output by a collected strategic project that has been implemented in Qatar during the period 2010-2020. Since a governmental executive office handled the dataset, the validity of the dataset is acceptable; however, detailed data could not be obtained due to ethical reasons and participants' unwillingness to share the information due to confidentiality reasons. This is consistent with the recommendation by Walford (2005)**,** who suggested anonymity and ethical guidelines in this type of research. The projects used in this study are shown in Table 4.10.

Table 4.10. Projects used in this study

Sector	Project Code	Duration (years)	Description	Revealed issues on the project
Transportation	T1	7	highways	Project in phases
	T2	8	Bridges and tunnels	
	T3	6	Construction and road upgrade	
	T4	4	Highway	
	T5	5	Road construction	Project history issues
	T6	6	Port related	
Real estate	R1	5	residential community	Project time extended
	R2	6	residential community	
	R3	5	compound	
	R4	2	residential	Budget allocation
	R5	8	Commercial and residential	
	R6	3	showrooms and shops	
	R7	7	Towers	

Table 4.11. Project criteria ranking (transportation and real estate)

Rank	Percentage	Description
1	0-20%	Negligible consideration at strategic project selection (Must ignore these factors)
2	20-40%	Low consideration at strategic project selection (Can ignore these factors)
3	40-60%	Moderate consideration at strategic project selection (May consider these factors)
4	60-80%	High consideration at strategic project selection (Can consider these factors)
5	80-100%	Very High consideration at strategic project selection (Must consider these factors)

4.4.1 Project Categorization

Both sectors have a social and economic effect on Qatari life. This study reports 13 projects: six in transportation and seven in real estate sectors. The list of collected project data is illustrated in Table 4.12. The experts took almost a month to provide this dataset; however, the researcher had only one focal point of communication with the government of Qatar during this process.

Table 4.12. Strategic transportation and real estate projects[1]

Project Code	Sector/Factor Type*	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
		B	B	B	B	B	B	B	B	B	NB	NB	NB
T1	Transportation	*5*	*5*	*4*	*5*	*3*	*	*	*4*	*5*	*4*	*3*	*5*
T2		*5*	*3*	*4*	*5*	*4*	*	*	*3*	*5*	*4*	*4*	*5*
T3		*4*	*5*	*4*	*5*	*4*	*	*	*4*	*5*	*4*	*4*	*5*
T4		*5*	*5*	*4*	*5*	*4*	*	*	*3*	*5*	*4*	*4*	*5*
T5		*5*	*5*	*5*	*5*	*4*	*	*	*4*	*5*	*4*	*5*	*5*
T6		*4*	*4*	*4*	*3*	*5*	*	*	*4*	*4*	*5*	*4*	*2*
R1	Real estate	*4*	*5*	*5*	*3*	*4*	*4*	*3*	*4*	*3*	*3*	*3*	*4*
R2		*4*	*5*	*5*	*3*	*4*	*4*	*5*	*4*	*3*	*3*	*3*	*4*
R3		*3*	*3*	*4*	*3*	*3*	*3*	*3*	*2*	*3*	*3*	*3*	*3*
R4		*3*	*3*	*3*	*3*	*3*	*3*	*4*	*4*	*4*	*4*	*3*	*3*
R5		*4*	*4*	*5*	*4*	*4*	*4*	*5*	*5*	*5*	*5*	*4*	*4*
R6		*3*	*3*	*3*	*3*	*3*	*3*	*3*	*4*	*2*	*2*	*4*	*4*
R7		*5*	*5*	*5*	*4*	*5*	*5*	*5*	*5*	*3*	*3*	*5*	*4*

One* B is a beneficial factor; NB is a non-beneficial cost factor, * factor not selected in industry

Considering that projects may have private figures (e.g., costs) that could affect strategic project organization, project names, descriptions, costs, and time was concealed for privacy concerns. A project can be categorized in ownership, application area or product, timing, geography, complexity, contracting, and internal and external stakeholders (Al-Sobai *et al.*, 2020).

4.4.2 Criteria Clustering

Since the previous attempts to normalize factors were unsuccessful, the researcher decided to group factors rather than eliminate them. The results of clusters are shown in Table 4.5.

4.4.3 Criteria Specialization

Given the clustered factors that work with any industry, the next step is to specialize in real estate and transportation projects. Based on the exercise of specialization (or minimization) of criteria based on each industry, as explained in

Table 4.14, the following list of factors is used in the case study (shown in Table 4.13). The specialization per the two industries is described in

Table 4.14.

Table 4.13. Criteria specialization per industry sector

#	Factor	Transportation	Real Estate	Beneficial (BN)/ Non-Beneficial
F1	Strategic Integration	Yes	Yes	Beneficial
F2	Develop Long-term business opportunity	Yes	Yes	Beneficial
F3	Political acceptance	Yes	Yes	Beneficial
F4	Social benefits	Yes	Yes	Beneficial
F5	Ease of operation	Yes	Yes	Beneficial
F6	Productivity (Technical feasibility)	No	Yes	Beneficial
F7	Project Location	No	Yes	Beneficial
F8	Ability to implement	Yes	Yes	Beneficial
F9	Economic Vitality (Customer point of view Ease of use)	Yes	Yes	Beneficial
F10	Operation Management	Yes	Yes	Non-beneficial
F11	Operating cost	Yes	Yes	Non-beneficial
F12	Investment Capital	Yes	Yes	Non-beneficial
F13	Safety & Security (environment and investment)	No	No	Beneficial

Table 4.14. Criteria specialization per industry sector (scores)

#	Factor	Transportation	Real Estate	Beneficial (BN)/ Non-Beneficial

F1	Strategic Integration	50-74%	50-74%	Beneficial
F2	Develop Long-term business opportunity	50-74%	75-100%	Beneficial
F3	Political acceptance	75-100%	50-74%	Beneficial
F4	Social benefits	75-100%	50-74%	Beneficial
F5	Ease of operation	50-74%	50-74%	Beneficial
F6	Productivity (Technical feasibility)	25-49%	50-74%	Beneficial
F7	Project Location	25-49%	50-74%	Beneficial
F8	Ability to implement	50-74%	50-74%	Beneficial
F9	Economic Vitality (Customer point of view Ease of use)	50-74%	50-74%	Beneficial
F10	Operation Management	75-100%	75-100%	Non-beneficial
F11	Operating cost	75-100%	75-100%	Non-beneficial
F12	Investment Capital	50-74%	75-100%	Non-beneficial
F13	Safety & security (environment and investment)	25-49%	25-49%	Beneficial

4.4.4 Criteria Weighting

Using the CRITIC method, equations (3.1-3.4) in Chapter 3 evaluate the correlation between factors for transportation and real estate sectors. Table 4.15 shows the conflict between pairwise factors and the total conflict using equation (3.3). The tables show that each factor has a zero-conflict and varying scores across different factors. It shows, for example, in Table 4.16, that the factor F1 (strategic integration) and F5 (ease of operation) has a lower measure of conflict (zero) than of the conflict between F1 and F7 (project location), which was (0.34).

The current projects' explanation indicates that the strategic integration and ease of operations have low conflict, while strategic integration might conflict if the project location was correctly selected. The total conflict of a factor with all others (a measure of conflict as shown in the last column) was the highest for F9 and F10 and lowest for F1, F5, F6 factors. However, the previous findings are situational dependent on scores of factors assigned by experts.

Table 4.17 shows results of the CRITIC method, the correlation between factors is evaluated using equations (3.1-3.4) for both industries, individually. The measure of conflict was calculated based on a correlation between factors ($r_{jj'}$) and using equation

(3.3a) as shown in equation 3.3b. The measure of conflict (row summation) is shown in Table 4.15 and Table 4.16.

Table 4.15. The measure of conflict between factors for Transportation

	F1	F2	F3	F4	F5	F8	F9	F10	F11	F12	Measure of conflict
F1	0.00	1.00	0.68	0.37	1.61	1.50	0.37	1.63	1.00	0.37	8.53
F2	1.00	0.00	0.71	0.71	1.38	0.54	0.71	1.29	1.00	0.71	8.04
F3	0.68	0.71	0.00	0.80	1.00	0.68	0.80	1.20	0.23	0.80	6.90
F4	0.37	0.71	0.80	0.00	1.77	1.32	0.00	2.00	1.00	0.00	7.97
F5	1.61	1.38	1.00	1.77	0.00	1.00	1.77	0.23	0.50	1.77	11.04
F8	1.50	0.54	0.68	1.32	1.00	0.00	1.32	0.68	1.00	1.32	9.35
F9	0.37	0.71	0.80	0.00	1.77	1.32	0.00	2.00	1.00	0.00	7.97
F10	1.63	1.29	1.20	2.00	0.23	0.68	2.00	0.00	1.00	2.00	12.03
F11	1.00	1.00	0.23	1.00	0.50	1.00	1.00	1.00	0.00	1.00	7.73
F12	0.37	0.71	0.80	0.00	1.77	1.32	0.00	2.00	1.00	0.00	7.97

Table 4.16. The measure of conflict between factors for the real estate sector.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Measure of conflict
F1	0.00	0.12	0.17	0.29	0.00	0.00	0.34	0.34	0.87	0.87	0.40	0.35	3.75
F2	0.12	0.00	0.12	0.66	0.12	0.12	0.50	0.50	1.00	1.00	0.79	0.32	5.24
F3	0.17	0.12	0.00	0.49	0.17	0.17	0.47	0.65	0.74	0.74	0.81	0.44	4.97
F4	0.29	0.66	0.49	0.00	0.29	0.29	0.32	0.32	0.49	0.49	0.19	0.60	4.42
F5	0.00	0.12	0.17	0.29	0.00	0.00	0.34	0.34	0.87	0.87	0.40	0.35	3.75
F6	0.00	0.12	0.17	0.29	0.00	0.00	0.34	0.34	0.87	0.87	0.40	0.35	3.75
F7	0.34	0.50	0.47	0.32	0.34	0.34	0.00	0.33	0.47	0.47	0.58	0.66	4.82

F8	0.34	0.50	0.65	0.32	0.34	0.34	0.33	0.00	0.65	0.65	0.36	0.32	4.80
F9	0.87	1.00	0.74	0.49	0.87	0.87	0.47	0.65	0.00	0.00	1.03	1.15	8.14
F10	0.87	1.00	0.74	0.49	0.87	0.87	0.47	0.65	0.00	0.00	1.03	1.15	8.14
F11	0.40	0.79	0.81	0.19	0.40	0.40	0.58	0.36	1.03	1.03	0.00	0.50	6.50
F12	0.35	0.32	0.44	0.60	0.35	0.35	0.66	0.32	1.15	1.15	0.50	0.00	6.20

Based on the measure of conflict,

Table 4.17 shows the weights for each factor for both transportation and real estate sectors, following equation 3.4, Chapter 3.

Table 4.17. Weights for factors, $\boldsymbol{W_j}$, for the transportation and real estate projects.

	Transportation		Real estate	
	Qty of information (Eq. 3b)	$\boldsymbol{W_j}$	Qty of information (Eq. 3b)	$\boldsymbol{W_j}$
F1	4.40	12%	1.03	4%
F2	3.36	9%	2.58	11%
F3	2.81	8%	2.44	10%
F4	3.25	9%	1.80	7%
F5	3.49	10%	1.03	4%
F6	Not selected	Not applicable	1.03	4%
F7	Not selected	Not applicable	2.37	10%
F8	4.83	13%	1.57	6%
F9	3.25	9%	2.80	12%
F10	4.91	14%	2.80	12%
F11	2.44	7%	1.68	7%
F12	3.25	9%	3.20	13%

4.4.5 Project Criteria Weighting

Weights from

Table 4.17 are used to calculate the rank for each project using the TOPSIS approach and project scores shown in Table 4.12. Equations 3.5-3.8 in Table 3.5 were used to accomplish this task. The results of TOPSIS are shown in

Table 4.18, Table 4.19. . The top projects were T6, R7 for the transportation and real estate industries, respectively. However, the decision-makers have to consider both industries simultaneously, tackled in the next section.

Table 4.18.TOPSIS for Transportation case study.

	F1	F2	F3	F4	F5	F8	F9	F10	F11	F12	Di+	Di-	Pi	Rk
T1	0.05	0.04	0.03	0.03	0.02	0.05	0.03	0.05	0.02	0.04	0.03	0.03	0.52	4
T2	0.05	0.02	0.03	0.03	0.03	0.04	0.03	0.05	0.02	0.04	0.03	0.02	0.43	6
T3	0.04	0.04	0.03	0.03	0.03	0.05	0.03	0.05	0.02	0.04	0.03	0.03	0.53	3
T4	0.05	0.04	0.03	0.03	0.03	0.04	0.03	0.05	0.02	0.04	0.03	0.03	0.50	5
T5	0.05	0.04	0.03	0.03	0.03	0.05	0.03	0.05	0.03	0.04	0.02	0.03	0.54	2
T6	0.04	0.03	0.03	0.02	0.04	0.05	0.03	0.06	0.02	0.01	0.02	0.03	0.56	1
V+	0.05	0.04	0.03	0.03	0.04	0.05	0.03	0.05	0.02	0.01				
V-	0.04	0.02	0.03	0.02	0.02	0.04	0.03	0.06	0.03	0.04				

Table 4.19. TOPSIS for the real estate case study.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Di+	Di-	Pi	Rnk
R1	0.01	0.04	0.04	0.02	0.01	0.01	0.02	0.02	0.03	0.03	0.02	0.05	0.04	0.04	0.53	4
R2	0.01	0.04	0.04	0.02	0.01	0.01	0.04	0.02	0.03	0.03	0.02	0.05	0.03	0.05	0.58	2
R3	0.01	0.02	0.03	0.02	0.01	0.01	0.02	0.01	0.03	0.03	0.02	0.04	0.05	0.04	0.43	6
R4	0.01	0.02	0.02	0.02	0.01	0.01	0.03	0.02	0.05	0.05	0.02	0.04	0.04	0.04	0.46	5
R5	0.01	0.03	0.04	0.03	0.01	0.01	0.04	0.03	0.06	0.06	0.02	0.05	0.04	0.05	0.54	3
R6	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.05	0.06	0.04	0.42	7

R7	0.02	0.04	0.04	0.03	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.05	0.03	0.05	0.58	1
V+	0.02	0.04	0.04	0.03	0.02	0.02	0.04	0.03	0.06	0.02	0.02	0.04				
V-	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.06	0.03	0.05				

4.4.6 Cross-Industry Project Ranking

The previous section showed the rank of projects across one industry (transportation or real estate); however, better decision-making must get the overall rank across different industries simultaneously. Therefore, this research adopts another hierarchical level of weighting across industries as per equation 3.10.b.

Table 4.20 shows the new ranks for projects.

Table 4.20. Projects prioritization for transportation and real estate case studies.

	Project	Score	Percentage	Cluster Rank	Weighting	Model-Rank	Expert Rank
Transportation	T1	0.53	42%	4	28.43%	8	6
	T2	0.43	34%	6	23.22%	12	12
	T3	0.53	42%	3	28.45%	7	10
	T4	0.50	40%	5	27.02%	9	7
	T5	0.55	43%	2	29.39%	4	9
	T6	0.56	44%	1	30.33%	3	3
Real Estate	R1	0.53	39%	4	28.55%	6	8
	R2	0.58	43%	2	31.21%	2	2
	R3	0.43	32%	6	23.22%	11	11
	R4	0.46	34%	5	24.92%	10	4
	R5	0.55	40%	3	29.36%	5	5
	R6	0.43	31%	7	22.89%	13	13
	R7	0.59	43%	1	31.54%	1	1

4.4.7 Decision Making

Following the detailed algorithm in Table 3.7, a decision-maker will be given the rank for each project from projects that were part of the decision-making process. Projects ranked on top are amongst the highest priority projects for execution, while projects at the bottom of the list could be executed later.

The results showed that the senior experts (decision-makers) ranked projects relatively similar to the proposed model output for projects ranked 1-3 and ranked from 11-13. The middle-ranked projects were an exception. However, projects' ranks generally had a mean absolute error of 1.85 and standard deviation of 2, where the error is the difference between experts' evaluation and the model output. Statistically, projects were ranked close to the rank made by the experts with an average absolute error of 1.53, representing the differences between experts' ranks and model ranks.

The evaluation done in the framework shows that transportation project T6 is ranked on the top among the transportation project; however, it is ranked third compared with the real estate project. Project T6 is evaluated 44% among transportation sector projects but approximately 30.3% among the two sectors based on equation (10b). Further analysis shows that T6 had the highest cost among the transportation projects.

4.5 Framework Evaluation

The evaluation of the framework is carried out using two approaches, internal validation using the Pearson correlation and the framework usability using the System Usability Score (SUS) of Brooke (1996).

4.5.1 Cross-Industry Project Ranking Evaluation

The proposed approach is validated using experts' actual ranks assigned to projects. The correlation between the experts' ranking and outputs from the proposed framework is calculated using the Spearman correlation coefficient, a statistical measure of the relationship between paired ranks of projects from the real-life scenario (model output) and the experts' ranking. The study tests if the data is significant for paired samples with $\alpha = .05$ to test the hypothesis if the difference between the ranks of projects between model ranks and expert's judgment is due to chance.

Three senior experts ranked the projects based on project data and their experience. Experts tend to recall information about the most important projects from the cognitive perspectives and neglect those related to the least important due to a phenomenon known as the solid temporal contiguity effects in free recall (Cortis Mack *et al.*, 2017). Therefore, the ranking might have been close to the model outputs. The rankings shown in the last column of

Table 4.20 provide a high Spearman Correlation coefficient (rho=0.76, p-value=0.003, α =0.05) between the outputs from the expert and the model. Therefore, the null hypothesis that the projects' model ranking was due to chance is rejected.

Moreover, typically, the differences between the ranks for the same project should be near zero, indicating that the ranks are well-matched and assuming that the two groups of ranks have roughly similar distribution (standard deviation = 3.9). Therefore, the standard error for the case study is obtained as 0.75, which is a low value indicating that the model outputs are reliable.

The results show that the experts ranked projects relatively similar to the proposed model output for top-ranked and lowest-ranked projects. Although the criteria sheets used in practice are unknown to the authors, the sensitivity of decisions taken by experts is generally affected by financials, political support, and social impacts. Furthermore, the experts would be focusing on different categories of projects, including healthcare, R&D, and IT projects. Therefore, given the outcomes obtained from the experts, the model output can be considered valid without loss of generality.

4.5.2 Framework Usability

The framework's output should be a list of ranked projects across industries. A decision could then be carried out to acquire resources to execute the projects. If projects get withdrawn, the next project is executed. The proposed approach's usefulness is measured using the System Usability Score (SUS) (Brooke, 1996). Brook's SUS measure is a questionnaire of ten items (shown in Appendix E). SUS was measured by 10 participants with experience in project ranking. Results are shown in Table 4.21.

Table 4.21. Experts Scoring for SUS questionnaire

Participant	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	SUS Score
E1	5	3	4	1	2	2	3	2	4	1	72.5
E3	4	2	3	1	4	3	5	2	4	3	72.5
E4	3	1	4	2	3	3	5	3	3	4	62.5
E5	4	2	4	2	4	2	3	2	4	2	72.5
E6	5	4	5	3	4	2	3	3	4	1	70.0
E7	4	3	5	2	5	3	4	3	4	3	70.0
E8	5	3	3	2	3	1	4	2	4	2	72.5
E10	3	2	4	1	3	3	5	2	5	4	70.0

E12	4	2	3	2	3	4	4	1	3	5	57.5
E13	3	2	3	2	2	3	3	1	4	2	62.5
										SUS Score	

The average SUS score is 68, which is above the 50th percentile using 241 industrial usability studies (Sauro and Lewis, 2016) created a curved grading scale (68 is at the center "C."), as shown in Table 4.22.

Table 4.22. SUS scores interpretability (source: Sauro and Lewis (2016))

Grade	SUS	Percentile
A+	84.1-100	96-100
A	80.8-84.0	90-95
A-	78.9-80.7	85-89
B+	77.2-78.8	80-84
B	74.1-77.1	70-79
B-	72.6-74.0	65-69
C+	71.1-72.5	60-64
C	65.0-71.0	41-59
C-	62.7-64.9	35-40
D	51.7-62.6	15-34
F	0-51.6	0-14

However, these findings should be carefully interpreted due to many external factors, such as experts' level, experience, and comprehension.

4.6 Discussion

This chapter discusses the findings based on the research questions to support the research objectives. The primary research question was prioritizing the strategic projects from different industries simultaneously. Next, evidence is shown to the accomplishment of each research objective.

4.6.1 Analysis of RQ 1

Research question 1 was: What factors are important for strategic project selection? The number of criteria that a decision-maker can process is limited; therefore, the researcher decided to limit factors. Reconciliation of factors obtained from the literature saved time. However, to reduce bias and automate the process, the researcher first reduced the compiled factors to 118 based on literature, as discussed in Chapter 2, collected based on quantitative and qualitative prioritization approaches. Such categories include Economics, Politics, Organizational, Social, Time, Quality, and Environmental.

With text clustering, the total of 118 factors was reduced to 13 factors using Agglomerative clustering (Murtagh and Legendre, 2014). It is found that the Agglomerative was the best choice as it was able to group factors with similar meanings to reach an abstract set of factors that could be used to prioritize projects. The list of factors using the Agglomerative clustering is Strategic Integration, Develop Long- term business opportunity, Political acceptance, Social benefits, Ease of operation, Productivity, Project Location, Ability to implement, Customer point of view Ease of use, Safety and Security, Operation, Management, Operating cost, Investment Capital. Reduced factors provide an abstract view of the most dominant factors used to rank strategic projects.

Researchers have no consensus on the best criteria for each project category. For example, evaluating geometrical, ownership/social, environmental, erosion, and morphology factors for land-related projects (Muchová and Petrovič, 2019), whereas financial factors, may be necessary for other projects. In addition, evaluation criteria are often organization-specific (Nowak, 2013), although they might be impacted by the stakeholder priorities (Ligardo-Herrera *et al.*, 2019). In complex situations with different aspects to be considered in the decision processes, endogenous and exogenous variables of the multi-criteria analysis methods could be used to synthesize various forms of input data (Guarini *et al.*, 2018).

Compared with previous works, factors are domain-specific and sometimes more than factors that experts could process according to Miller's rule (the limits are seven minus plus two according to where a person has limited processing information). For example, 21 factors for (Büyüközkan and Güleryüz, 2016), 20 factors reported by (Dutra *et al.*, 2014), and 18 by (Ginevičius and Zubrecovas, 2009). Therefore, this study has listed only a few influential factors comparable to the 43 factors proposed by (Ginevičius and Zubrecovas, 2009) and evaluated subjectively by experts.

Table 4.23 shows sample related works in Transportation and Real estate set of factors. Compared to this research list of factors, the proposed list is more generic and comprehensive.

Table 4.23. Proposed factors with the list of related works in Transportation and real estate

Proposed Factors	**Transportation**			**Real Estate**	
	(Ivanović *et al.*, 2013)	(Li *et al.*, 2019)	(Novak *et al.*, 2015)	(Ginevičius and Zubrecovas, 2009)	(Cheng and Li, 2005)
Strategic Integration			Environment	Analysis of investment environment ,	Environmental protection
Develop Long-term business opportunity		Governance mechanism	Preserving of the existing system		Conflict resolution
Political acceptance					Governmental regulations and standards, Legal implications, Company objective and policy, Terms of contract
Social benefits	Benefits		Energy and Quality of life	techno-economic analysis of the object	Public relations Profitability
Ease of operation					Project duration
Productivity (Technical feasibility)	Exterior projects Inner	External environment	Mobility and Connectivity		Staffing, Resource requirements, Technological implications
Project Location	Traffic				Geographical location
Ability to implement				Analysis of legal environment	Technical know-how,

					Project-identification ability
Economic Vitality (Customer point of view Ease of use)	Environmental impacts		Economic Vitality		
Operation Management		Governance structure	Efficient system management		Managerial competence
Operating cost					
Investment Capital	Costs		Prior Listing in TIP	Financing parameters	Risk/return ratio, Budget control
Safety & Security (environment and investment)			Safety & security	Risk analysis	Health and safety

Therefore, this objective aims to reduce the number of factors considering the different types of strategic projects across different industries.

4.6.2 Analysis of RQ 2

Research question 2 was: What methods can be used to reduce the factors? In contrast with many research projects, the selection is applied in a single industry (Taylan *et al.*, 2014a). This research opts to apply the selection across industries. Therefore, the list of 13 factors was again filtered using experts to remove further factors that have little or no impact on the overall project ranking. The experts filtered the factors that apply to the case study: transportation and real estate. In transportation, the number of new factors becomes 10 out of 13, while in real estate, the number of factors becomes 12.

As a result, the transportation sector's factors are Strategic Integration, Develop Long-term business opportunities, Political acceptance, Social benefits, Ease of operation, Ability to implement, Customer point of view, Ease of use, Operation Management, Operating cost, Investment Capital. On the other hand, the real estate sector has productivity, project location, and previous factors. The productivity seems relevant to real estate as it is computed by dividing average output (e.g., buildings) per period by the total costs incurred or resources. It was found that real estate location is a pivotal contributor to the real estate industry. Subfactors are usually unavailable in pre-stages of strategic projects; for example, 38 sub-factors were reported for site selection (Hassanain *et al.*, 2018). The location has several strategic, project implementation, and operation perspectives. The proposed model's usefulness is that the list of factors should be minimized in a strategic project without project data's preexistence.

4.6.3 Analysis of RQ 3

Research question 3 was: What type of generic framework is most suitable for strategic project prioritization? This research used the project prioritization framework to rank strategic projects started with raw data and ended with ranked projects. The weighting of factors is challenging with multi-objective criteria; therefore, CRITIC was used to weight the most dominant factors. With the method, objective weights were calculated, as shown in

Table 4.17. The transportation sector's highest weight was Operation Management (14%), and the lowest factor was operating cost (7%). The operational phase in a transportation infrastructure poses several negative impacts in the operational phase such as habitat fragmentation and changes, animal mortality, and light pollution (Karlson *et al.*, 2014).

For real estate strategic projects, the highest weight for the investment capital (13%) and the lowest factor was for each of the following factors (4%): Strategic Integration, Develop Long- term business opportunity, Political acceptance, Social benefits, Ease of operation. The investment capital for real estate is a critical factor in what has been paid so far and when the return is expected. Evidence shows that investment returns and capital flows correlate with urban density and office real estate (Pain *et al.*, 2020). According to the conceptual megaproject governance model (Li *et al.*, 2019), the criteria was in three primary levels: governance structure, governance mechanism, and external environment; where the sub-criteria level includes: organization structure, stakeholder role, project financing structure, target management system, communication mechanism, coordination mechanism, conflict resolution mechanism, supervision mechanism, market environment, government regulation.

The study (Ivanović *et al.*, 2013) applied the Analytic Network Process (ANP) for transportation project selection. They used the criteria of traffic, cost, environmental impacts, benefits, and exterior projects. The social benefits were the highest criteria rating followed by locations of Gases stations. Although the study does not match the criteria weighting used in this thesis, the study is useful to note that the factors have to be included for selecting projects.

There can be disparities between project ranking between experts and that obtained from the proposed framework. The case example in this paper shows that project R4 was ranked higher by experts (model: 10 vs. exp: 4) by the proposed framework. Experts reported contractual issues and budget allocations in project R4, a common issue in large construction projects but not captured in the model. Likewise, project R1 was ranked lower by experts (model: 4 vs. exp: 8). During the selection of these projects, there was a change in management decisions by allocating a new expert in the selection model. Therefore, the new management's strategic objective (considered a project selection constraint) might have changed, resulting in different project prioritization scores. However, the framework provided lower importance to T5 (model: 9 vs. exp: 4) than the experts as the experts were aware of project importance not captured in the analysis. The outputs from the models show that, while the framework provides an excellent guideline to streamline the ranking, the final decision could be made by the decision-makers considering the data that could not be provided for the analysis.

4.7 Chapter Summary

This chapter summarizes the interview and questionnaires carried out before and after the proposed framework development. In the first stage of the research, a list of 118 criteria was first extracted from literature, then scored and validated by 15 experts. The experts reported actual and ideal scores for each identified factor; however, this exercise does not provide enough statistical evidence to reduce the number of factors. Next, in stage two, the number of factors was clustered using Agglomerative Clustering text clustering. Thirteen clusters were reported: Strategic Integration, Develop Long- term business opportunity, Political acceptance, Social benefits, Ease of operation, Productivity, Project Location, Ability to implement, Customer point of view Ease of use, Safety and Security, Operation Management, Operating cost, Investment Capital. In stage 3, participants selected only 12 factors that suit transportation and real estate industries. In the last stage, the framework usability was evaluated, which shows a usability score of 68.3(“C)”). The framework was also evaluated by comparing its output with existing ranks from experts.

The case studies of real estate and transportation were used to rank strategic projects using the developed framework. First, factors were specialized for each of these industries, which resulted in 10 factors for transportation and 12 for real estate sectors. Next, the factors were weighted based on raw data using the CRITIC method. Then, projects were ranked within each industry. Finally, the new method of cross-industry ranking was used to rank projects across different industries. The results were validated with experts’ ranks.

CHAPTER 5: CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

The thesis proposed a comprehensive and generic framework that can be used for selecting and ranking a number of strategic projects for implementation. The framework is considered strategic as they are usually larger in scale and has long-term impacts. Therefore, understanding different factors, the weighting of factors and using them on projects for their ranking (for a type of projects, for example, roads), and cross-industry ranking (for example, roads type and information technology type). Therefore, the contribution of the thesis is on the development of a framework and the tools that can be used for selection for projects through ranking not only in one industry but across the set of projects usually executed in the public and large private organizations. Three research questions were developed to guide the development of the framework, and the answers to these questions are discussed below.

The thesis proposes Agglomerative text clustering to reduce the number of factors to be considered for decision making. Based on the review and clustering, 13 factors were useful for the strategic projects. These factors are tested on two different types of projects, transportation, and real estate. Only 10 factors were found applicable in the transportation sector, whereas in real estate, only 12 were found applicable. The chosen factors for transportation sector are strategic integration, development of long-term business opportunities, political acceptance, social benefits, ease of operation, ability to implement, customer point of view, ease of use, operation management, operating cost, and investment capital. Two additional factors, productivity and project location, are considered applicable for real estate. The productivity is relevant to real estate as it is computed by dividing average output (e.g., buildings) per period by the total costs incurred or resources. It was found that the location of the real estate facility and the capital investments are pivotal contributors to the real estate industry.

The factors were weighted using the CRITIC method based on two project case studies. Second, the TOPSIS method was used to rank strategic projects for an industry group. Finally, a new approach was used to compare cross-industries. Experts evaluated the results subjectively and listed only a few influential factors based on semantic similarity between factors. The clustering reported high cohesion and separation between clusters, yielding a set of criteria that are deemed applicable for projects at early stages in project development. The proposed model's usefulness is that the list of factors should be minimized in strategic projects without project data's preexistence. The list of projects generated by the model is highly correlated with the results reported by decision-makers (with 95% confidence). The proposed framework results compared to the ranks assigned by experts showed that the framework is promising and can be used to rank projects regardless of their industry.

Conclusions on RQ1

A list of factors was generated from the literature review and then corroborated with the experts involved in strategic project selection. The list comprises of 118 factors, which had to be reduced further by using synergies (or avoiding duplications in their meaning). It is identified that the perspectives of risk, quality, stability, sustainability, governance, resources, organizational strategy, value, and stakeholder management are essential in project selection. It is also found that organization and economic factors are the most influencing factors in the project selection of quantitative approaches.

Conclusion on RQ2

The list of factors was reduced based on text clustering from machine learning side by side with expert judgments. Agglomerative clustering provided high separation between clusters and low cohesion between internal factors in the same cluster. The clustering method resulted in 13 factors, which were found applicable by the experts.

The criteria were automatically weighted by the CRITIC method. The CRITIC method considered the correlation between factors and the quality of information. Therefore, weighting factors increase the probability of a high weighted factor to change the final project's rank order.

Conclusions on RQ3

For developing the framework, the current models were studied, and the decision-makers' requirements were elicited from the experts. A framework with analytical guidelines was developed for reducing factors, developing factor weights and analyzing them for application for a particular type of projects, and using the multicriteria decision method for ranking of the projects for a type of projects (one industry) or multiple types of projects (across-industry). The results of the ranking obtained for projects in transportation and real estate from the proposed framework were compared with the ranks assigned by experts for the same projects. The rankings were similar, validating the outcomes and the selection process considered analytical framework to mimic decision-making process, in the given set of constraints, which verifies that the framework can replicate the decision-making process. The system usability through system usability score (SUS) was developed to verify that the process is usable in the real world application.

5.1 Implications to Theory and Practice

The research provides implications to theory and practice. First, it is one of the first studies that aimed to rank projects across industries. Second, the proposed framework reduces the number of factors based on clustering algorithms from machine learning without losing the context of the factors. Finally, unlike methods that conceal the semantics of factors (e.g., principal component analysis), the new approach keeps each factor's semantics, leaving the chance for decision-makers to review and provide feedback. Finally, as experts have also mentioned, the proposed framework saves time and provides more freedom for experts to review and update project weights when needed.

5.2 Implementation Recommendation

The proposed framework can be implemented with the applicable factors for each type of strategic project. The decision-makers can use MS Excel tools to analyze the data.

- The method can be used when there are reasonable criteria (factors) for selecting competing projects in an organization.
- The method is suitable for the decision-maker who can interact with the framework to obtain project decisions in each analysis cycle based on the decision-making constraints prevalent in the organization.
- The method requires the analyst's competence to reduce the number of factors, cluster them, analyze them with weights, and multi-criteria decision-making method. Therefore, the framework contains analytical methods which are shown as applicable in a multi-project situation. Therefore, these methods can be automated to provide decision support for strategic project selection.

5.3 Limitations

One possible limitation could be the sample size of decision-makers employed to rank projects. Although the number is consistent with the literature, more experts could be used in the analysis. The data used in the study is based on non-confidential data made available to the researcher. Therefore, the result should be judged based on the parameters used in the analysis.

5.4 Contribution

The following are the contributions of this research:

The thesis contributes by proposing a generic conceptual framework that an organization can use to select different types of projects. The framework also provides the applicable methodologies for developing a rank for the projects and comparing those across different types of projects (e.g., projects across application areas like information technology projects or healthcare projects). The framework extends current frameworks such as the Archer framework (Archer and Ghasemzadeh, 2007; Ghasemzadeh and Archer, 2000). The framework is interactive and can be implemented through an available software and database for interaction with the decision-makers.

5.5 Future Work

The research can be extended in the following direction.

1. In the thesis, the TOPSIS and CRITIC methods are analyzed independently. For the best value of the decision-making framework, they can be integrated. Such an integration for supply chain risk management is also mentioned in Abdel-Basset & Mohamed (2020). However, such integration also requires a strong database and developing dynamic decision-making.
2. It was assumed that the projects were new in the projects basket without considering whether the project was rejected before or not. History information includes project failures at the operational or tactical levels, contractual issues, unexpected ambitious decisions, and many others. While project criteria such as economic vitality, project risks, and complexity provide a solution to the problem, no specific criteria are specified for previously unattended or held projects in the literature. The strategic manager's propensity to select more or less risky projects might be affected by tactical and operational history information (Drake and Kohlmeyer III, 2010).

Therefore, alongside the strategic level, the factors chosen for strategic projects could be fine-grained at the tactical and operational levels. A starting point could be the work of (Liu *et al.*, 2021), which builds a risk-based decision model based on R-numbers to address the risk factors and a pairwise comparison method over R&D projects.

3. The dynamics of the similar previous project in terms of time, technology development, and technology adoption may impact the selection process. As the current model is static, the model can be extended to use the dynamic parameters and periodic decision-making by considering the changes that impact the implementation aspects of the projects.

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APPENDICES

Appendix A- List of factors extracted from literature

Ref.	Method	Area/case study	Indust.	Criteria		
Amer & Daim (2011)	multi-criteria decision-making framework using interval type-2 fuzzy weighted averaging operator	Distributed energy generation	Renewable Energy	Environment	Social	Technical
				Economic value	Political	
Bhattacharyya *et al.* (2011)	Multi-objective genetic algorithm (MOGA)	Civil, mechanical, and electrical fields	General	Outcome	Risk and sharing cost interdependencies	Technical and resource (fund and HR) interdependences
Broniewicz and Ogrodnik (2020)	PROMETHEE,FAHP, TOPSIS	expressway section in north-eastern Poland	Rail Transportation	Conformity		
Can and Delice (2018)	A fuzzy integrated MCDM	Shopping mall selection considering universal design criteria	Construction	Ability to implement	Product range growth potential	Ability to meet likely future regulations
Chatzimouratidis & Pilavachi (2009)	hierarchy tree for optimization of technology/sustainability and economic criteria	Ten types of power plants	Power Plant	Technology and sustainability:	Economic:	
				Availability	Capital cost	
				Capacity	Operation and management cost	
				Efficiency	Fuel cost	
				Reverse or production ratio	External cost	
Cheng *et al.* (2017)	ANP method	Projects include building,	General	Managerial	Budget control	Resource requirements
				Financial	Risk/return ration	Project duration

Ref.	Method	Area/case study	Indust.	Criteria		
		infrastructure, and industrial projects		Technological	Technical know-how	Company objective and policy
				Legal	Technological implications	Project-identification ability
				Environmental categories that include staffing	Governmental regulations and standards	Managerial competence
				Public relations	Terms of contract	Conflict resolution
				Environmental protection	Legal implications	Profitability
				Geographic location	Health and safety	
Constantino *et al.* (2015)	ANN	Applied in engineering procurement and engineering.	General	Project mission	Technical task	Client consultation
				Top management support	Client acceptance	Personnel
				Project schedule/plan	Monitoring and feedback	Communication
						Troubleshooting
da Silva Neves and Camanho (2015)	AHP	Selection of IT projects in Oil and Gas	Oil & Gas	Growth productivity	Innovation	Continuity
Dell'Ovo *et al.* (2018)	Weighted Linear Combination	The proposed methodology has been applied to the location of a new hospital in the city of Milan (North of Italy)	Healthcare	Prerequisites	Location quality	
				Functional quality	Environment quality	

Ref.	Method	Area/case study	Indust.	Criteria		
Deng *et al.* (2014)	AHP methodology extended by D numbers. Solve supplier selection problem	Supplier selection	General	Cost	Supplier profile (e.g., size of subsidiary firms)	Service performance
				Quality	Risk profile	
Dey (2006)	AHP	Cross country petroleum pipelines	Pipeline Construction	Technical analysis:	Environmental impact assessment:	Socio-economic assessment:
				Length	Effect during failure in pipelines	Effect during planning
				Operability	Effect during failure in stations	Effect during construction
				Maintainability	Effect during normal operations of pipelines	Effect during operations
				Approachability	Effect during normal operations of stations	
				Constructability	Effect during construction	
Dutra *et al.* (2014)	Global economic index using Monte-Carlo simulation	Comprising a portfolio of investment projects at a power distribution company	Power Distribution	Investment criteria:	Project description:	Market potential
				Investment in technology	Scope	Competitiveness improvement
				Investment in suppliers	Time involved	Attention to regulatory aspects
				Investment in logistics and distribution	Ease of execution	
				Investment in marketing	Ease of maintenance	
				Benefits:	Relationship with other projects	

Ref.	Method	Area/case study	Indust.	Criteria		
				Increase in revenues	Uncertainties involved	
				Environmental benefit	Project implementation urgency	
				Social benefit	Degree of innovation	
				Intangible benefit	Patentability	
				Extended benefits in other projects	Potential for replication or expansion	
Garcez *et al.* (2014)	Multidimensional Risk Assessment	Hypothetical study to assessing and ranking the risks from underground vaults	Rail Transportation	Location of manhole cover	The radius of the hazard zone	Consequence
Ghaleb and Kaid (2019)	MCDM (AHP,TOPSIS,VIKOR)	Selection of Manufacturing Processes	Engineering	Productivity accuracy	Material utilization	Flexibility
				Complexity	Quality operation	
Ghorabaee *et al.* (2015)	complex proportional assessment (COPRAS) method with interval type-2 fuzzy sets	Supplier selection	General	Responsiveness	Delivery reliability	Defect rate
				Cost	Flexibility	
Ginevičius & Zubrecovas (2009)	ELECTRE III	Real estate projects' efficiency evaluation	Real Estate	Financial:	Liquidation value	Number of inhabitants living in 1 km radius
				Refunding time of debt	Internal rate of return (IRR)	Price of the land plot
				Credit demand	Net present value(NPV)	Public transport flows

Ref.	Method	Area/case study	Indust.	Criteria		
				Investor's participation rate in general investment	Payback period of investments	Visibility from the main streets
				Need of own financial resources	Profitability index	Infrastructure of communications
				Net income	Project environment:	Expected environmental changes in the future
				Expenditure on project's maintenance and management	Criminology	Funds exchange market index
				Net cash flow	Legal environment	Euro Interbank Offered Rate
				Taxes to be paid to the government	Car parking possibilities	Changes in national GDP
				Calculated profit	Existence of equal competitors	Consumption prices index
						Unemployment level
Haddad *et al.* (2017)	AHP	Evaluation of renewable energy sources for the Algerian electricity	Renewable Energy	Technical: solar wind	Reliability	Co2 emissions
				Economical: hydropower	Safety	Social benefits
				Environmental: geothermal	Investment cost	Social acceptability
				Sociopolitical :biomass	Operation and maintenance cost	Political acceptance
				Energy production capacity	Service life	Impact on ecosystem
				Technological maturity	Payback period	

Ref.	Method	Area/case study	Indust.	Criteria		
Hansen *et al.* (2019)	Structured model to integrate decision criteria into a DMF for infrastructure project selection	Not applied	Infrastructure	Strategic fit:	Operating philosophy	Workforce
				Needs & purposes:	Maintenance philosophy	Resource handling & utilization
				Consistency	Future expansion	Scope of work
				Government priority	Innovation	Value engineering:
				Investment studies	Risk	Value engineering procedures
				Economic issues & impacts	Contractual conditions & procurement model	Design simplification
				Social issues & impacts	Project requirements:	Material alternatives
				Environmental issues & impacts	Project objectives statement	Constructability procedures
				Team member & stakeholder	Functional classification & use	Project funding & timing:
				Coordination	Evaluation of compliance	Funding & programming
				Public involvement	Existing environmental conditions	Preliminary project schedule
				Good governance	Site characteristics	Contingencies
				Owner philosophies:	Dismantling & demolition	

Ref.	Method	Area/case study	Indust.	Criteria		
Iftekhar and Tisdell (2014)	A mathematical model to maximize profit aggregate offer	Securing contracts for environmental services for two regions	Wildlife corridor auctions	Design philosophy	Determination of utility impacts	
				Project agreement	Benefit-cost	Corridor benefit
				corridor aggregate	Ratio (Benefit-cost ratio)	Net benefit
				Aggregate cost	Expected profit	Maximizing bid
Jain et *al.* (2020)	Fuzzy AHP and Fuzzy TOPSIS	Selection of a green marketing strategy for a manufacturing firm	Manufacturing	Greenmarket size	Availability of resources	Price parity
				Potential revenue	Top management commitment	Competitors' green performance
				Government incentives		
JakielaDariusz and Fabianowskib (2015)	Fuzzy AHP	Assessment of highway RC bridge structural and technological arrangements	Construction	Bridge structure geometry adjustable (flexible modeling) to locality conditions	safety and sustainability of a structure	structure design technologic ability
				mitigation of impact upon the natural environment	economic criterion	
Janic (2003)	TOPSIS	evaluation of High-Speed Rail, Transrapid Maglev and Air Passenger Transport in Europe	Rail Transportation	Distance to the high-speed terminal (km)	social welfare	operating revenues
				generalized travel cost	specific energy consumption (wh/seat-km)	technical productivity (seat-km/h)
				in-vehicle comfort and convenience	safety (deaths per 100 million p-km)	investments
				operating costs	air pollution	socio-economic rate of return (%)
				congestion (the average delay)	noise (db(a))	land-use (ha/km)

Ref.	Method	Area/case study	Indust.	Criteria		
Jeng and Huang (2015)	DEMATEL-ANP	Renewable energy resources selection	R&D	Technical aspects:	Operation and maintenance cost	Political aspects:
				Efficiency	R&D cost	Foreign dependency
				Reliability	Return on investment	Compatibility with political legislative situation
				Resource availability	Production cost	Compatibility with national energy policy objectives
				Capacity of investment	Environmental aspects:	Public policy and financial support .social aspects:
				Technology maturity	Greenhouse emission	Social benefits
				Technological innovation .economic aspects:	Land use/requirement	Social acceptability
				Investment cost	Impact on ecosystem	Job creation
Kahraman and Büyüközkan (2008)	Fuzzy TOPSIS	IS Project Sustainability Evaluation	IT	Economic sustainability:	Social sustainability:	Environmental:
				Direct financial benefits	Labor practices in the workplace	Procurement
				The indirect financial benefit	Human rights	Energy
					Public acceptability	Waster

Ref.	Method	Area/case study	Indust.	Criteria		
					Organization's reputation	
Kahraman *et al.* (2010)	Fuzzy multicriteria decision- making methodologies	Selection among renewable energy alternatives	Renewable Energy	Technological criteria:	Social and economic criteria:	Cost of saved primary energy and environmental criteria:
				Targets of primary energy saving on a regional scale	Labor impact	Sustainability according to other pollutant emissions
				Technical maturity	Market maturity	Sustainability according to other environmental impacts
				Reliability consistency of installation and maintenance	Compatibility with political	Land requirement sustainability according to greenhouse
				Requirements with local technical know-how	Legislative and administrative situation	Pollutant emissions
				Continuity and predictability of performances		
Karasakal & Aker (2016)	Data envelopment analysis	Evaluate 60 R&D projects	R&D	R&D content, technological level & innovational aspects:	Applicability of the project outcomes:	Project plan capabilities & company's infrastructure:
				Technology used in the project	Profitability to the company	Quality of the project plan

Ref.	Method	Area/case study	Indust.	Criteria		
				Novelty of the project output	Socio-economic & socio-cultural achievements	R&D infrastructure and culture of the company
				Methodology of the project	Contribution to the state of knowledge	
Kaul *et al.*(2020)	FAHP and FTOPSIS	Selection of facility location	Manufacturing	Health and safety	Job security	Geography and climate
				Community life	Infrastructure and transport	Gender equality
Khalili-Damghania & Sadi-Nezhad (2013)	Fuzzy TOPSIS	Sustainable project selection of an Iranian financial and credit institute	Financial	Economic effect	Risk of investment	Environmental effect
				Social effect	Strategic alliance	Organizational readiness
Konyalıoğlu *et al.*(2020)	A Fuzzy MCDM Approach	Project Prioritization in a Big-Four Company	Consultancy Sector	Financial:	Risks:	
				NPV	Financial risks	
				IRR	Technical risks	
				Cost/benefit ratio	Social:	
				Technical:	Reputation of the company	
				Availability of technology	Workers motivation	
				Infrastructure of company		
Kundu *et al.* (2017)	Fuzzy multicriteria group decision-making (FMCGDM)	Transportation mode selection problem to find the preferable	Transportation	Cost	Flexibility	Product characteristics
				Speed/time	Safety factor	

Ref.	Method	Area/case study	Indust.	Criteria		
		mode among available modes				
Lee *et al*. (2009)	AHP	Selection of wind farms projects	Wind Farms	Benefits:	Cost:	Support:
				Wind availability	Wind turbine	Financial schemes
				Site advantage	Connection	Policy support
				Wind gusting functions	Foundation	Advanced technologies
				Risks:		
				Concept conflict		
				Technical risks		
				Uncertainty of land		
Lee *et al*. (2017)	AHP	R&D project selection	R&D	Technology fit:	Business fit:	Market attractiveness:
				R&D capabilities	Suitability for new products	Customer-perceived functional value
				Manufacturing capabilities	Suitability for R&D investment	Customer-perceived economic value
				Technology attractiveness:		
				Technology innovativeness		
				Technology appropriateness		
Liu *et al*. (2015)	Integrating the 2-tuple DEMATEL technique	Evaluating health-care waste	Healthcare	Economic: net cost per ton	Noise	Technical:

Ref.	Method	Area/case study	Indust.	Criteria		
	and fuzzy MULTIMOORA	treatment alternatives		Environmental:	Release with health effects	Reliability
				Waste residuals	Social: public acceptance	Treatment effectiveness
						Occupational hazards
Lizarralde *et al.* (2020)	Decision tree and MIVES method	Selection process of new technologies at a Spanish R&D Center specialized in manufacturing	R&D	Technology:	R&D center: internal factors R&D center	
				Maturity	Customers: internal factors customers	
				Relevance		
				Market		
Mahmoudi *et al.* (2020)	Fuzzy TOPSIS (TOPSIS-F) and Ordinal Priority Approach	Evaluation of the trust in cloud service provider selection and factoring company which is producing refinery equipment	IT & Manufacturing	Evaluation for a cloud service provider:	Sequential read/write disk performance	Evaluation for cost on demand. for manufacturing:
				Project Duration	Random read/write disk performance	Time
				Number of Item in each Project	Sequential disk read/write consistency	Number of items in each project
				Memory performance on a scale	Random read/write consistency	Score of the client
				Memory performance on traid	Network latency	Physical weight
						Design status
						Level of difficulty
			Infrastructure	Cultural & economy	Society	Globalization

Ref.	Method	Area/case study	Indust.	Criteria		
Marcelo *et al.* (2016)	The Infrastructure Prioritization Framework	Investment decision process		Environment	Innovation and	Technology environmental risks
Nikloaos *et al.* (2006)	Fuzzy linguistic terms	Establishing a Computer Infrastructure for the Local-Area Hospital of Chios Island	IT	Innovativeness	Cost efficiency	User-friendliness
				Flexibility human interference	Feedback	Structural compatibility
				Environmental character		
Pourjavad and Mayorga (2018)	A fuzzy MCDM	Measure project complexity	Engineering	Project size	Project interdependency	Project context-dependence
				Project variety		
Quadros & Nasri (2015)	AHP	Prioritize transportation infrastructure investments in Brazil	Infrastructure	Logistics/transportation:	Social: reduction of regional inequalities	Environmental:
				Expansion of the modal integration	Economic/financial:	Reduction of environmental interfaces
				Expansion of the regional transports offer	Reduction of transportation costs	Reduction of the emission of air pollutants
					Internal rate of economic return	
Read *et al.* (2017)	Stakeholder-driven multi-attribute analysis (stochastic decision analysis framework)	Fairbanks, Alaska energy supply alternative assessment	Energy	Economic:	Socio-political:	Environment:
				Project levelized costs	Political support by state of legislator	Net carbon footprint
				Capital costs	Sponsor credibility	Air quality

Ref.	Method	Area/case study	Indust.	Criteria		
					Local	Ecological/land footprint
					Timing	Water footprint
					Social acceptability	
Salling & Pryn (2015)	Sustainable planning and decision support framework	Evaluation of the current bridge crossing Roskilde Fjord in the city of Frederikssund	Transportation	Economic:	Environmental:	Social:
				Affordability	Climate and global warming	Accessibility to employment
				Movement of goods	Biodiversity	Accessibility to public services
				Efficiency	Consumption of resources	Free movement
				Resulting employment	Existing assets and recycling	Mobility costs
				Social costs	Space consumption	Aesthetics and culture
					Air pollution	Territorial cohesion
					Noise	Safety
					Water quality	
					Natural and technological risks	
Sedady and Ali Beheshtinia (2019)	TOPKOR MCDM	Prioritizing the renewable power plants in Iran	Renewable Energy	Technical:	Political:	Social:
				Energy efficiency	Government regulation	Safety
				Reliability	Government support	Job creation
				Development capabilities	Social acceptance	Social acceptability

Ref.	Method	Area/case study	Indust.	Criteria		
				Ease of access to the technology	Dependence on foreign technologies	Geographical acceptability
				Setup and implementation times	Compatibility with national energy policy objectives	Local development and social advantages
				Economic:	Environmental:	
				Investment costs	Influence on environment	
				Maintenance costs	Land usage	
				Service life	Visual effect	
				Operational costs	Noise pollution	
				Payback period	Emissions	
Shaygan and Testik (2017)	FAHP with cause and effect method	Prioritization of flawed performing appointment of a system at a hospital	General	Capacity related	Staff related	Hardware and software (equipment) related
				System and connection related	Breaking an appointment related	
Siksnelyte-Butkiene *et al.* (2020)	Review of MCDM	Evaluate renewable energy technologies in households	Renewable Energy	Economic	Energetic	Environmental
				Social	Usability	Institutional
				Technological	Comfort	Thermodynamic
				Cost	Functionality	Acidification
				Benefit		
			Defense	Strategic	Analysis	

Ref.	Method	Area/case study	Indust.	Criteria		
Simplício *et al.* (2017)	risk and portfolio analysis methodologies	Portugal's National Defense projects prioritization		Operational	Portfolio project management	
Smith-Pereraa *et al.* (2010)	ANP method	Portfolio selection in the company EDC (Venezuela) .	Renewable Energy	Service continuity	Execution feasibility	Costs
				Service quality	Customers' satisfaction	Response time
				Investment	Staff satisfaction	Network flexibility
Solangi *et al.* (2018)	Factor Analysis, AHP, and Fuzzy-TOPSIS	Wind project site selection	Wind energy	Economic:	Political:	Technical:
				Development cost	Government policies	Wind data availability
				On-grid accessibility	Land acquisition	Climate conditions
				Road availability	Relocation and rehabilitation	Skilled human resources availability
				Environmental:	Social:	
				Public health and community impact	Effect on economic development of nearby areas	
				Wildlife and habitat impact	Distance from residential areas	
				Area of flatland and without forest cover	Effect on employment and agriculture	
					Social acceptance	

Ref.	Method	Area/case study	Indust.	Criteria		
Stojčić *et al.* (2019)	Review of MCDM	Sustainable engineering projects selection	construction and infrastructure, supply chains, transport and logistics, energy, and other	Adoption of sustainable material & renewable resource		
Tavana *et al.* (2015)	A fuzzy hybrid project portfolio selection method using Data Envelopment Analysis, TOPSIS and Integer Programming	30 projects from the literature in sustainability	Environmental	Opportunity:	Technology:	Finance:
				Environmental friendliness	Technology importance	Cost
				Partnership	Gap concern	Return on investment
				Potential risks:	Impact	Expected monetary
				Resource availability	Intellectual property rights	Employment (expected number of employees to be employed)
				Technical success		
				Budget control		
				Schedule control		
Wang et al .(2018)	Integrating Analytic Hierarchy Process (AHP) and Entropy Weight (EW)	Applied on criteria from literature	Logistics	Quality:	Economy:	Sustainability:
				Damage condition	Cost	Energy consumption
				Remaining service life	Profit	Negative impact
				Risk:		
				Performance degradation		

Ref.	Method	Area/case study	Indust.	Criteria		
				Demand risk		
Wei *et al*. (2005)	AHP	Selecting a suitable ERP system	IT	Implementation time	System reliability	System flexibility
				User-friendly interface	Vendor reputation	Vendor technical capability
				Supplying ongoing service		
Yadollahi & Zin (2011)	Applied Multi-Criteria Ideal Rehabilitation Model	Budget management in the rehabilitation process of road infrastructure	Infrastructure	Safety	Anticipated service life	Architectural aspects
				Functionality	Operational considerations	Economic issues
				Sustainability	Rehabilitation duration	Social issues
				Environmental issues	Constructability	Seismic vulnerability
				Political restrictions	Cost of new construction	Weather conditions
				Historical aspects	Cost of rehabilitation	Hydraulic vulnerability
				Physical condition	Other hazards vulnerability	
Yousefi and Hadi-Vencheh (2016)	DEA, TOPSIS, AHP	20 sigma projects selection	General	Cost	Customer's satisfaction	Duration of executing the project (time)
				Drop-off in costs due to poor quality	Increasing the sigma level (sigma)	Responsibility of top management

Appendix B- First Structured interview with Experts

Q#	Question
Q1	What is your job title?
Q2	How long have you been working in this organization?
Q3	Which type of organization? (owner, contractor, consultant)?
Q4	What’s your job level? (Senior, middle, lower management)?
Q5	Would you please indicate your experience with the project prioritization (public or private or both)?
Q6	Which sector do you have experience in transportation, infrastructure, health, other (please specify)
Q7	How frequently do you be part of a project selection process? (often (yearly), Intermediate (1-3 years), Rarely (3+years))
Q8	Other open questions (any other information which is not mentioned above) -What are the most common issues in the project selection process? -What is your definition of an ideal factor weight? -Is project selection affected by cost more than social aspects? -What is a possible way to reduce the number of collected factors?

Appendix C- Strategic Project Selection Factors (Consolidated)

Criteria	Sample Reference
Ability To Implement	Can and Delice (2018)
Ability To Meet Likely Future Regulations	Can and Delice (2018)
Access To Public Services	Solangi *et al.* (2018)
Accessibility	Salling & Pryn (2015)
Adoption Of Sustainable Material & Renewable Resource	Stojčić *et al.* (2019)
Affordability	Salling & Pryn (2015)
Air Quality	Read *et al.* (2017)
Applicability To Other Products And Processes	Karasakal & Aker (2016)
Approachability	Dey (2006)
Availability	Solangi *et al.* (2018)
Availability Of Advanced Technologies	Lee *et al.* (2009)
Availability Of Funds	Ginevičius & Zubrecovas (2009)
Availability Of Local Materials & Labor	Kahraman and Büyüközkan (2008)
Budget	Cheng *et al.* (2017)
Capability	Wei *et al.* (2005)
Capacity (Technology)	Chatzimouratidis & Pilavachi (2009)
Energy Production Capacity	Haddad *et al.* (2017)
Capacity Of Investment	Jeng and Huang (2015)
Capital Cost	Read *et al.* (2017)
Client Acceptance	Constantino *et al.* (2015)
Climate	Kaul *et al.*(2020)
Compatibility Of The Expenses To The Market	Jeng and Huang (2015)
Compatibility With The National Energy Policy	Jeng and Huang (2015)
Compensation	Ginevičius & Zubrecovas (2009)
Competitive Advantage	Karasakal & Aker (2016)
Conflict Risk	Cheng *et al.* (2017)
Conformity	Broniewicz and Ogrodnik (2020)
Constructability	Hansen *et al.* (2019)
Credit Demand	Ginevičius & Zubrecovas (2009)
Cultural & Environmental Risks	Marcelo *et al.* (2016)
Cultural Impact	Marcelo *et al.* (2016)
Customer Satisfaction	Smith-Pereraa *et al.* (2010)
Degree Of Completion	Simplício *et al.* (2017)
Develop Long-Term Business Opportunity (Business Fit)	Lee *et al.* (2017)
Differentiation	Jeng and Huang (2015)
Ease Of Operation	Sedady and Ali Beheshtinia (2019)
Ease Of Use	Nikloaos *et al.* (2006)
Economic Effect	Khalili-Damghania & Sadi-Nezhad (2013)
Economic Value	Amer & Daim (2011)
Economic Vitality	Kahraman and Büyüközkan (2008)
Effect On Existing Market Outlook	Lizarralde *et al.*(2020)

Effect On Existing Market Share	Lizarralde *et al.*(2020)
Employment	Solangi *et al.* (2018)
Energy Consumption	Ginevičius & Zubrecovas (2009)
Environmental Cost	Jeng and Huang (2015)
Environmental Safety	Kundu *et al.* (2017)
Experience	Wei *et al.* (2005)
Facility	Kaul *et al.*(2020)
Feasibility	Smith-Pereraa *et al.* (2010)
Flexibility	Nikloaos *et al.* (2006)
Functionality	Siksnelyte-Butkiene *et al.* (2020)
Growth Productivity	da Silva Neves and Camanho (2015)
Impact On Society	Khalili-Damghania & Sadi-Nezhad (2013)
Implementation Cost	Dutra *et al.* (2014)
Incremental Innovation	Hansen *et al.* (2019)
Infrastructure Availability	Konyalıoğlu *et al.*(2020)
Intangible Benefits	Dutra *et al.* (2014)
Integration	Quadros & Nasri (2015)
Interdependency	Pourjavad and Mayorga (2018)
Investment Capital	Chatzimouratidis & Pilavachi (2009)
IRR	Ginevičius & Zubrecovas (2009)
Job Creation	Jeng and Huang (2015)
Legal Environment	Ginevičius & Zubrecovas (2009)
Level Of Political Ambition	Sedady and Ali Beheshtinia (2019)
Maintainability	Dey (2006)
Maintenance Cost	Haddad *et al.* (2017)
Market Size	Jain et al. (2020)
Net Cash Flow	Ginevičius & Zubrecovas (2009)
Net Income	Ginevičius & Zubrecovas (2009)
Net Present Value (NPV)	Konyalıoğlu *et al.*(2020)
Operability	Dey (2006)
Operating Cost	Janic (2003)
Operation Management	Dey (2006)
Operational Considerations	Lee *et al.* (2009)
Opportunity	Tavana *et al.* (2015)
Organization Readiness	Khalili-Damghania & Sadi-Nezhad (2013)
Organizational Risk	Cheng *et al.* (2017)
Payback Period	Ginevičius & Zubrecovas (2009)
Political Acceptance	Jeng and Huang (2015)
Political Priority	Hansen *et al.* (2019)
Political Support	Read *et al.* (2017)
Product Range Growth Potential	da Silva Neves and Camanho (2015)
Productivity	Ghaleb and Kaid (2019)
Project Agreement	Iftekhar and Tisdell (2014)
Project Complexity	Pourjavad and Mayorga (2018)
Project Location	Solangi *et al.* (2018)
Functional Quality	Deng *et al.* (2014)

Environment Quality	Ghaleb and Kaid (2019)
Recoverability	Wei *et al.* (2005)
Reduction in Environmental Interfaces	Quadros & Nasri (2015)
Reliability	Kahraman *et al.* (2010)
Risk Of Investment	Bhattacharyya *et al.* (2011)
Risk Probability	Garcez *et al.* (2014)
ROI	Ginevičius & Zubrecovas (2009)
Safety	Sedady and Ali Beheshtinia (2019)
Safety & Security	Haddad *et al.* (2017)
Security	Kaul *et al.*(2020)
Size Of Subsidiary Firms	Dutra *et al.* (2014)
Social Acceptability	Sedady and Ali Beheshtinia (2019)
Social Welfare	Janic (2003)
Sponsor Credibility	Read *et al.* (2017)
Stability	Wei *et al.* (2005)
Stakeholder Commitment	Read *et al.* (2017)
Strategic Agile Implementation	Wei *et al.* (2005)
Strategic Alliance	Khalili-Damghania & Sadi-Nezhad (2013)
Strategic Match	Hansen *et al.* (2019)
Supplier	Dutra *et al.* (2014)
Technical Feasibility	Smith-Pereraa *et al.* (2010)
Technology Efficiency	Chatzimouratidis & Pilavachi (2009)
Technology Maturity	Haddad *et al.* (2017)
Time	Dutra *et al.* (2014)
Topography	Karasakal & Aker (2016)
Trends	Jain *et al.* (2020)
Upgrade Ability	Wei *et al.* (2005)
Vendor Reputation	Kahraman and Büyüközkan (2008)

Appendix D- Project Selection Factors (Using Agglomerative Clustering)

Cluster Name	Develop Long-term business opportunity (15)		
Actual Average	**2.52**		
Ideal Average	**3.54**		
List of factors			
Economic Value	Develop Long-term business opportunity	Effect on existing market outlook	Market Trends
Effect on existing market share	Product range growth potential	Vendor reputation	Supplier Capabilities
Competitive advantage	Product or service Differentiation	Intangible Benefits	Size of subsidiary firms
Market size	in-house development	Cost Benefit Analysis	
Cluster Name	**Project Location (10)**		
Actual Average	**2.34**		
Ideal Average	**3.26**		
List of factors			
Economic Effect	Climate	Availability of Local materials & labor	Impact on society
Long run cultural impact	Project Location	Topography	Environmental Flexibility
Compensation	Pollution		
Cluster Name	**Investment Capital (9)**		
Actual Average	**3.47**		
Ideal Average	**3.45**		
List of factors			
Net cash flow	Net Present Value (NPV)	Return on Investment (ROI)	Internal rate of return (IRR)
Net Income	Payback Period	Investment Capital	Capital Cost
Credit Demand			
Cluster Name	**Productivity (13)**		
Actual Average	**2.36**		
Ideal Average	**3.46**		
List of factors			
Growth Productivity	Energy consumption	Adoption of Sustainable Material & renewable resource	Technical feasibility
Productivity	Job creation	Incremental innovation	Technology maturity
Technology efficiency	Upgradeability	Employment	Reduction in environmental interfaces
Growth Productivity			
Cluster Name	**Ease of operation (9)**		
Actual Average	**2.35**		
Ideal Average	**3.65**		
List of factors			
Infrastructure availability	Ease of operation	Operability	Maintainability

Availability	Recoverability (Resilience)	Availability of Advanced technologies	Reliability
Availability of Funds			

Cluster Name	**Operation Management (7)**		
Actual Average	**2.62**		
Ideal Average	**4.01**		
	List of factors		
Organization Capability	Operation Management	Organization Readiness	Organizational Experience
capacity (technology, strategic)	energy production capacity	Organization Capacity	

Cluster Name	**Ability to implement (17)**		
Actual Average	**2.79**		
Ideal Average	**3.55**		
	List of factors		
Ability to implement	Constructability	Operational considerations	Project Stability
Risk Interdependencies	Affordability	Strategic match	Functionality
Strategic agile implementation	Stakeholder commitment	Project Agreement	Project Complexity
Approachability	Project Budget	Implementation Cost	Project Time
functional quality			
Cluster Name	**Political acceptance (5)**		
Actual Average	**3.33**		
Ideal Average	**3.40**		
	List of factors		
Political acceptance	Political support	Political priority	Level of political ambition
Compatibility with the national energy policy			
Cluster Name	**Safety & security (12)**		
Actual Average	**2.79**		
Ideal Average	**3.58**		
	List of factors		
Legal environment	Organizational Risk	Risk of investment	Opportunity Risk
Risk Probability	Cultural & environmental risks	Global Conflict Risk	Safety & security
Safety	Security	Environmental Safety	Ability to meet likely future regulations
Cluster Name	**Economic Vitality (Customer point of view Ease of use) (10)**		
Actual Average	**2.43**		
Ideal Average	**3.29**		
	List of factors		
Economic Vitality	Conformity with standards	Ease of use	Quality of life
Degree of completion	Sponsor Credibility	Quality Requirements	Customer satisfaction

Client acceptance	Staff satisfaction		
Cluster Name	**Social benefits (4)**		
Actual Average	**2.53**		
Ideal Average	**3.48**		
	List of factors		
Social benefits	Social welfare	Access to public services	Accessibility
Cluster Name	**Strategic Integration (3)**		
Actual Average	**2.49**		
Ideal Average	**3.82**		
List of factors			
Strategic Integration	Strategic Alliance	Applicability to other products and processes (Strategic Integration)	
Cluster Name	**Operating cost (4)**		
Actual Average	**2.10**		
Ideal Average	**3.62**		
	List of factors		
Compatibility of the Expenses to the Market	Operating cost	Maintenance Cost	Environmental Cost

Appendix E- SUS Questionnaire

The System Usability Scale (SUS) as initially proposed by Brooke (1996). When a SUS is used for receiving the information on the proposed framework and models. The ten criteria used for receiving their inputs are given below. The system used 5-Likert type scale for their perception as shown in Table E.1.

Table E.1: Addapted SUS questionnaire from Brooke (1996).

	Strong agreement	Somewhat agree	Neutral	Somewhat disagree	Strong disagreement
1. Possibility of me using of the proposed system frequently					
2. The proposed methods are not complex for me to understand and use					
3. Using of the system is easy					
4. The models are reasonably technical but they do not require extra technical personnel for use					
5. The system provides integrated view of the functions for decision making					
6. The system seems to have very little inconsistencies					
7. The system is easy to learn and adapt					
8. The system is straight forward to use.					
9. The system can be used with confidence					
10. The process and guidelines are reasonably clear for understanding the system.					