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Selection of Projects for Project Portfolio Using Fuzzy TOPSIS and Machine Learning

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ABSTRACT:

Project portfolio management (PPM) is extremely important nowadays due to the increasing severe competitions, accelerated product developments, project complexity, uncertainty, and challenges from global competitors. Therefore, businesses involved in many (dozens or even hundreds) projects need to formulate tactics and strategies to secure firms' competencies and, most importantly, increase their productivities. Under this globalization context, PPM is to optimize the value provided to the customers while minimizing risks and the resources committed to the projects, while critical success factors (CSFs) is applied to anticipate the project's risk and financial value by early assessment thus to help from the organizational level to predict the performance. Despite its importance, the literature on PPM and CSFs at a project level is rather limited, which demands a more profound knowledge about the assessment, ranking, and prioritization of projects in the early stage. This study seeks to address the following two research questions: Do CSFs vary according to the project category, and how a supportive method can be established to help portfolio managers to select the project for portfolio. As a result, this research focuses on the multi-project context in order to fill the above-mentioned research gaps. As the contributions of this study, this study intends to (1) verify the hypothesis that different project category has different CSFs, and (2) contribute to explore how machine learning technology can be utilized for project selection.

KEYWORDS: Project Portfolio Management, Project Selection, Project Category, Critical Success Factors, Fuzzy TOPSIS, Machine Learning Methods

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Abbreviations

CSFs – critical success factors

FNIS – fuzzy negative ideal solution

FPIS – fuzzy positive ideal solution

KNN – K-nearest neighbor

MCDM – multi-criteria decision-making

NIS – negative ideal solution

PIS – positive ideal solution

PPM – project portfolio management

PM- project management

RQs – research questions

TOPSIS – the technique for order of preference by similarity to ideal solution

1 Introduction

1.1 Background

Companies are now facing severe competition because of the accelerated product developments, project complexity, uncertainty, and challenges from global competitors. This is especially true for businesses involved in many (dozens or even hundreds) projects at a certain given time, where each project pursues the same strategic goal while competes for the same resources (Martinsuo 2013). Therefore, appropriate tactics and strategies must be formulated and adopted to secure firms' competencies and, most importantly, increase their productivities. To achieve this goal, many companies have advocated for project portfolio management (PPM), incorporating program management and project management (PM), to optimize the value provided to the customers while minimizing risks and the resources committed to the projects (Müller et al. 2008). As a result, PPM is of growing importance and a key competence worldwide to organize multiple works and necessitates successful PM (Jonas 2010; Martinsuo and Lehtonen 2007). For instance, a PPM benchmarking report conducted by Axelos (2019) indicated that 8 out of 10 project managers thought PPM was a crucial process determining business success.

Archer and Ghasemzadeh (1999) described the project portfolio as a set of projects with similar property and should be executed together under the same sponsorship and management to maximize the benefit. In contrast to PM (focusing on a specific project) and program management (focusing on management of a collection of projects linked by common capital, goals, or clients), PPM focuses on the whole project portfolio while making choices on which projects to prioritize, apply to, or exclude from the portfolio (Teller et al. 2012). PPM is, therefore, primarily concerned with "doing the right projects" (De Reyck et al. 2005, p.524). According to Müller et al. (2008, p.28), PPM is a "dynamic decision process where a list of active projects is constantly updated and revised."

PPM as a discipline has been explored from different perspectives, contributing to different research streams (Adams-Bigelow 2006; PMI, 2006). For instance, some investigate the interface between PPM and IT technologies (e.g., De Reyck et al. 2005), while some explore the PPM for product innovation (e.g., Hunt et al. 2008). Apart from that, a bulk of PPM research focuses on project assessment and decision makings (e.g., Ibbs and Kwak 2000), where PPM frameworks and techniques were developed for assessing, selecting, and allocate projects, as well as information sharing between projects (e.g., Martinsuo and Lehtonen 2007; Müller et al. 2008). The research on critical success factors (CSFs) in PPM has increased in recent years, reflecting the increasing significance of project selection success and performance outcomes. That is, anticipating project's risks and financial value by early assessment requires help from the organizational level to predict the performance (Thomas and Mullaly 2007).

The process of project selection and assessment should always evaluate features of project, CSFs, and some performance indicators. The dependent metrics on which we can assess a project's successful performance are known as project success criteria. Project success criteria differ from one to another. According to Wateridge (1998), when selecting a PM approach, the project sponsor or managers should first define the applicable success criteria, then assess relevant success factors to improve the likelihood of meeting those success criteria, and finally choose a PM methodology that achieves those success factors.

The CSFs concept provides an integrative and systematic way to link the environmental factors or affecting factors to desired performance outcomes (Ram and Corkindale 2014). CSFs were defined as limiting factors whose satisfaction will result in the success of organizational efficiency (Roukart 1982). In other words, CSFs are "the few key areas where things must go right for the business to flourish" (Bullen and Rockart 1981, p. 7). However, using risk analysis considering all the possible scenarios in the early stage may lead to an unsuccessful conclusion. According to the statistics shown on (fiancesonline 2020), business dissatisfaction with PPM increases from 45% in 2016 to 56% in 2018, while 36% of projects have delay issues and 33% of projects have budget overrunning problems. To make the risk evaluation process more robust and reliable, project managers must investigate and monitor risks by implementing any methods that assess how the CSFs can impact the project's performance.

1.2 Research gap

The utility of CSFs was first discussed by Rockart (1979) and later developed by several researchers on different applications. Some researchers (e.g., Iazmi and Zairi 2003; Baškarada and Koronios 2014; Trkman 2010) focused on the managerial process while some studied (e.g., Eberlein 2008; Abraham 2003; Chen 1999) in different industries. A few studies (e.g., Alias et al. 2014; Hagen and Park 2013; Ofori 2013) paid more attention to using CSFs in a PM context.

The literature on PPM and CSFs at a project level is rather limited, particularly in international projects where people from multiple cultures are involved. Thus, understanding PPM and applying CSFs now demands a more profound knowledge about the assessment, ranking, and prioritization of projects in the early stage to ensure the investment-worthy. Notably, as organizations struggle with project assessment in the early stage, it is becoming increasingly clear that many firms utilize CSFs to gain insights about the project. However, evidence on the implications of using the generalized CSFs is weak. Will the general good practices of project assessment lead to good successes? If not, what can explain these successes?

Furthermore, depending on the interests they serve, projects take on a multitude of shapes. They may be categorized according to the nature or intent of the initiative, the degree of technological complexity, or some other style that correlates to the organization's specific tasks and personality (Crawford et al. 2006;). There are also differences in project importance, urgency, and completion level (Patanakul and Milosevic 2009). Despite the diversity of projects, there is a definite lack of linkage mapping the project group and CSFs and how the linkage can be used for portfolio management project collection. According to researchers and professionals, recognizing mission diversity, adjusting management practices, and awarding appropriate competencies are critical success drivers.

1.3 Research purpose and research questions

The purpose of this research is to define a standard mechanism that can support portfolio managers to make the decision on project selection. Precisely, this research aims to develop a process using CSFs assessment for selecting a specific type of project for portfolio. Following this research aim, I intend to answer the following two research questions (RQs):

RQ 1: Do CSFs vary according to the project category?

RQ 2: How can a supportive method be established to help portfolio managers to select the project for portfolio?

As a result, this research focuses on the multi-project context to fill the above-mentioned research gaps. As the intended contributions of this study, I aim to (1) verify the hypothesis that different project category has different CSFs, and (2) contribute to explore how machine learning technology can be utilized for project selection.

1.4 Key terms in this thesis

The key terms used in this thesis is listed in the following table 1.

Table 1. Key Terms adopted in this thesis

Portfolio management	"Portfolio management is defined as the centralized management of one or more portfolios to achieve strategic objectives." (PMBOK, 5TH edition, p. 15)
Project management	"PM is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. PM is accomplished through the appropriate application and integration of the PM processes identified

	for the project. PM enables organizations to execute projects effectively and efficiently." (PMBOK, 5TH edition, p. 10)
Program management	"A program is defined as a group of related projects, subsidiary programs, and program activities managed in a coordinated manner to obtain benefits not available from managing them individually." (PMBOK, 5TH edition, p.13)
Project Selection	"Project selection is a strategic process that involves reviewing individual projects or sets of projects and then selecting a set of them to implement in order to meet the parent organization's goals." (Meredith et al. 2015)
Critical success factors	"In PM, CSFs are attributes, conditions, or variables that, whether properly maintained, retained, or managed, may have a direct or indirect impact on the project's success." (Milosevic and Patanakul 2005).
Project Success Criteria	"Project success criteria are a collection of factors used to evaluate a project's success. These criteria can be used to decide whether a project's outcome is acceptable." (Jugdev and Muller 2005).
Fuzzy TOPSIS	Hwang and Yoon (1981) developed the procedure, which "stands for order preference by similarity to an ideal solution (TOPSIS)". It is one of the most well-known classical techniques for multiple criteria decision-making.
Machine learning	"Machine learning is the study of computer algorithms that improve automatically through experience and by the use of data (Mitchell 1997). Machine learning algorithms build a model based on sample data, known as 'training data', in order to make predictions or decisions without being explicitly programmed to do so." (Koza et al. 1996, p.151-170).

1.5 Research Framework

In this study, the most critical task is to identify the causal relation between CSFs and variables of project success with the project category as a mediator, which can be used for project assessment. In other word, this paper tries to measure the level of impact to the project success made by every CSFs for different project categories. Figure 1 depicts the conceptual framework for this research.

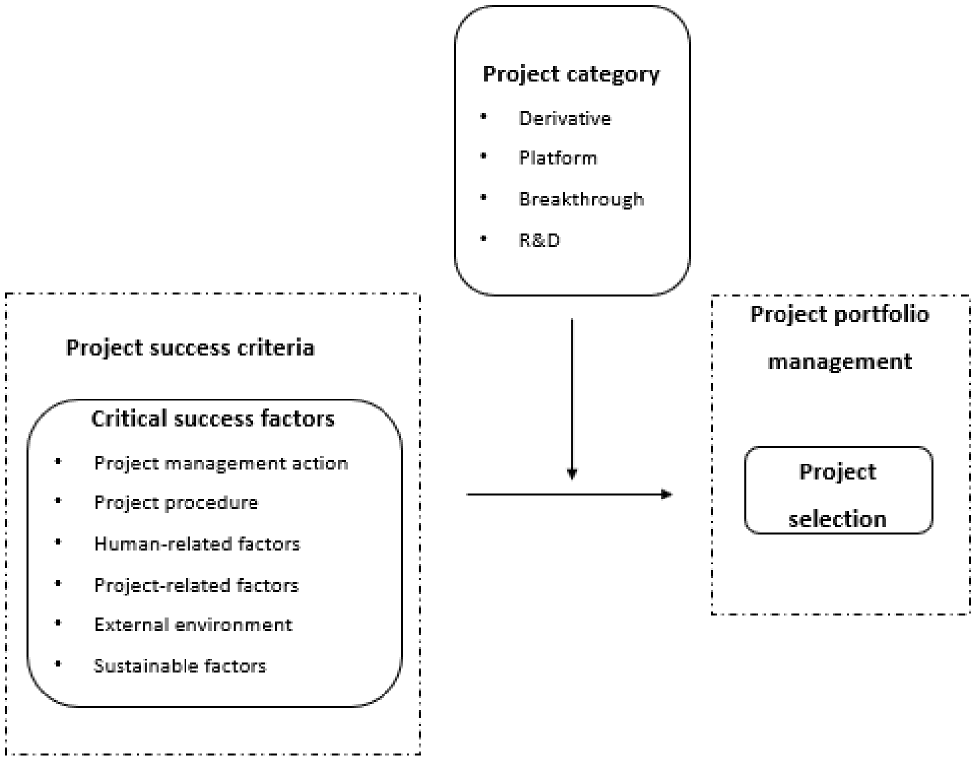

Figure 1. Research framework

1.6 Research process

To begin the study, an extensive relevant literature has been reviewed in project portfolio management, CSFs, and project categorizations. Following that, a multi-criteria decision-making method, TOPSIS, was applied to rank the CSFs for every project category so that the difference of CSFs among four categories can be revealed. Then, this research built a machine learning model to assess the project, which can later be incorporated into the project selection mechanism developed in the research analysis part. In the end, this research summarized the findings and interpreted the implication in reality. Figure 2 illustrates the research steps.

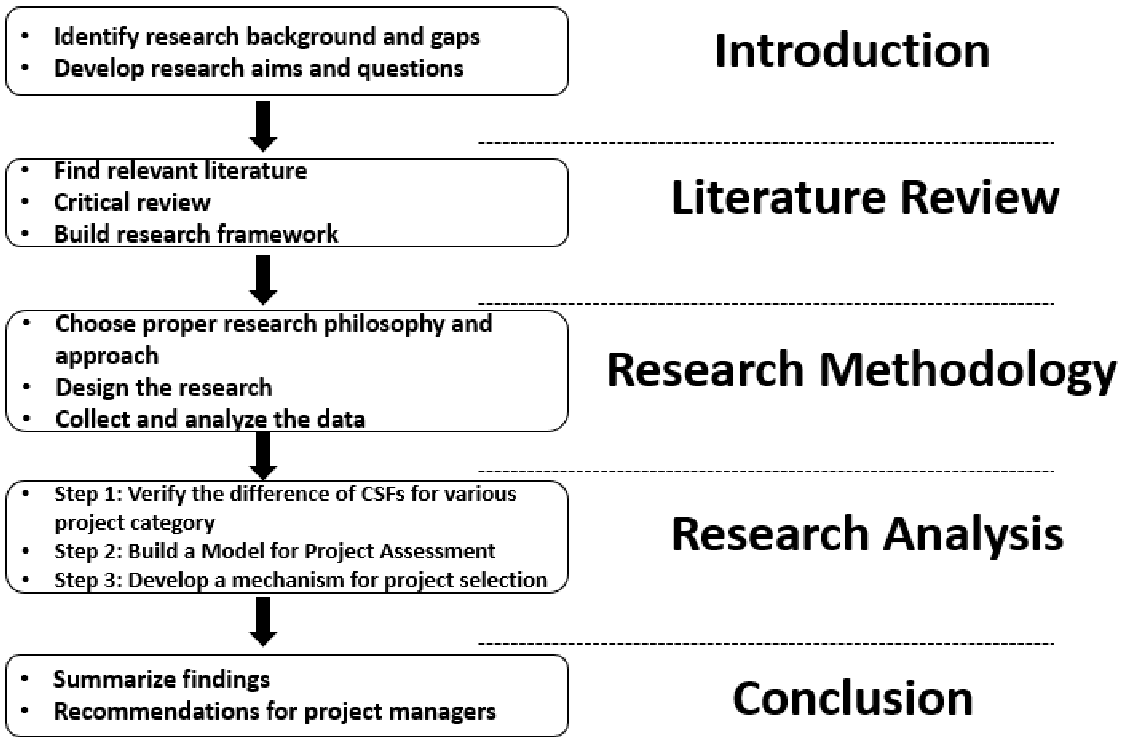

Figure 2. Research process

1.7 Research limitations

First of all, this research only focuses on the categorizations based on product. There are also other ways to categorize the project. Secondly, the data used for verification are collected only from the high-speed train industry. The businesses of companies from which the data has been collected are manufacturing train components and train-related infrastructure construction. More detailed information about these companies is described in chapter 3.4. Thus, the findings of this research and their implication may still have some gaps when it is generalized to other industries, or other products and services.

1.8 Structure of the thesis

Chapter 1 Introduction: This chapter presents the background of this study and outlines the research purpose.

Chapter 2 Literature Review: Key extensive literature was reviewed in chapter 2 to obtain the relevant knowledge and theories related to the topic.

Chapter 3 Research Methodology: This chapter dives into the underlying philosophy of this research and interprets how this research is designed.

Chapter 4 Research Findings and Analysis: This chapter designs a mechanism for project selection and uses data collected from a global company to verify it.

Chapter 5 Summary and Conclusion: There is a discussion of the research results concerning the research questions and literature. Besides, a discussion on the further study is provided.

The following figure (figure 3) provides an outlook of the thesis content structure.

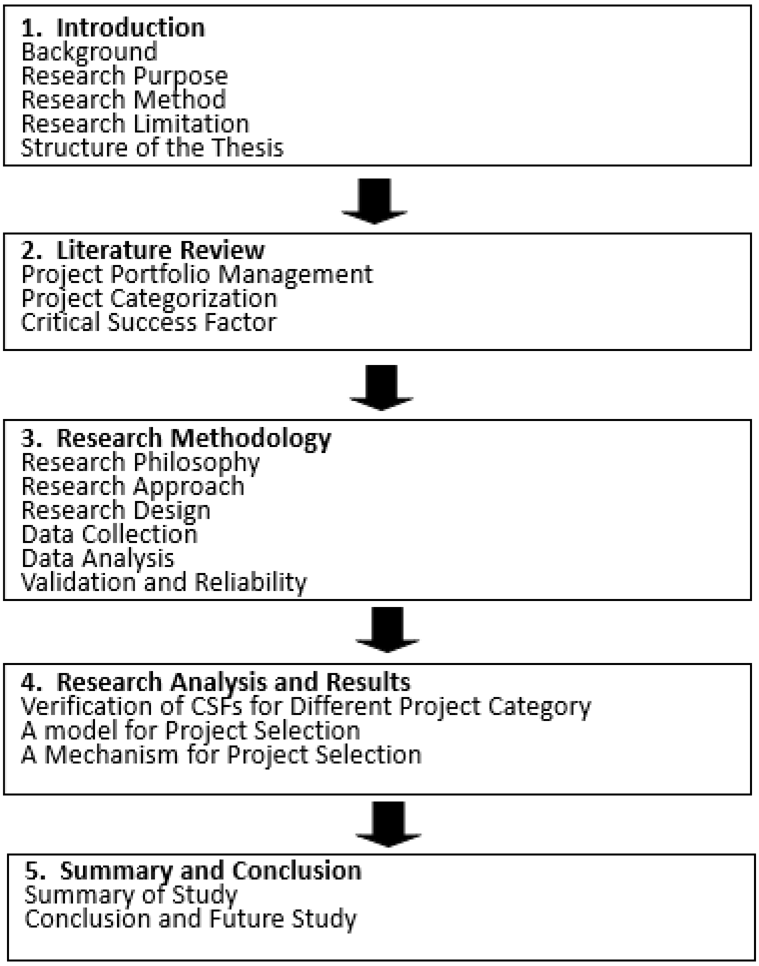

Figure 3. Content structure of this thesis

2 Literature Review

2.1 Project portfolio management (PPM)

2.1.1 The importance and concept of PPM

Organizations having multi projects intend to compose a single project to portfolio and program to secure the strategy and improve the management performance. Considering the complexity and scale of the project, some of them can be handled separately. The term multi-project, also known as portfolio management, is described as a holistic organizational environment where all the projects are managed simultaneously (Patanakul and Milosevic 2009). As a result, multiple PM isn't just another tool or process for PM but instead includes frameworks and provisions for integrating projects and generating synergies. Portfolio management comprises single PM, management of multi-projects in a group, and program management (Patanakul and Milosevic 2009). Single PM describes a variety of projects, the majority of which are strategic in nature and are undertaken to gain a competitive advantage. Because of the complexity and scale of the project, full-time PM has been authorized to take full responsibility. The management of a group of multi-projects comprises several smaller tactical programs. Under the supervision of a single manager, projects are grouped together and are managed simultaneously. Since every project has its specific goal and priorities, there is a low level of mutual dependence. Projects grouped in a program are interdependent and have a unitive purpose. Figure 4 depicts a possible multi-project operational environment (Patanakul and Milosevic 2009).

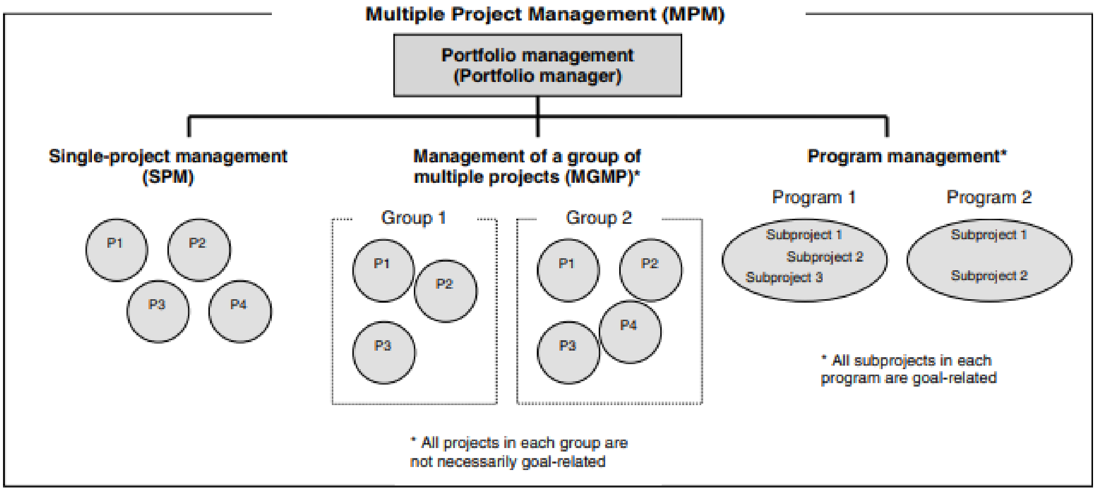

Figure 4. The concept of multiple PM (Patanakul and Milosevic 2009)

Specifically, many features of projects running at the same time may increase the complexity of managing them (Gareis 1991). As a result, the author suggests that a distinct management discipline be established to address the holistic project network. By selecting projects, analyzing advantages, managing synergies, and supporting proper competition, a comprehensive examination of the controlling scope and interactions among the projects is required.

A project portfolio allows a business to achieve its development and profit targets in accordance with its strategic plan without incurring excessive costs (Mikkola 2001). Both monetary factors and non-monetary factors are highlighted in PPM performance measurement. For instance, Cooper et al. (2000) emphasized the goal of maximizing value as monetary goal, while non-monetary factors such as project type, the level of risk, and the adequacy of resource, were equally addressed (Killen et al., 2008). Furthermore, Archer and Ghasemzadeh (1999) added the importance of project scale and short-term versus long-term project measurements. According to Meskendahl (2010), these measurements can be mutually dependent. For example, long-duration project usually is caused by the large size of project, while a high level of project creativity could lead to more risks. A portfolio which is balanced well can effectively limit the number of programs, avoiding the capital bottleneck (Adler et al. 1996).

2.1.2 The difference between program management, PM, and PPM

PPM and program management are generally recognized as effective organizational strategies for aligning initiatives and projects with corporate policies while also optimizing overall business efficiency (Partington et al. 2005). Rather than being alternatives, all strategies must be used in tandem to ensure a successful strategy implementation. A corporate strategy is a theory that outlines how a company plans to accomplish its objectives (Morris and Jamieson 2005). It's easy to plan but complicated to carry out. One way to operationalize it is to take a cascading approach at the business stage, clustering initiatives into networks and portfolios. According to Dietrich and Lethonen (2005), single project, program containing a group of projects, and PPM are critical components of the corporate planning process, whereas program or portfolio success evaluation is part of the strategy implementation phase. Meanwhile, the existing research is limited to the scale of product development and internal project. Morris and Jamieson (2005) demonstrate the link between corporate strategy and project strategy, emphasizing the need of project alignment with corporate strategy. Furthermore, Partington et al. (2005) explain that program management in corporate level can be used to coordinate and steer the multiple interlinked programs that comprise an organization's strategy.

The contingent approach to improve portfolio management is advocated by several authors (e.g., Blomquist and Müller 2006; Pellegrinelli 1997; Martinsuo and Hoverfält 2018), implying a change in the specific operational context and market form. The approach to transition, monitoring, and appraisal processes differs significantly between portfolio and program management (PMI, 2008). Program management is concerned with market policy, while the portfolio is concerned with organizational strategy, which is predictable, deliberate, and long-term. The first includes well-identified goals and, as a result, predefined success metrics. The second must be able to capture the complexities of the corporate world while still being very adaptable to changes. These values are also reflected in the positions and duties of their managers. To help deliver the benefits and value to the internal and external customer, managers working on portfolios or projects must agree to and participate in a steering committee. Portfolio managers complete their assignments to leverage the organization's performance, which necessitates portfolio coordination and efficient knowledge access (Gareis 2000; Kopmann et al. 2017).

Program managers are opportunity-driven, and required to improvise rather than execute, amid the complex and constant changing business environment (Blomquist and Müller 2006; Parker 2021). To accomplish project goals, single project managers' responsibilities are condensed or limited. This attitude carries the danger of project managers to push their projects ahead regardless of long-term orientation, and not seeing the big picture, even if it means sacrificing value-added initiatives. Although interdependencies are minor at this point of the project, project managers should be aware of them (Fricke and Shenhar 2000; San 2018). The fundamental differences between program management, PM, and PPM are summarized in Table 2.

Table 2. The summary of program management, PM, and PPM (PMI, 2008)

	PROJECTS	PROGRAMS	PORTFOLIOS
Scope	Projects have defined objectives. Scope is progressively elaborated throughout the project life cycle.	Programs have a larger scope and provide more significant benefits.	Portfolios have a business scope that changes with the strategic goals of the organization.
Change	Project managers expect change and implement processes to keep change managed and controlled.	The program manager must expect change from both inside and outside tile program and be prepared to manage it.	Portfolio managers continually monitor changes in the broad environment.
Planning	Project managers progressively elaborate high-level information into detailed plans throughout the project life cycle.	Program managers develop the overall program plan and create high-level plans to guide detailed planning at the component level.	Portfolio managers create and maintain necessary processes and communication relative to the aggregate portfolio.
Management	Project managers manage the project team to meet the project objectives.	Program managers manage the program staff and the project managers; they provide vision and overall leadership.	Portfolio managers may manage or coordinate portfolio management staff.
Success	Success is measured by product and project quality, timeliness, budget compliance, and degree of customer satisfaction.	Success is measured by the degree to which the program satisfies the needs and benefits for which it was undertaken.	Success is measured in terms of aggregate performance of portfolio components.
Monitoring	Project managers monitor and control the work of producing the products, services or results that the project was undertaken to produce.	Program managers monitor the progress of program components to ensure the overall goals, schedules, budget, and benefits of the program will be met.	Portfolio managers monitor aggregate performance and value indicators.

2.1.3 The process of PPM

The project portfolio was conceptualized in a variety of ways by people with varied backgrounds. Roberts (2020, p. 38) define it as “a group of initiatives undertaken under the sponsorship and/or administration of a single organization”. A project portfolio, according to PMI (2008), is the effective management of different initiatives, projects, or other work meet strategic corporate objectives, emphasizing project multiplicity. A portfolio, according to Turner and Müller (2003), is a temporary/permanent structure within which multi-projects are managed jointly in order to coordinate interfaces, prioritize and allocate resource, and decreasing uncertainty.

To maximize project value in accordance with organizational priorities, strategic directions, and portfolio, a holistic approach that corresponds to the strategies is needed (Cooper et al. 2000; Rempel and Young 2017). Portfolio management starts activities and picks projects based on criteria to ensure the right strategic fit (APM 2006; Isikli et al. 2018). Elonen and Artto (2003, p. 395) define PPM as “doing the right projects, establishing a connection from the projects to the organization’s plan, and simultaneously embracing the long-term view.” Therefore, PPM is an administrative process that includes the initial screening, collecting proposals, prioritization and reprioritization of projects, as well as the allocation and reallocation of resources to projects based on priorities (Blich-feldt and Eskerod 2008; RezaHoseini et al. 2020). A continuous search of active and new entry programs is part of the complicated process. As a result, a decision-making mechanism for selecting the best projects and allocating resources to them could be created (Cooper et al. 2000; Rempel and Young 2017). Effective portfolio management may support an organization’s policy, according to the PMI (2008), and the mechanism refers to a series of integrated processes that lead to improvements in the strategic plan through updating the aligning processes (See Figure 5).

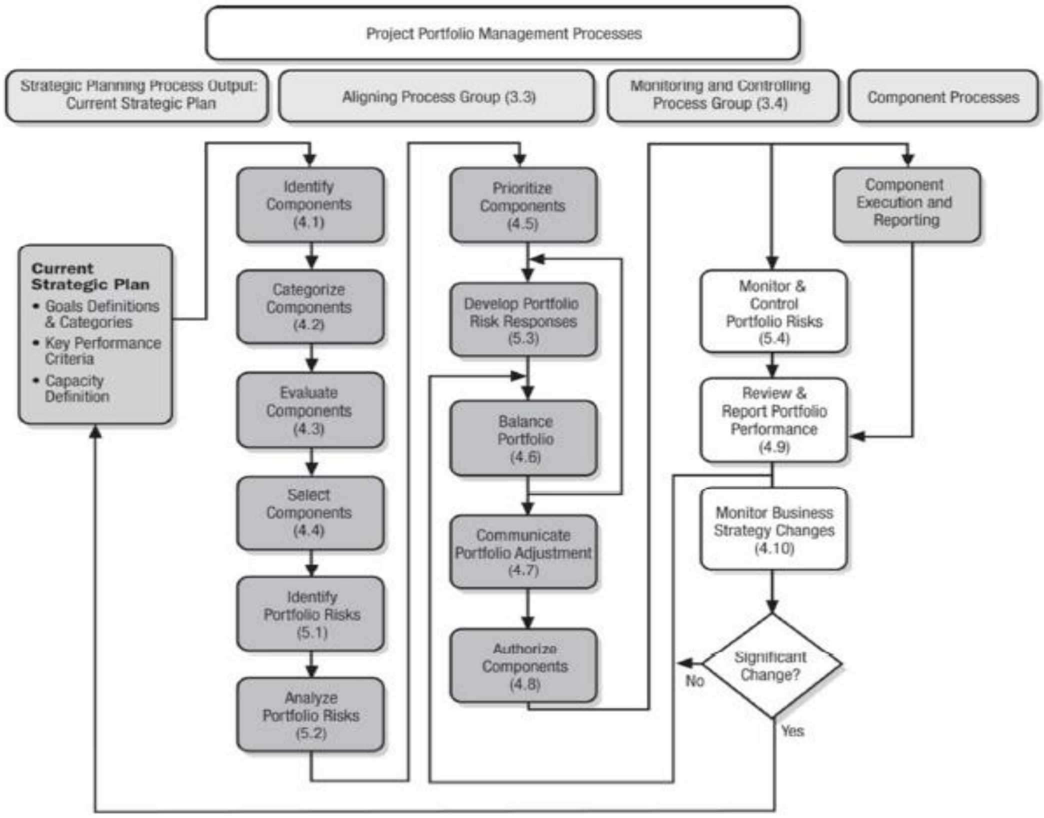

Figure 5. PPM process (PMI 2008)

2.1.4 A key process step in PPM---Project selection and prioritization

Müller et al. (2008) underline the necessity of matching project selection with portfolio success strategy. According to Rempel and Young (2017), project selection is the process of selecting a portfolio from potential and current projects that meet the firm's stated objectives, while not topping obtainable budget or other constraints. They recognize the importance of excellent project assessment ratings, but they prioritize the most important activities until all resources have been depleted. This strategy, however, fail to provide the optimal portfolio. A good way to initiate a project might be based on a study of the project network, rather than examining projects separately (Gareis 1991; Sanchez and Terlizzi 2017). According to Chien (2002), picking individual successful companies does not result in the optimum portfolio mix. Furthermore, the portfolio's overall priorities must be evaluated throughout the evaluation process. Existing selection techniques, according to the author, do not address the problem of project interdependencies and do not provide access to non-numerical variables such as project variety.

Müller et al. (2008) established a connection between portfolio selection and portfolio performance, as well as project and program goals. As a result, portfolio selection entails matching programs to plan and prioritizing them. When it comes to project selection, organizations that have been recognized as top performers appear to focus on policy rather than only financial approaches (Killen et al. 2008). This method entails capital allocation to various types of programs, resulting in improved portfolio efficiency. When it comes to choosing which programs to launch, organizations generally have two options. To begin, the decision can be matched to a scoring matrix by considering all projects equally. Second, making meaningful groups and groupings of programs. A fixed proportion of an organization's annual capital could be allocated to each category, and the selection process will take place within that category. Nguyen et al. (2018) favor the second alternative, recommending that higher-level management devote resources to specific project groups before project selection. Strategic fit, ability to raise sales and create market share, degree of product differentiation, and technical innovation are the key parameters for ranking R&D projects (Liu et al. 2017).

Figure 6 shows a theoretical model called funnel and filters, describing how projects proceed in the funnel. This filter represents go/no-go decisions. There are three different phases in the funnel, namely Initiation, development, and production. Each competing project travels through the funnel as it goes through its phase-gates. A portfolio management committee assesses the project's current status on its own and relative business case value before recommending a go or no-go decision to the execution board. The final go/no-go decision is decided by the board. A 'go' decision indicates that the project is worth investing in and will be allowed to proceed to the next phase.

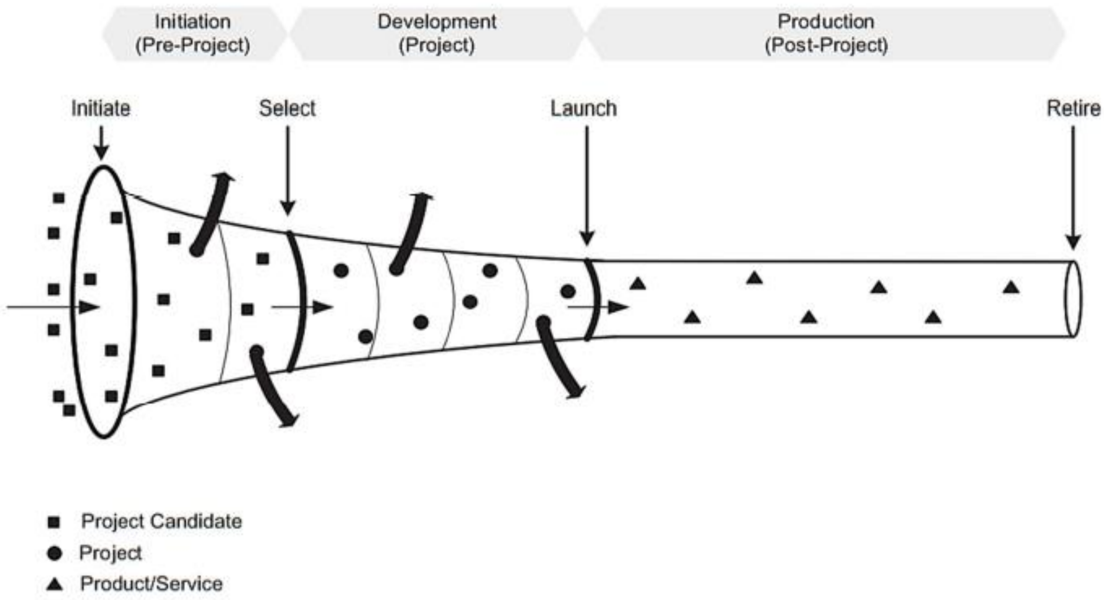

Figure 6. Funnel and Filter for Project Selection (Kodukula 2014)

2.2 Critical success factor (CSFs)

2.2.1 CSFs in PM

CSFs are project characteristics that have been established as being essential to produce outstanding results: if the CSFs are absent or taken into account, one may anticipate challenges to arise that serve as roadblocks to overall good outcomes (Rockart 1979; Holthe 2017). Given the particular existence of every project, PM is benefit from management's focuses on certain crucial performance factors.

Pinto and Slevin (1987) made a significant contribution to the PM field with the explanation of how to use CSFs to diagnose the state of a project using their project execution profile. CSFs included the factors such as, project mission and plans, technical tasks, top management support, personnel recruitment, selection, and training, client consultation and acceptance, communication and feedback, monitoring and crises management. Subsequent authors have expanded this collection, researchers have later on focused on crucial performance drivers (e.g., Belassi and Tukel 1996; Magge 2002; Johnson et al. 2021). Factors relating to the project, the project team members, the organization, and the external environment are divided into four categories (Mavi and Standing 2018). However, finding a unifying structure remains challenging.

Magge (2002) categorizes the various essential success variables using the European foundation for quality control model. The following critical performance indicators are presented in a project excellence model: stakeholder management, policy and planning, leadership and team resources, contracting and PM. Naturally, there are differing viewpoints about which aspects are most important for project completion.

This study takes a somewhat different approach compared with previous studies which used critical performance factors on the basis of a step-by-step structure reflecting project progression. As a result, all elements of project work known from earlier studies into performance factors were routinely included, with factors extracted from experience augmented. There are both hard (technically focused) and soft (behavioral) problems to consider.

2.2.2 Sustainable CSFs

In recent years, the issue of sustainability has gotten a lot of attention, especially in the architecture industry (Tsai and Chang 2012). According to Marcelino-Sadaba et al. (2015), numerous construction firms have adopted sustainability strategies, but translating business goals into tangible project objectives is challenging. These challenges include the need to use fewer resources and materials, generate fewer carbon emissions, and reduce other harmful environmental effects (Zhong and Wu 2015). Given the impacts of the construction industry on the environmental quality, eco-innovative practices are needed to improve sustainability and environmental friendliness (Mavi and Standing 2018).

The construction industry consumes half of all mined raw materials, resulting in more than half of all waste material (Mourao and Pedro 2007). As a result, environmental issues must be addressed in the early design and development phases to reduce the negative impact on the environment (Harrington et al. 2010). The majority of environmental sustainability indexes are concerned with renewable energy use, waste management, water protection, material efficiency, recycling, and pollution. Waste generation accounts for a significant portion of building cost overruns, thus, minimizing construction waste is not only climate-beneficial, but also cost-saving (Ajayi and Oyedele 2018). As a result, the economic indicators should also be considered in CSFs, including costs of life cycle, building and maintenance, quality and infrastructure expansion issues, sustainability, and work creation (Heravi et al. 2015). Among which, the most crucial social sustainability facets are safety, well-being, public service, cultural heritage, user protection, and public comfort (Shen et al. 2011).

2.2.3 A summary of CSFs

The bottom line of a PM firm's performance is identifying crucial success factors that can provide the organization/company with a competitive edge. As a result, the PM company will prosper, with healthier customers and professional partnerships. Based on PM literature, PM approaches, PM priorities, main success factors, and project performance, Alias et al. (2014) identified five project CSFs groups: PM actions, procedures, human-related factors, project-related factors, and other external factors.

- *PM actions*: The coordination framework, organizing committee, designing an efficient organizational structure, implementing an adequate protection policy, implementing an effective quality assurance program, and overseeing and controlling subcontractors' work would focus on PM activity.
- *Project procedures*: Procurement and tendering processes and techniques are used in project procedures.
- *Human-related factors*: Human-related factors include the client's expertise, the disposition of the client, the complexity of the client's company, the client's focus on low construction costs/high construction quality/quick construction, and the client's ability to brief, which includes the ability to make decisions, identify roles, contribute to design.

- *Project-related factors*: Project-related factors will include the project's form, design, and difficulty, as well as the project's duration.
- *Other external issues*: Fiscal, societal, and political issues, as well as physical and technological advancements, are all examples of external issues.

16 CSFs in total have been collected from previous literature. After careful choosing to simulate reality, sixteen CSFs (see table 3) classified into five CSFs groups have been determined to be used in this research.

Table 3. The chosen CSFs

CSFs Group	CSFs Item	Represent Authors
PM Action	Stakeholder management	Ojoko et al. (2018); Mavi and Standing (2018)
	Project Administration Efficiency	Shakya and Shakya (2020); Haron et al. (2017)
	Strategy	Shayan et al. (2019); Banihashemi et al. (2017)
Project Procedure	Scheduling	IY and GQ (2020); Mavi and Standing (2018)
	Control and Monitoring	Singh et al. (2020); Mavi and Standing (2018)
	Scope and Change	Frinsdorf et al. (2014); Mavi and Standing (2018)
Human-related Factors	Leadership and team	Inayat et al. (2015); Banihashemi et al. (2017)
	Customer Relation	MM Omoush (2020); Mavi and Standing (2018)
Project Related Factors	Resource	Rashidi and Ibrahim (2017); Mavi and Standing (2018)
	Use of Technology	Sinesilassie et al. (2018); Pacagnella et al. (2019)
	Top Management Support	IY and GQ (2020); Mavi and Standing (2018)
External Environment	Policy	Santos et al. (2014); Mavi and Standing (2018)
	Legal Agreement	Cserhat and Szabo (2014); Mavi and Standing (2018)
Sustainable Factors	Social Factor	Nunes and Abreu (2020); Mavi and Standing (2018)

	Energy Consumption	Ojoko et al. (2018); Mavi and Standing (2018)
	Recycling and Waste Management	Ojoko et al. (2018); Mavi and Standing (2018)

2.3 Project Categorization

2.3.1 The importance of project category

Several projects are expected to be handled concurrently in a corporate environment. This has further highlighted the importance of success factors when managing a group of projects. In other words, the portfolio effectiveness. When considering the objectives of portfolio management as specified by, portfolio effectiveness can be described as "the degree to which a portfolio has succeeded in fulfilling its objectives" (Mülle et al., 2008 p. 29). Project performance is highly linked to portfolio success (e.g., Fricke and Shenhar 2000; Müller et al. 2008; Kopmann et al. 2017). According to Martinsuo and Lethonen (2007), achieving project objectives is an intermediary of solitary PM performance and portfolio management productivity. The practical assignment of a project manager to a project, taking into account uncertainty and project process is one aspect that leads to successful management in a multi-project setting (Patanakul and Milosevic 2009; Hoonsopon and Puriwat 2021). They go on to say that a project manager with the right expertise and time availability will be more competitive. Their results suggest that standard procedures are essential for managing individual tasks, but how dependent they are on project styles can affect successful multi-PM.

The importance of differentiating projects can also be explained by classical contingency theory (Shenhar 2001; Toljaga et al. 2017). Hong et al. (2019) show more significant progress in joint projects where processes have been updated according to resource type and project scale. Small to medium-sized projects place a greater focus on resource prioritization, while big projects emphasize activity management and resource distribution. Certain project features necessitate various planning and control processes. For example, data processing and information availability are more important for major projects, but using a standardized methodology for all project types raises the probability of failure (Hong et al. 2019). Several other studies (e.g., Fricke and Shenhar 2000; Patanakul and Milosevic 2009) affirm their results, despite their analysis being confined to program administration and lacks statistical significance.

Dietrich and Lethonen (2005) found that competitive companies use a scalable management style to handle various types of projects after studying the strategies of 288 organizations in addressing strategic intentions through projects. According to Bresner and Hobbs' (2008) longitudinal survey of PM methods, different tools and approaches are used by different project styles, project sizes, and project customers.

When comparing IT and engineering and construction (B&C) (B&C) programs, for example, there are significant variations in the methods used for planning and monitoring. Though cost and estimation tools are more commonly used in B&C projects, scheduling and resource allocation tools are more commonly used in IT projects. The number of devices used is clearly influenced by the scale of the project, with more significant projects requiring more tools. However, their research does not show a connection between the methods used and project performance.

Even though companies expressly analyze project attributes to categorize them, PM researchers do not include these practices in their manuals, even though multiple life cycle models are appropriate for different project types. Prioritizing, approving, preparing, implementing, and managing then must be adapted accordingly (Archibald 2004).

2.3.2 Project categorization in literature

Niknazar and Bourgault (2017) suggest a typological approach to theory growth, with reasons that outweigh the general criticism of organizational typologies. Typologies are dynamic theoretical structures that have been formed as a set of interconnected ideal forms (Niknazar and Bourgault 2017). Typologies are abstract theoretical constructs created as an interrelated set of ideal categories, as opposed to classification systems, which merely differentiate phenomena or objects in order to assign them to mutually exclusive groups (Niknazar and Bourgault 2017). Another viewpoint on project theory is offered by Söderlund (2004), who claims that conceptualizations and models can explain and predict the shape and behavior of projects.

The calculation of an entire organization's deviation from the ideal form is possible thanks to the concept of ideal forms. As a consequence, variance can be used to forecast a dependent variable like operating efficiency. The willingness of typologies to adhere to three theory conditions is crucial to their justification as theories. According to Niknazar and Bourgault (2017), the proper formulation and description of typologies include (1) identifying structures, (2) evaluating relationships within these constructs, and (3) testing these relationships. The distinction between grouping or categorization systems and typologies is critical in order to prevent misunderstandings. In the field of PM, though, developing a typological framework necessitates categorizing real activities centered on a set of pre-specified parameters inside a structured structure. On a larger scale, a formal model of project taxonomies and typologies as a theoretical framework may contribute to standardization and professionalization in a relatively new area (Crawford et al. 2005). As a consequence, the strong consensus is needed before developing standards, tools, and techniques that can be applicable to a wide range of project characteristics (Shenhar and Dvir 1996, Evaristo and van Fenema 1999; Mohammadi et al. 2018). Other PM typologies are essentially classification systems with a set of guidelines for separating tasks. Söderlund (2004) puts it this way that these are either inadequate in providing proof of causal relationships for each category (Niknazar and Bourgault 2017) or existing mechanisms or are not properly defined. The problem, according to the author, is that these contingency considerations are not expressly scientifically verified.

2.3.3 A product-based project categorization

Dixit and Tiwari's (2020) classification of product creation programs has gotten a lot of coverage in the PM world. To best achieve business goals and comply with capability limits, the authors recommend creating an aggregate project schedule. Identifying and mapping different forms of construction schemes is the primary task in developing the above program. The degree of transition in the product and the production process are the primary factors used to identify projects in their model. This system is useful for determining resource requirements and serves as an interface to the resource allocation process. In general, projects with more transition bind more money. There are five categories of project differentiation, the first three of which are referred to as commercial projects.

- **Derivative projects**: This type of project is most often an updated version of a current product with minimal or gradual innovation in the product, process, or content. There is no input from management, and resource use is limited.
- **Platform projects**: Platform projects are the forerunners of derivative projects. The production work focuses on lowering costs, improving efficiency, and increasing efficiency using well-known technology or materials. They have a greater degree of transition than derivative projects, which necessitate intensive pre-project work. For these types of projects, a network of specialists from various departments such as marketing, sales, engineering, and senior management must be created. Platforms have a strategic edge for businesses with significant consumer growth opportunities.
- **Breakthrough projects**: Breakthrough projects revolutionize the industry and introduce a brand-new range of products that deliver innovative creativity. Unknown tools or components are used in these goods, and production techniques must be reinvented.
- **R&D projects**: R&D investments and operations are high-risky, and they compete with commercial projects for funding and other resources.
- **Alliances and partnership**: This kind of project may take the form of some kind of commercial or non-commercial.

Figure 7 shows the core difference of 4 project categories: the level of product change and process change. The derivative projects have the least level of both product change and process change, while R&D projects have the most.

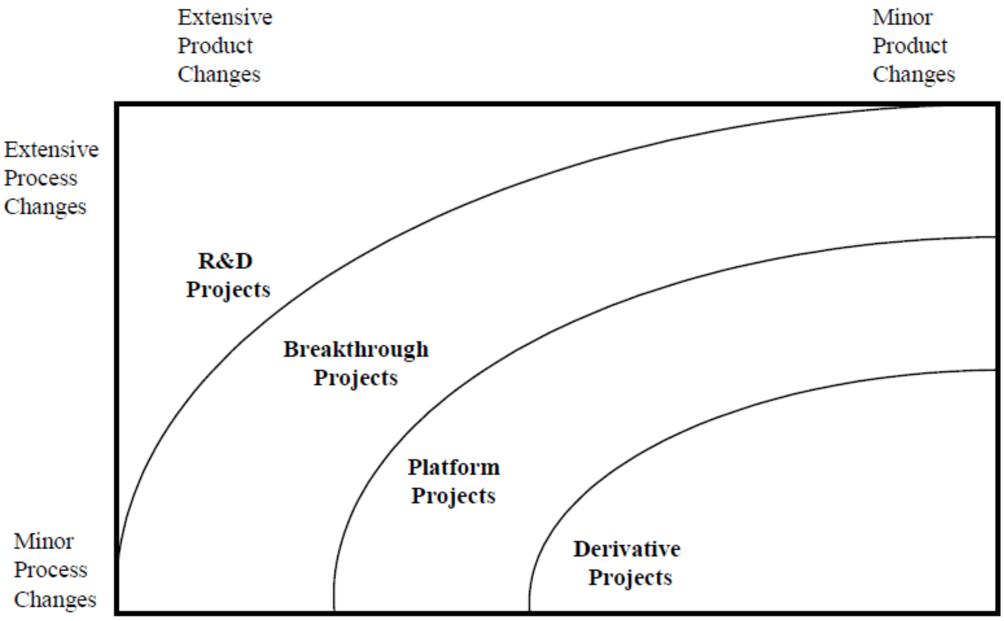

Figure 7. The level of change in four project categories (Jung 2009)

Any project group necessitates a distinct management methodology as well as specific resource categories. The best combination of styles would help the company retain a competitive perspective by mapping tasks within one of these groups.

2.4 Fuzzy TOPSIS

Various multi-criteria decision-making (MCDM) techniques have been developed in the decade to address numerous decision problems in a variety of fields. Hwang and Yoon (2012) developed a technique for order of preference by similarity to ideal solution (TOPSIS), which is one of the most potent MCDM methods. It has been widely implemented in many applications due to its simplicity, computational performance, and powerful mathematical concept. The fuzzy TOPSIS approach, which extends the classical TOPSIS method with respect to fuzzy logic, has also been successfully applied in numerous implementation areas, such as manufacturing (He et al. 2016), energy (Şengül et al. 2015), environment (Onu et al. 2017), and business (Shen et al. 2018).

TOPSIS' fundamental principle is to compare the distances between each option and positive ideal solutions (PIS) and negative ideal solutions (NIS) at the same time to discover the optimum answer. PIS is a strategy used by decision-makers (DMs) to maximize profit objectives while minimizing costs. At the same hand, when it comes to optimizing cost criteria while lowering benefit criteria, NIS is the least preferred alternative. The decision order is then constructed using the alternative that is closest to the PIS and is farthest from the NIS, yielding a scalar criterion that combines the two distance measurements as well as the optimal alternative (Roszkowska and Wachowicz, 2015). The steps of TOPSIS (FTOP-SIS) are as follows:
The first step is to create the judgment matrix.
Step 2: The parameters' weights are determined using a number of ways, including a human technique or entropy.
Step 3: Make the choice matrix normal.
Calculate the weighted normalized fuzzy decision matrix in step four.
Step 5: Determine the fuzzy PIS (FPIS) and fuzzy NIS (fuzzy NIS) (FNIS).
Step 6: The distance between the FPIS and FNIS is determined for each option.
Step 7: The proximity coefficient CCi is determined for each option.
Step 8: The following is the order in which the alternatives are ranked: The ideal option, according to Nad aban et al. (2016), is the one with the highest proximity coefficient.

TOPSIS, on the other hand, has encountered a number of problems, including the normalization approach utilized, its influence on data, and its influence on the final collection. Furthermore, TOPSIS distance estimate uses a number of ways to calculate the distance between PIS and NIS, each of which produces different results. In general, MCDM techniques involve DM expectations and individual assessments, as well as ratings and weights for objective and/or qualitative factors. However, when applied to real-world issues, these questions might be vague, indefinite, and unpredictable, making the decision-making process more difficult (Vahdani et al., 2011). Real numbers aren't always the best method to solve real-world problems, especially when making subjective judgements (Yang et al. 2020). random judgments may be accommodated by Zadeh's fuzzy set theory (Vahdani et al., 2013).

2.5 Machine Learning

Some well-known examples of business-sector growth today, such as Amazon (Rastogi 2018) and Zillow, utilize machine learning to improve manufacturing, supply chains management, marketing process, and the pricing of products (Sangani 2017). From the entrance of “fintech” enterprises in the banking industry (Belanche et al. 2019) to breakthroughs in healthcare sector by precision medicine, machine learning is underpinning future development across a wide variety of sectors (Lock et al. 2021). The major draw of machine learning is how effectively it outperforms human intellect (Thorn 2015). Portfolio management will undoubtedly need to follow suit as companies seek productivity gains through the kinds of intelligent, more contextually relevant decisions enabled by computational data mining. This will improve the portfolio management team's ability to cope with a variety of all sort of risks and contingencies (Costan-tino 2015).

Machine-learning algorithms are used to create predictions in the most basic sense. Traditional statistical approaches, which strive to understand fundamental data-generating processes in reality, contrast sharply with this emphasis on prediction. Traditional statistical methods may yield predictions, but only provided the analyst's model is compatible with the underlying processes being analyzed. The analyst must first write a mathematical equation that represents an outcome variable as a function of a set of chosen explanatory variables integrated in a certain manner, and then analyze how well the data matches the analyst's choices. Machine learning, on the other hand, is nonparametric in the sense that it does not need the researcher to specify any particular functional form of a mathematical model in advance. Rather, these algorithms let the data decide how input variables' data is combined to predict the value of an output variable (Berk 2008). Machine learning functional correlations aren't always the same as those discovered in natural data production. As a consequence, no one can argue that machine learning can represent real-world phenomena, and there are no causal results from which mathematical modeling can be used to get machine-learning outcomes. To summarize, no matter how natural causal links between inputs and outputs seem on the surface, they may not exist when it comes to machine learning. Machine learning's unique predictive and nonparametric orientation, on the other hand, turns out to be key to its astounding efficiency in creating reliable forecasts from a technical position. It's also crucial to comprehend how such algorithms "learn" to make mechanical predictions, as the term "machine learning" implies.

Several machine-learning algorithms attempt to maximize performance criteria utilizing existing data in different mathematical approaches (Khan et al. 2008). The research wants to appraise the project based on the CSFs for project selection, thus the classification machine learning methodology is an appropriate tool to use. Classification, also known as supervised machine learning algorithms (Bhavsar et al. 2012), is the process of extracting insights, patterns, and correlations from a labeled training dataset, which means that each data set's outcome has already been determined. After the correct answer is provided to a problem during training, the machine learning model may learn the remainder of the goal's features, allowing it to uncover insights and make predictions about feature outcomes based on past data. There are several categorization techniques available, including decision trees, neural networks, naive Bayes, k-nearest neighbor (KNN), and support vector machine. Researchers Bhavsar et al. (2012) compared all of these algorithms in a comparative analysis. The outcome is reported in Table 4 below. The KNN method was chosen for this work because of its advantages of dealing with discrete attributes, overfitting, incremental learning capacity, allowing multi-classification, and being suited for small databases (Ducharme et al. 2017).

Table 4 Comparison of classification algorithms (Bhavsar et al. 2012)

	Decision Trees	**Neural Network**	**Naïve Bayes**	**K-Nearest Neighbor**	**Support Vector Machine**
Accuracy	Good	Good	Average	Good	Excellent
Speed of learning	Good	Average	Excellent	Excellent	Average

Tolerance to irrelevant attributes	Good	Average	Good	Good	Excellent
Dealing with discrete/binary/continuous attribute	All	Not Discrete	Not continuous	All	Not discrete
Dealing with danger of overfitting	Good	Average	Good	Good	Good
Attempt for incremental learning	Good	Good	Excellent	Excellent	Good
Explanation ability/ transparency of knowledge/ classification	Excellent	Average	Excellent	Good	Average
Support Multiclassification	Excellent	Naturally extended	Naturally extended	Excellent	Binary Classifier

3 Research Methodology

This research aims to understand the underlying connection between CSFs and the success of different project categories and develop a method to select projects more accurately for portfolio management. This chapter will interpret what methodology this research used, beginning from research philosophy.

3.1 Research philosophy

The research philosophy must be identified to explain what the research is working on. A search philosophy describes the researcher's perspective on the study and its aim (Saunders et al. 2009). According to Saunders et al. (2009), the researcher's theory should be investigated because the researcher's philosophy has an impact on all the contexts taken during the research, even though the researcher is unaware of it. The research approach and methodology are based on these principle and assumption (Saunders et al. 2005). Postmodernism, pragmatism, interpretivism, pragmatic realism, and positivism are the five main research philosophies that are widely recognized throughout academia (Saunders et al. 2009).

This study applies a positivism. Positivism uses the hypothetico-deductive approach to validate a priori assumptions that are often expressed quantitatively, where functional correlations between causal and explanatory factors (independent variables) and results may be extracted (dependent variables) (Ponterotto 2005). However, positivist analysis does not necessarily use quantitative approaches. An academic research using qualitative methodology to examine the results of an action, for example, falls under the positivist model (Chua et al. 2019).

Positivism aims to explore natural laws based on these ideas, expressing them by theory explanations. Centered on the hypothetico-deductive paradigm, these hypotheses depend on interpretation and prediction. One of the main goals of positivist research is to find predictive correlations or causal relationships that can be used to forecast and monitor the phenomena in question (Gergen 2001). In its purest form, positivism is based on the concepts mentioned below, as categorized by Mill (1843) in his classic textbook- A System of Logic:

(1) Science's goals: The social and natural sciences should concentrate on the exploration of rules that make interpretation and prediction easier.

(2) Methods: The social and natural sciences can use the same methodology (theory, hypothesis, operationalization, and experimentation) focusing on the hypothetico-deductive paradigm of science.

(3) Natural laws: Natural laws affirm the existence of a single factual and identifiable truth, which are created by synthesis and syntheses of empirical observations and theories.

(4) Legal evidence: Natural laws are derived from scientific facts.

(5) Sampling and inference: Bigger samples are preferable to tiny, idiosyncratic samples since they show generalizable tendencies, triggers, and reality's existence.

The idea that large sample sizes are preferred over smaller samples (i.e., objective data obtained over a large sample is preferable to data gathered from smaller samples) is embedded in this emphasis. Larger samples increase data accuracy and representation of population traits, allowing for greater generalizations about the causes of natural phenomena. Furthermore, validation of results is respected by systematic and supervised trials in order to make stronger statements about generalizations (Picho et al. 2016). In this way, positivist science is concerned with proving hypotheses (Hansen 2004).

3.2 Research approach

This research contains both theoretical and empirical parts. The theoretical aspect entails a thorough review of previous literature in order to gain a holistic understanding of portfolio management, CSFs, project category, and project selecting process. This review part will help you get a better understanding of the topic. The theoretical part and empirical part need to be distinguished in this sector.

In academia, there are two research approaches mainly used: inductive and deductive. The inductive approach, also named inductive reasoning, begins with observations, and hypotheses are proposed as a result of the study (Goddard and Melville 2004). The inductive approach entails "involves the search for pattern from observation and the development of explanations theories for those patterns through series of hypotheses" (Bernard 2011, p. 7). Inductive experiments do not need any theories or hypotheses at the start of the analysis process, and the researcher is free to change the proposal of the study once it has begun (Saunders et al. 2012).

The deductive approach, also named deductive reasoning, is the practice of arriving at a conclusion based on facts that are widely accepted as fact (Gulati 2009). The process begins with the development of a theory. In science, the deductive approach is mainly based on general statements. The deductive research method is an analytical technique in which the inference is based on the agreement of specific hypotheses assumed to be accurate, also known as a top-down strategy. This paper explores the relationship between CSFs and project categories based on which the project selecting process can be developed. Thus, a deductive approach is a proper method to conduct the research.

This study applies the quantitative method. Quantitative research is to uses a numerical method to describe and interpret the phenomena that those observations constitute. It is used in astronomy, genetic, psychology, sociology, and geology, among natural and social science. Quantitative analysis is characterized as social research that utilizes scientific methods (Cohen 1980). According to Cohen (1980), an empirical observation is a description of the 'real world,' instead of what ought to be the case. Empirical studies are usually formulated numerically and tested empirically, which determines the degree to which a program or policy empirically meets or fails to meet a given criterion or norm.

3.3 Research design

Research design is the plan of how the research is conducted. Sanders et al. (2007) describe the research design as the detailed plan to answer the research questions. It incorporates several components, including strategy, research purpose, time scale, and procedure. The research typically starts with intention. Saunders et al. (2009) define three purposes: exploratory, descriptive, and explanatory. It is quite common that the study has not only one kind of purpose, and the purpose may change very often. This research aims to explore the link between CSFs and project category, which is an exploratory study. Researchers use the expletory study to learn more about an emerging concept and obtain new insights into it to formulate a more specific problem. It starts with a broad concept, and the research findings are used to uncover relevant problems to the research subject.

Apart from the research purpose, the research strategy is to lead the researcher closer to the research questions. The research strategy also refers to the way for answering the research questions. There are a variety of research strategies available in academic literature, and it is quite often to use several strategies simultaneously. For this research, a survey is an appropriate choice.

The research method is using surveys to collect data from respondents. The data were then statistically evaluated to draw concrete research conclusions. The standard concept of survey study is a quantitative study collecting answers from a group of people. It's helpful for researchers who want to inform their respondents about new features or patterns. In general, it's the first step toward gathering fast insights on popular subjects, after which more systematic and comprehensive quantitative polling methods such as surveys/polls or qualitative research methods such as focus groups/on-call interviews can be conducted. In certain cases, researchers may perform studies using a combination of qualitative and quantitative methods.

3.4 Data collection

As mentioned in the last chapter 3.3, this study utilized survey strategy to achieve deductive research purpose. Therefore, the empirical data was gained through survey. Researchers Hunt and Foddy (Hunt et al. 2002; Foddy 1994) defined a survey as a dynamic communication mechanism in which the outcome of the researcher's interactions with respondents contributes to the exchange and creation of value. To begin, researchers agreed on what questions to pose inside a context or model that included the research questions and theories that would be answered and evaluated using data from the analysis (Vikat et al. 2007). Second, at the start of the procedure, researchers or interviewers encrypted their request for clarification in a carefully standardized physical cue called a query. Respondents then translated the stimuli and encoded a response, which was normally articulated in terms of a standardized format that the researcher had already encoded. Finally, the researchers deciphered the response before analyzing the data and drawing conclusions based on their findings.

Surveys can be self-administered or administered by a specialist, provided independently or in groups. They usually include a set of items that reflect the study goals. With accurate and reliable test tools, surveys can contain demographic questions (DuBenske et al. 2014). When researchers explain the contents of the survey, it helps readers understand and determine the validity and reliability errors (e.g., objects or devices that do not quantify what they are supposed to measure).

The survey of this study was conducted by Excel, including an explanation about sixteen CSFs, six success criteria, and four project categories, and an evaluation table, which needed respondents to answer. The language was in English and Chinese, and all the data were collected in April and May 2021. The survey was sent to the 20 project managers to collect the data and finally got 10 responses involving 8 companies. The participants (see table 5) in the survey were all senior project managers with theoretical knowledge about PM and practical experience. All of them had PPM experience. Table 5 shows more detail about their background and industries they are working in. Before they did the survey, a detailed explanation of CSFs, success criteria, project category, and instruction of evaluation was presented to understand this topic and evaluation better.

This thesis targets product-manufacturing companies and construction companies who have international business. Thus, the data made by 10 respondents from 8 Chinese companies were mainly based on product manufacturing industries, especially in the high-speed train industry. Five companies manufacture the interiors of train and metro, and two of five also have the business of constructing train track and power supply room. The other companies have the businesses in the aircraft industry and solar energy industry. Besides, the data used for the machine learning model was collected from a Chinese company that manufactured train components and exported products all over the world. All the products had been developed as projects. This company has more than 500 employees, and it usually has thirty or forty projects running at the same time.

Table 5. Background of respondents

Respondent	Education Background	Work Experience in PM	Industry
1	Bachelor degree of Industrial Management	10	High-speed train
2	Master degree of Technology	13	High-speed train/ aircraft
3	Bachelor degree of Engineering	10	High-speed train
4	Bachelar degree of Engineering	3	High-speed train
5	Bachelor degree of Engineering	6	High-speed train
6	Bachelor degree of Engineering	3	Aircraft
7	Bachelor degree of Engineering	8	High-speed train
8	Bachelor degree of Engineering	3	Aircraft
9	Bachelor degree of Engineering	3	Solar energy

10	Bachelor degree of Engineering	4	Solar energy

3.5 Data analysis

The process of data collection is where the expected data is gathered. The aim of data analysis is to observe the gathered information objectively while eliminating bias. Absolute objectivity in the research process is needed to analyze results properly. Data reduction is a data processing concept that entails processing, reorganizing, and concentrating results. Another term is data show, which refers to how captured data is minimized and organized acceptably when adhering to a technical data processing process. The data display's performance is a conclusion drawing that summarizes the information (Miles and Huberman 1994).

The study of interview transcripts and the exploitation and recognition of typical trends are parts of the data reduction process. The gathered data could then be reflected in philosophy to have common ideas with the collected literature. Nonetheless, because of the essence of PM, each project can be exceptional, this was discovered to be artificial. As a result, rather than focusing on literature, it was more practical to move forward. The data show process follows the data reduction phase, which entails categorizing and establishing relationships between patterns found.

3.6 Validation and reliability

The various measurements of social science studies necessitate the quantification of abstracts, intangibles, and constructs that are not always visible (Miller et al. 2009). These quantifications, on the other hand, will come in various ways of inference. Ascertaining the validity and efficiency of a measuring instrument is one of the most common challenges found in social science research (Kember and Leung 2008).

The degree to which a calculation tests what it claims to test is referred to as validity. Face validity, construct validity, content validity, and criterion validity are all examples of validity. Internal and external validity checks are the two major components of all validity tests (Wong et al. 2012). External validity refers to how accurately the measurements obtained from the study sample represented the referred population, while internal validity refers to how accurately the measures obtained from the test were simply quantifying what it was intended to measure. (Wong et al. 2012).

Reliability refers to the degree to which the effects of measure and operation can be repeated (Wong et al. 2012). While reliability is critical in determining the validity of a survey, it is not a requirement (Cooper et al. 2006). The divergence between observers or instruments of measurement, such as a survey, will cause a lack of reliability, as an instability of the attribute being measured (John 2001), which would invariably affect the validity of the survey. Equivalence, stability, and internal consistency are the three dimensions of durability (homogeneity) (Wong et al. 2012). The differentiation between these three factors is critical since it will direct the researcher in determining the efficacy of a test instrument such as a survey (Miller 2017).

The participants were anonymous to encourage them to answer the survey freely. The information of companies where the participants were working was also not mentioned to avoid the confidential issue. A presentation about research topics, research purpose, relevant concepts, and instruction of evaluation was given to every participant through Zoom to decrease the ambiguity of the survey. As mentioned in section 3.4, all the participants were chosen carefully to ensure they had enough knowledge and experience to understand this topic and do the survey. Besides, this survey only concentrated on specific industries, especially the manufacturing industry. Therefore, the outcomes of this study are suitable within the context.

4 Research Analysis and Results

In this chapter, I applied three steps to analyze the empirical data, which leads to solid research results. Step one aims to prove the CSFs vary among four project categories by the survey and fuzzy TOPSIS. In step two, to provide a supportive tool for project assessment, I build a model using KNN classification to analyze the causality between CSFs and project selecting decisions. The last step is to develop a mechanism for project selection containing the findings in step one and step two. All the steps will interpret in the following part.

4.1 Step 1: verify the difference of CSFs for various project categories

In the stage of determination of CSFs for every project category, figure 8 shows the whole process of using fuzzy TOPSIS to get the rank of CSFs. The project's CSFs were evaluated as alternatives by the survey respondents in the first step as well as evaluating the weight of project success criteria. The decision matrix and the weights of the parameters were determined in the second step, based on the project's success criteria. The decision matrix ranked the project's CSFs in the third step, using the weights of the project success obtained in the previous step and the Fuzzy TOPSIS process.

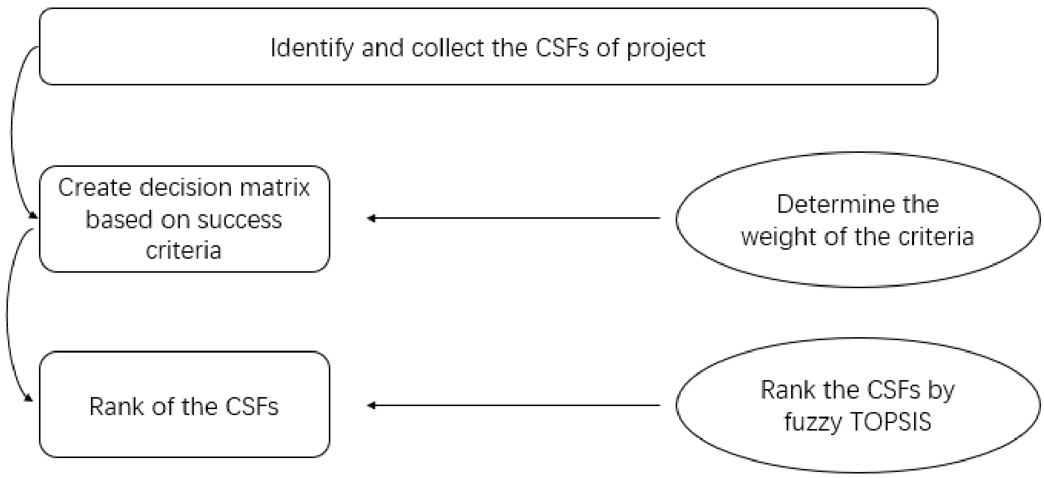

Figure 8. Process of ranking the CSFs using fuzzy TOPSIS

4.1.1 Overview of survey design

This survey aims to build the relationship between the CSFs and project categories. However, it is not complex to directly connect these two concepts. Instead, it is necessary to study the four project categories separately. Thus, the eventual purpose of this survey is to reveal the change of the CSFs in different project categories by assessing project performance. Because projects must be performed to meet particular goals that require the use of a company's resources, the project performance here can be indicated by success criteria (Bakar et al. 2011). Therefore, the survey was conducted in the following table 6.

6 success criteria were listed in table 6, incorporating them together to the project success. The explanation of these six success criteria is interpreted below:

- *Time (Frefer et al. 2018)*: On-time delivery (OTD) is one of critical requirements and KPI for PM. It is typically expressed as a ratio that can be measured over several periods.
- *Cost (Frefer et al. 2018)*: Project cost management is a system of forecasting, budgeting, and handling costs over the project life cycle with the intention of staying under the negotiated budget.
- *Quality (Frefer et al. 2018)*: Project quality control refers to the processes and methods used to assess and achieve the accuracy of a project's deliverables. Project managers are in need of implementing a quality management strategy for their projects. The main goal is to provide a product/service that meets consumer/stakeholder needs.
- *Sustainability*: Sustainability includes environment and safety (Silvius et al 2016). The environment is a part of the concept of sustainability. The concept of sustainability is introduced by PM policies, structures, and practices, which can be divided into social (people), environmental (planet), and economic dimensions (profit). In this case, environment refers to the project's outcome and process, which may benefit the environment for sustainability. The criterion of safety means ensuring that any employee has been prepared to do their work professionally, meet or exceed regulatory standards, and, in many situations, provide a behavioral or observational

safety policy in place to actively guarantee that workers are doing what the task requires. Combine these with the procedure and administrative protection approaches, as well as a never-ending commitment to ensuring that any employee returns home safely.

- *Expectation (Raziq et al. 2018)*: Any stakeholder has certain expectations when they participate in the project. The project team anticipates having all of the time, equipment, and help they need to complete the project without big mistakes occurring. The mission is expected to be finished successfully, according to top management. Clients want their requirements to be met and carried out that directly determines the customer's satisfaction.
- *Performance (Efficiency) (Kabirifar et al. 2019)*: It means a ratio used to assess the relationship between the outcomes of a process and the money expended in the project's completion. The number of outputs achieved for the inputs used can be used to determine project performance.

To rank and prioritize the CSFs for every project category, this research conducts a conceptual framework including sustainable success factors based on the framework developed by Zarina (2014), which has been introduced in literature review chapter. All the CSFs will be collected by reviewing existing literature and grouped into these six aspects, namely PM actions, project procedures, human-related factors, project-related factors, other external environment, and sustainable factors. Then use a mathematical method to score them so that the rank of all the CSFs can be gained to show the importance of the CSFs to the project success. In other word, project managers should pay more attention on those higher-ranked CSFs to ensure the project success.

After the literature review, 16 success factors have been collected for evaluation, including three sustainable success factors. The following part will explain them one by one:

- *Stakeholder management*： Stakeholder management is the art of maintaining constructive partnerships for those who have the most impact on your job. Maintaining good communication with each person is essential for keeping them involving.

- *Scheduling*: Scheduling in PM is the listing of projects, deliverables, and objectives within a project. A timetable usually includes a start and end date, as well as the duration of each operation and the services assigned to it. Effective project scheduling is a critical component of effective time management.
- *Project administration efficiency*: Under the direction of a project manager, project administration organizes the requisite team members and focuses on facilitating, monitoring, and evaluating tasks. Both project variables must be constantly monitored and controlled.
- *Control and monitoring*: The PM and control process happens at the same time as the project implementation phase. Monitoring and monitoring the project's development entails keeping track of its progress, assessing potential roadblocks, and making needed changes. Throughout this process, organizations must manage several activities, including catching up the schedule, staying on budget, preventing scope creep, and mitigating risk.
- *Strategy*: Strategy is a high-level approach to accomplish one or more targets in an uncertain environment. In a project context, project strategy is a guide in PM, leading to project success in its environment.
- *Leadership and team*: A project team comprises individuals who work together toward a shared purpose in partnership or cooperation. Team members must be considered individuals in terms of their skills, interests, societal norms and desires, and the relational interactions between team members for teams to be successful. To achieve achievement, leaders must develop their ability to develop vision and mission, influence and unite others against a shared goal, and encourage and inspire people.
- *Relationship with client*: It is about managing the relationship with past, new, and future clients. Good customer interactions are delivered by companies who handle their customer engagement well, increasing customer engagement and encouraging customer growth.
- *Resource*: To complete project tasks, PM necessitates the use of resources. This may include people, equipment, utilities, finances, or everything else that can be defined

(other than labor) required to complete a project process. As a result, the lack of capital will be a stumbling block in completing the project.

- *Use of technology:* The product developer will design and prototype the product with the help of technology. In some instances, various types of technologies are needed depending on the product. The developer must determine which areas of technology are required so that the appropriate practitioners can be found.
- *Scope and change:* Scope management is to produce a client-required deliverable. When change occurs, the project manager needs to manage the change while also ensuring the project is complete on schedule and on budget.
- *Policy:* International project aims to deliver product or service conducted among individual and companies in various countries. Thus, the product or service should comply with the laws and policies of the customer's country. Sometimes the diversity of policy and law may cause project issues while sometimes expanding some market opportunities for business and eliminating competitors.
- *Social factor:* The social factor is becoming increasingly important in PM. The project manager should create a supportive social network for diverse collaborators who have varying values, responsibilities, and perspectives. Besides, the organization should ensure the safety and health of the employees.
- *Legal agreement:* A legal arrangement is a formal text that spells out the obligations and duties of the parties involved in the contract. Contracts for the procurement of goods should be legally binding on all sides.
- *Top management support:* To ensure the possibility of project completion, project managers should have clear access to top management, and senior management must still assist project managers by providing funding, giving authority, providing help in emergencies, and developing competencies by training and learning initiatives.
- *Energy consumption:* The project team emphasizes a continuous improvement approach used to keep the energy usage, conditions, and carbon dioxide emissions of assets under management. The process-based operating model guarantees that the condition continues as desired while still allowing for further improvement.

- *Recycling and waste management:* Waste management and recycling are critical for the health of the environment and the human species. As a result, along with technological advancements in this area, the emphasis has shifted to waste management approaches such as minimal waste generation, waste sorting, waste processing, and so on.

These CSFs provide a robust roadmap for the project manager, which will guide them not only for project selection but also for achieving project success. The project manager should pay more attention to these CSFs, especially those that need to be strengthened in the PM lifecycle to ensure the project success, particularly in the planning, executing, and monitoring, and controlling phases. Nevertheless, the collected sustainable CSFs also remind project managers about the sustainable concept, which may contribute to the financial benefit, employees, society, and even our planet.

Table 6. Survey used in this study

Success Factors / Criteria	Evaluation of Weights					
	Time	Cost	Quality	Sustainability	Expectations	Performance (Efficiency)
Stakeholder management						
Scheduling						
Project Administration Efficiency						
Control and Monitoring						
Resource						
Strategy						
Leadership and team						
Customer Relation						
Use of Technology						
Scope and Change						
Policy						
Social Factor						
Legal Agreement						
Top Management Support						
Energy Consumption						
Recycling and Waste Management						

4.1.2 Ranking the CSFs using TOPSIS method

In this study, fuzzy TOPSIS was applied to evaluate the contribution made by success factors to the project success. The m alternatives and n attributes are incorporated into a geometric structure that is defined as a multi-criteria decision-making problem. The fuzzy TOPSIS is a method based on that the optimized alternative should be the most similar to the positive ideal solution while being the least similar to the negative ideal solution. Similarity to the positive-ideal solution and remoteness from the negative-ideal solution are two TOPSIS indices. The process then selects an alternative that is the most equivalent to the positive-ideal solution (Hwang and Yoon, 1981; Wang and Chang, 2007). A decision-maker's ability to allocate a particular performance ranking to an option for the qualities under consideration is often hampered. The advantage of using a fuzzy approach is that it allows you to attach relative value to attributes using fuzzy numbers rather than exact numbers, which is more appropriate for the real world in a fuzzy setting. The TOPSIS is extended to the fuzzy world in this portion (Kuo et al. 2007; Yang and Hung 2007). This approach is especially well suited to solving the problem of group decision-making in a fuzzy setting. Prior to the development of fuzzy TOPSIS, we quickly study the reasoning for fuzzy theory.

The next step is to determine the rank of CSFs for different project category, after the surveys have been collected from respondents. As mentioned in literature review, fuzzy TOPSIS is a method for multi-criteria decision making, which will be used for the determination. In the following, some basic definition and formulation will be explained.

4.1.2.1 Fuzzy number

Fuzzy set: Each part of the $\tilde{A}$ Fuzzy set is assigned a real number in the [0, 1] interval using the $\mu_{\tilde{A}}(x)$ membership function. The numerical value of $\mu_{\tilde{A}}(x)$ indicates the degree to which the x element is a part of the set.

Fuzzy number: Fuzzy number $\tilde{A}$ is a normal and convex subset of X, while normality means $\exists x \in \mathbb{R},\ \bigvee_{x} \mu_{\tilde{A}}(x) = 1$ and convex means

$$\forall x_1 \in X,\ x_2 \in X,\ \forall \alpha \in [0,1],\ \mu_{\tilde{A}}(\alpha x_1 + (1-\alpha)x_2) \geq \min\big(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\big) \quad (1)$$

As seen in figure 9, a triangular fuzzy number A can be defined by a triple (a, b, c).

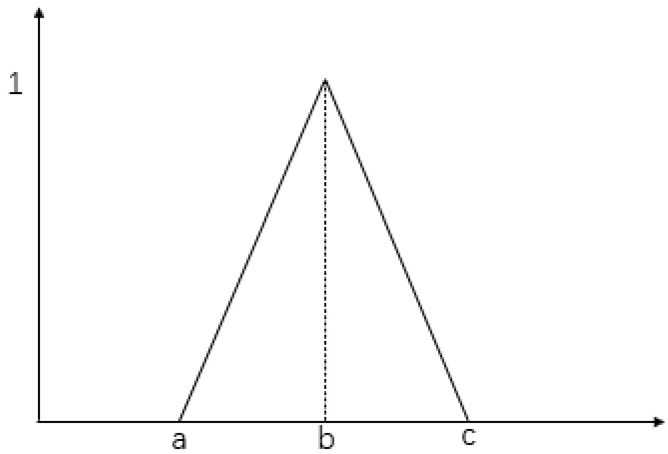

Figure 9. Triangular fuzzy number

$$\mu\tilde{A}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & x > c \end{cases} \quad (2)$$

4.1.2.2 Linguistic variable

When grappling with situations that are too complex or loosely described to be properly interpreted using conventional quantitative expressions, the concept of a linguistic variable comes in handy. A fuzzy set can be used to model any linguistic value. Terms, sentences, and artificial languages are used to communicate linguistic variables. The linguistic variables in this article are the significance weights of various indices, as well as the ratings of qualitative parameters. Tables 7 and 8 show how positive triangular fuzzy numbers can be used to represent these linguistic values.

Table 7. Use triangular fuzzy number to represent linguistic value

Very low (VL)	(0, 0.1, 0.3)
Low (L)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
High (H)	(0.5, 0.7, 0.9)
Very high (VH)	(0.7, 0.9, 1)

Table 8. Another way of presenting linguistic value by triangular fuzzy number

Very poor (VP)	(0, 0, 3)
Poor (P)	(0, 3, 5)
Fair (F)	(2, 5, 8)
Good (G)	(5, 7, 10)
Very good (VG)	(7,10,10)

4.1.2.3 Fuzzy number representation

This paper uses the canonical representation of operations on triangular fuzzy numbers to create a simple fuzzy TOPSIS technique. This methodology employs the graded mean integration representation procedure.

The graded mean integration representation of a triangular fuzzy number $\tilde{A}$= (a_1, a_2, a_3) is defined as:

$$P(\tilde{A})=1/6\ (a1,\ a2,\ a3) \qquad (3)$$

Tables 9 and 10 demonstrate the graded mean integration representation of each criterion's significance weight and ratings using Eq. 4. Let $\tilde{A}$= (a1, a2, a3) and $\tilde{B}$= (b1, b2, b3) be two fuzzy triangular numbers. The graded mean integration representations of triangular fuzzy numbers $\tilde{A}$ and $\tilde{B}$ can be obtained as follows by adding Eq. 4 and 5:

$$P(\tilde{A})=1/6\ (a_1,\ a_2,\ a_3) \qquad (4)$$

$$P(\tilde{B})=1/6\ (b_1,\ b_2,\ b_3) \qquad (5)$$

Table 9. Graded mean integration of $\widetilde{A}$

Very low (VL)	0.12
Low (L)	0.3
Medium (M)	0.5
High (H)	0.7
Very high (VH)	0.83

Table 10. Graded mean integration of $\widetilde{B}$

Very poor (VP)	0.5
Poor (P)	2.83
Fair (F)	5
Good (G)	7.17
Very good (VG)	9.5

The following is a description of the addition operation on triangular fuzzy numbers A and B:

$$\begin{aligned} P(\tilde{A} \oplus \tilde{B}) &= P(\tilde{A}) + P(\tilde{B}) \\ &= \frac{1}{6}(a_1 + 4 \times a_2 + a_3 + b_1 + 4 \times b_2 + b_3) \end{aligned} \tag{6}$$

The following is the canonical representation of the multiplication operation on triangular fuzzy numbers A and B:

$$\begin{aligned} P(\tilde{A} \otimes \tilde{B}) &= P(\tilde{A}) \times P(\tilde{B}) \\ &= \frac{1}{6}(a_1 + 4 \times a_2 + a_3) \times \frac{1}{6}(b_1 + 4 \times b_2 + b_3) \end{aligned} \tag{7}$$

In contrast to the modern multiplication operation, the canonical representation of the multiplication operation on triangular fuzzy numbers found in Eq. 8 produces a crisp integer, not a triangular fuzzy number. This property is particularly useful for reducing decision-making computational complexity.

Assume that there are k decision-makers on the committee (D_1, D_2, ..., D_k). A multiple criteria decision-making (MCDM) dilemma can be expressed succinctly in matrix format as follows:

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{8}$$

where A_1, A_2, ..., A_m are potential alternatives, C_1, C_2, ..., C_n are parameters that assess alternative results, and x_{ij} is the ranking of alternative A_i against criteria C_j. The weights of parameters and the rank r_{ij} of alternative A_i are evaluated in linguistic terms expressed as triangular fuzzy numbers in this article.

4.1.2.4 Aggregate the importance weights

Let $w_{jt} = (a_{jt}, b_{jt}, c_{jt}), j = 1,2, \dots, n, t = 1,2, \dots, k$ be the weight provided to criterion C_j by the decision-maker D_k. First, Eq. 9 is used to achieve the graded mean integration representation of fuzzy numbers $w_{jt} = (a_j, b_{jt}, c_{jt})$, denoted as w'_{jt}. The committee of k decision-makers will then determine the aggregated value weight W_j of criterion C_j as follows:

$$W_j = \frac{\sum_{t=1}^{k} w'_{jt}}{k} \tag{9}$$

where w'_j is a crisp number with the graded mean integration representation of fuzzy numbers as its value.

4.1.2.5 Aggregate rating of alternatives

Let $r_{ijt} = (o_{ijt}, p_{ijt}, q_{ijt}), r_{ijt} \in R^+, i = 1,2, \dots, m, j = 1,2,$ ...n, t=1, 2, ..., k be the suitability rating given to alternative A_i by decision-makers D_t in relation to parameters C_j. First, using the graded mean integration representation of fuzzy numbers, the ranking r_{ijt} can be converted into crisp numbers r'_{ijt}. The aggregated ranking $R_{ij} = (o_{ij}, p_{ij}, q_{ij})$ of alternative A_i for parameters C_j can then be calculated as follows:

$$R_{ij} = \frac{\sum_{t=1}^{K} r'_{iji}}{K} \tag{10}$$

It's important to note that there are two types of fuzzy or non-fuzzy criteria: benefit and cost. To maintain continuity between the fuzzy (or non-fuzzy) evaluation values of all criteria, the fuzzy (or non-fuzzy) evaluation values of objective parameters must be converted into a consistent scale (into dimensionless indices). The process is used to convert triangular fuzzy numbers in this paper since it retains the property that the ranges of transformed triangular fuzzy numbers belong to [0,1]. If $T_{ij} = (g_{ij}, u_{ij}, v_{ij})$ (where $i = 1,2, \dots, m, j = 1,2, \dots, n$) is the fuzzy (or nonfuzzy) cumulative cost/benefit applied to alternative A_i versus objective parameters C_j, then the transformed criteria, $r_{ij}^* = (o_{ij}, p_{ij}, q_{ij})$, may be determined as follows:

For benefit criteria:

$$r_{ij}^* = (g_{ij}/v_j^*, u_{ij}/v_j^*, v_{ij}/v_j^*) \tag{11}$$

Where $v_j^* = \max v_{it}$

For cost criteria:

$$r_{ij}^* = (g_j^-/v_{ij}, g_j^-/u_{ij}, g_j^-/g_{ij}) \tag{12}$$

Where $g_t^- = \min g_{it}$

Then, formulation for the rating of objective criteria is:

$$R_{ij} = \left(\frac{1}{6} \times o_{ij} + \frac{4}{6} \times p_{ij} + \frac{1}{6} \times q_{ij}\right) \tag{13}$$

4.1.3 Result of rank

After collecting the data from respondents, the fuzzy TOPSIS method has been implemented by MATLAB to determine the rank of all the CSFs for four project categories. The procedure of ranking the CSFs is interpreted using data about derivative project as an example.

The first step is to determine the weight of project success criteria after the survey respondents evaluate the importance of criteria using 'Very Low', 'Low'. 'Medium Low', 'Medium', 'Medium High', 'High', and 'Very High', which are later transferred to numeral value (see below code).

```
VL=[0 0 0.1 0.2 1];      %VL
L=[0.1 0.2 0.2 0.3 1];  %L
ML=[0.2 0.3 0.4 0.5 1]; %ML
M=[0.4 0.5 0.5 0.6 1];  %M
MH=[0.5 0.6 0.7 0.8 1]; %MH
H=[0.7 0.8 0.8 0.9 1];  %H
VH=[0.8 0.9 1.0 1.0 1]; %VH
```

The next step is to calculate the weight of the project success criteria with the equation 9. The code is listed as follow.

```
function W=aggregatew(WD,k,n)
for i=1:n
    tmp1=[];     tmp2=[];     tmp3=[];     tmp4=[];
    for j=1:k
        tmp1=[tmp1 WD{j}{i}(1)];
        tmp2=[tmp2 WD{j}{i}(2)];
        tmp3=[tmp3 WD{j}{i}(3)];
        tmp4=[tmp4 WD{j}{i}(4)];
    end
    Wj1a(i)=min(tmp1);
    Wj2a(i)=1/k*sum(tmp2);
    Wj3a(i)=1/k*sum(tmp3);
    Wj4a(i)=max(tmp4);
end
W=[Wj1a;Wj2a;Wj3a;Wj4a];
```

The weight of the derivative project success criteria is shown as

$$W=\begin{bmatrix} 0.50 & 0.70 & 0.75 & 0.90 \\ 0.50 & 0.80 & 0.83 & 1.00 \\ 0.50 & 0.78 & 0.82 & 1.00 \\ 0.10 & 0.31 & 0.33 & 0.60 \\ 0.20 & 0.68 & 0.71 & 0.90 \\ 0.50 & 0.78 & 0.79 & 0.90 \end{bmatrix}$$

The third step is to transfer the linguistic evaluation of CSFs to the numeral value and calculate the aggregate rating of alternative by equation 13.

```
VP=[0,0,1,2, 1];      %vp
P=[1,2,2,3, 1];       %P
MP=[2,3,4,5, 1];      %MP
F=[4,5,5,6, 1];       %F
MG=[5,6,7,8, 1];      %MG
G=[7,8,8,9, 1];       %G
VG=[8,9,10,10,1];     %VG
for i=1:m
    FDMA(i,:)=aggregateFDM(FDM,i,k,n);
```

```
end

for j=1:n
    for i=1:m
        matrixB(i,j)=FDMA{i,j}(4);
        matrixC(i,j)=FDMA{i,j}(1);
    end
end

    dividerB=max(matrixB);
    dividerC=min(matrixC);

for i=1:m
    for j=1:n
        if criteria(j)==1
            FDMN{i,j}(1:4)=FDMA{i,j}(1:4)./dividerB(j);
        elseif criteria(j)==2
            FDMN{i,j}(1:4)=dividerC(j)./FDMA{i,j}(4:-1:1);
        end
    end
end

for i=1:m
    for j=1:n
        FDMNW{i,j}(1:4)=FDMN{i,j}(1:4).*Wagg(j,:);
    end
end
```

Table 11. Rank of CSFs

CSFs Group	CSFs Item	Derivative	Platform	Break-through	R&D
Project Management Action	Stakeholder Management	3	3	10	5
	Project Administration Efficiency	1	1	5	6
	Strategy	10	7	14	8
Project Procedure	Scheduling	4	4	4	4
	Control and Monitoring	6	14	9	13
	Scope and Change	12	9	3	1
Human-related Factors	Leadership and Team	2	5	1	3
	Customer Relation	7	6	2	0
Project Related Factors	Resource	14	10	6	9
	Use of Technology	5	2	8	7

	Top Management Support	15	13	11	14
External Environment	Policy	13	11	7	2
	Legal Agreement	8	12	16	10
Sustainable Factors	Social Factor	11	8	15	11
	Energy Consumption	16	15	12	15
	recycling & waste management	9	16	13	12

The above table 11 shows all the ranks of CSFs for 4 project categories. All the ranks of CSFs are transferred to the importance of CSFs to visualize and analyze. The importance of the CSFs group is first shown below figure 10 to gain a holistic picture of all the CSFs. Then the figure shows the importance of some picked CSFs, which have obvious trends.

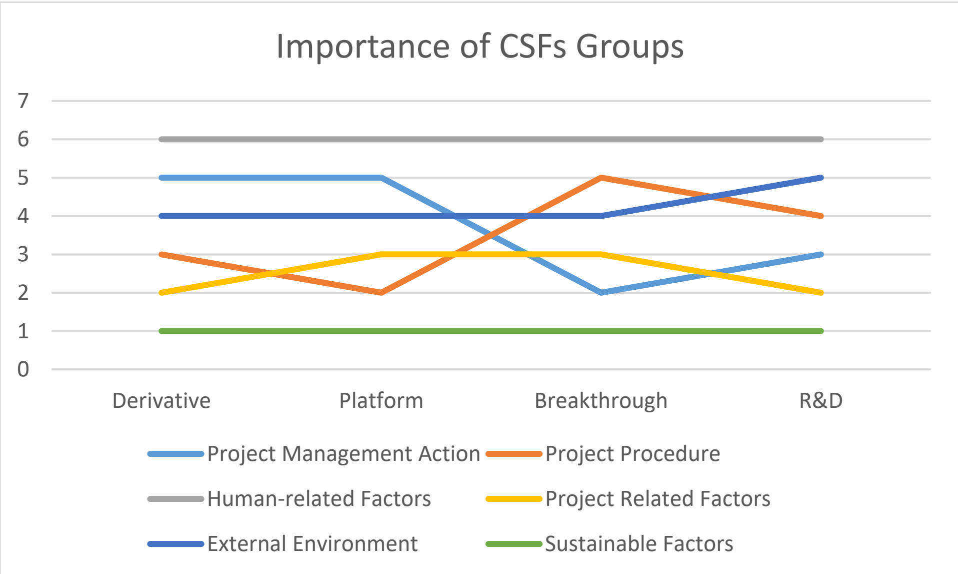

Figure 10. Importance of CSFS groups

Some findings from CSFs groups perspective emerge from the figure 10:

- Human-related factors are the most critical factor group among all.
- The importance of PM action, project procedure, project-related factor, and external factors vary in different project category.
- Sustainable factors have the least importance to the project success.

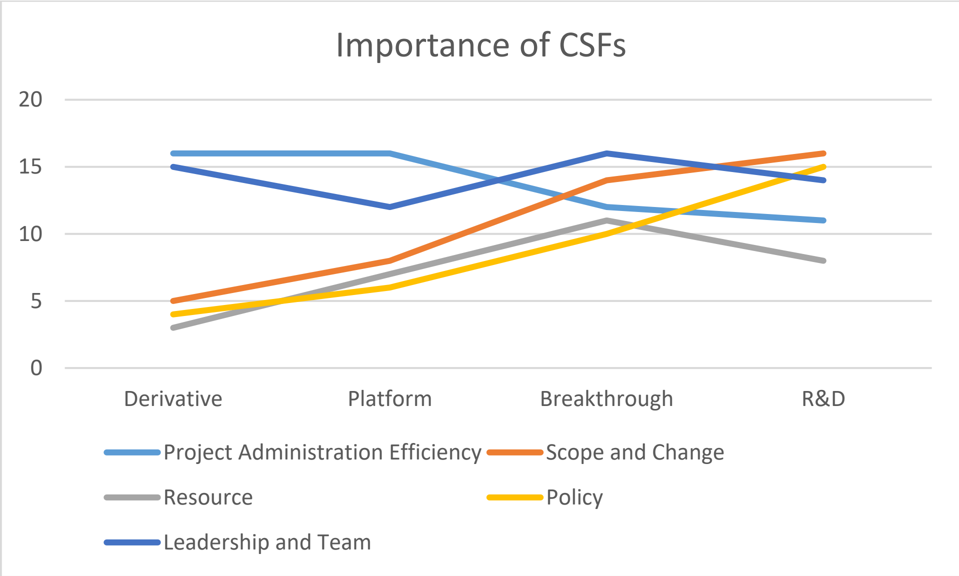

Figure 11. Importance of CSFs

According to the figure 11, the importance of scope and change, resource, and policy is clearly increasing from derivative project to R&D project while project administration efficiency is decreasing. The leadership and team factor stays constant and shows its importance among other factors.

Overall, all the findings regarding CSFs of different project category can be concluded as:

- The CSFs vary significantly corresponding to the project category, particularly those 11 factors in 4 CSFs groups which are PM action, project procedure, project-related factor, and external factor.
- Sustainable CSFs do not play an important role in PM in China. One reason is that China is still a developing country, and Chinese companies more intend to pursue the profit instead of considering sustainability, although the Chinese government has realized the importance of the environment and society, especially the crisis regarding the global warming and other pollution. Thus, the Chinese government has enacted a set of laws to protect environment and human rights. It still needs time to let companies to change their mindsets, particularly the small and medium-sized enterprises. Furthermore, the concerning about employees' healthy is overwhelming over the world in the pandemic time except in China. The virus has been under control very soon in China, and now Chinese return back to normal life, which may

not drive them to concern about the health issue. Otherwise, the social factor about safety and health will show significance.

- The factors regarding humans, both internally and externally, have the most impact on the project outcome. It is not difficult to understand this finding because human makes all the operation and project activity. Thus, these factors can have a significant influence on other factors. For instance, the capacity of the project manager and team member can impact the PM efficiency and positively
- When the level of product change and process change increases, the project team should pay much more attention to the policy, especially on the non-commercial project. The main reason for focusing on policy is that non-commercial projects do not have a specific customer. It needs to identify the potential targets living in various countries and analyze the policies correspondingly, which makes the analysis significantly essential and complex.
- When the level of product and process change increases, the project success relies more on the scope management and availability of resources instead of project administration efficiency. The increased level of product and process change implies the complexity and uncertainty of the project increasing. The increasing complexity and uncertainty may lead to all kinds of change requirements in every PM area as well as mistakes occur, which requires more resources to apply the change and cope with contingencies and mistakes. In this scenario, the project team will suffer from the project's uncertainty and changes that result in management efficiency. That is the reason the PM efficiency becomes less important from derivative project to R&D project.

4.2 Step 2: build a model for project assessment

4.2.1 A model for assessing project in early stage

As previously highlighted, this study used a machine learning algorithm to propose a model for project assessment focused on CSFs of project execution. In this paper, the K-nearest Neighbor (KNN) classification is chosen because it is a simple but very effective tool for classification, particularly for the small database. It is a non-parametric algorithm, which can lead to the discovery of secret relationships in the records, which can lead to a whole new insight or the discovery of unexpected outcomes. Another advantage of KNN is that it can perform well when the relationship among all the features is not linear. In a word, it is suitable for project selection.

4.2.2 KNN classification

The K-nearest neighbor algorithm is an example of instance-based learning (IBL) that allows classifications to be made based on specific training instances rather than creating a model from training data. IBL approaches use a proximity metric and a classifying function to estimate the distance between data inputs. The eventual class of a test case is determined by its proximity to other examples (instances). A closest neighbor classifier that represents an instance may be created, and the instance may then be placed as a data origin in the d-dimension space, where d is the number of features. Next, determine the distance between the instance and the remainder of the training data. When k = 1, 2, or 3, for example, Figure 12 depicts the closest neighbors among the data in the circle's center. To forecast, the neighbors' class labels are employed. When there are many groups of neighbors, the data item is allocated to the plurality class of the closest neighbors. In figure 12a, the data point's 1 -nearest neighbor is a negative instance. As a result, the data point has been classified as negative. As shown in Figure 12c, when the closest neighbors are three, the neighborhood comprises two positive samples and one negative sample. The data point is assigned to the positive class using a majority vote technique. The distance between each test instance point $r = (x, y)$ and all the training instances (x, y) ∈D is measured via K-closest neighbor to construct the nearest neighbor array (D represents the entire dataset). There are several ways to calculate the distance between a point and its neighbor class for continuous features, including Euclidean, Manhattan, and Minkowski, which are formulated in equations 13, 14, and 15, respectively; for discrete features, hamming distance is used to enforce XOR between points.

$$\text{Euclidean Dist} = \left[\sum_{i=1}^{k} (|x_i - y_i|)^2\right]^{1/2} \quad (14)$$

$$\text{Manhattan Dist } = \sum_{i=1}^{k} |x_i - y_i| \quad (15)$$

$$\text{Minkowski Dist } = \left[\sum_{i=1}^{k} (|x_i - y_i|)^q\right]^{1/q} \quad (16)$$

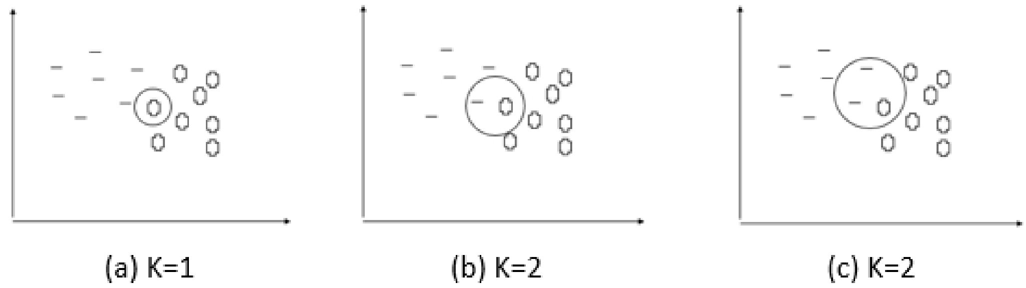

Figure 12. Nearest neighbors among the data when K = 1, 2, 3

4.2.3 Result of classification

Total 48 derivative projects have been collected from a Chinese company to show how the KNN classification model works. These 48 projects all have individual linguistic evaluations, including the result of project performance standardized in the company's format. In the KNN model, 8 CSFs are chosen as the project's features to simplify the simulation and be closer to reality. However, the CSFs in that company's linguistic evaluation are not the same as the 8 CSFs defined. Some are missing in the evaluation, while some have been combined. The first step of the validation is to cover the evaluation to another format using the CSFs defined before. Then re-evaluate the CSFs of every project qualitatively using "very poor", "poor", "air", "good", and "very good" which can be represented by numbers 1, 3, 5, 7, and 9 accordingly. Meanwhile, project performance has been classified as 1 and 0, which mean the acceptable and high risky. The example of data collected is shown in table 12.

Table 12. Example of derivative project data

	control and monitoring	Customer relation	stakeholder management	scheduling	Leadship and team	project administration efficiency	use of technology	Legal aggreement	Result
1	9	7	7	9	5	3	3	9	1
2	7	7	3	3	5	3	7	3	0
3	7	9	7	3	5	7	3	5	0
4	3	7	7	3	5	3	7	5	0
5	3	5	5	3	7	3	7	5	0
6	5	3	9	3	5	9	3	7	0
7	3	9	7	9	7	7	9	3	0
8	9	5	9	5	9	9	5	5	1
9	9	5	5	5	3	9	9	5	1
10	9	3	3	5	3	9	7	5	1

The next step is to divide collected data into two groups: training data and test data. The recommended ratio of the two groups is 1:3. Thus, 12 projects are grouped into the training data, and left projects are grouped into the test data. All the numeral value needs to be separated into features and results and then needs to be normalized. The below code shows the separating the data and normalizing them.

```
    training_data = load('train_data.txt');
     testing_data = load('test_data.txt');
     train_target = training_data(:, end);
     test_target = testing_data(:, end);
     train_data = training_data(:, 1: end-1);
     test_data = testing_data(:, 1: end-1);
     mean_of_dimension = mean(train_data);
     std_deviation = std(train_data, 1);
     train_data = normalise(train_data, std_deviation, mean_of_dimen-
sion);
     test_data = normalise(test_data, std_deviation, mean_of_dimen-
sion);
```

After normalization, the nearest neighbor distance is calculated using Euclidean equation and then sort the minimum distance.

```
for i = 1:size(test_data, 1)
        D = test_data(i, :) - train_data(: , :);
        D = D.^2;
        dist_mat = sum(D, 2);
        dist_mat = sqrt(dist_mat);
        dist = [dist_mat train_target];
        dist = sortrows(dist, 1);
```

After verifying the prediction with the result in test data, the accuracy can be determined by the number of correct predictions dividing by the total number of predictions. The result is listed below. It indicates the accuracies are very close regardless the number of K and the accuracy is the highest when K equals to 10.

The table 13 shows the accuracy of different K value. The highest accuracy is 0.75 which seems not a satisfied result mainly because of the size of the samples. Large size of samples usually gets the better result. Besides, there are several available methods to increase the accuracy. The most popular way of combining several models to increase accuracy using bagging and boosting is ensemble models. More than any single model, the Ensemble method will increase prediction accuracy. And random forests is a common technique for putting together machine learning models. There are two reasons to use ensemble approaches to increase the model's accuracy. First, they're more complicated than conventional methods, and second, traditional methods have a good starting point from which you can refine and draw ensembles with your ML model. Re-validating a machine learning algorithm at regular intervals will also increase the model's accuracy. This necessitates scoring the model after using the latest data on a regular, weekly, or monthly basis, depending on the data adjustments.

Table 13. Accuracy of the KNN classification

	Accuracy
K=1	0.73
K=5	0.71
K=10	0.75

This model can be used for predicting the project. For example, if the evaluation of derivative project for each feature is [1 1 1 8 9 8 1 3], the model outputs a result "0" that means the project will have high risk and needs to be rejected.

4.3 Step 3: develop a mechanism for project selection

Figure 13 depicts how an organization should use the KNN appraisal model in project selection. Starting with the classifying the project category and then project statement and the business scenario, the company environmental considerations and expertise accumulated in previous projects, as well as business case, are critical for defining reliable and viable tenders. Managers, on the other hand, may use prior experience to describe or re-define project CFSs.

Portfolio managers need to prepare an evaluation for a new project by considering the same CSFs, including other inputs. Meanwhile, the KNN classification model identifies the best practices pattern from previous knowledge and data and then outputs the possible result. The project is important and poses a 'usual' level of danger to the company's project portfolio plan if the outcome is satisfactory. Managers can adjust the project's CSF characteristics or consider a higher degree of risk if the performance is inadequate (low chance of success). The model enables action modeling, including simulating and checking several CSFs in the different circumstance to assess various project scenarios before they are launched.

The project manager will be responsible for the project charter, which will be used to review the project. If the portfolio management accepts it and it goes on to the initiating phase. Main progress indicators based on the same project CSFs can be used to measure project performance under the project portfolio approach. The final version of the business case, which includes the project appraisal and project category, which are usually used to extend a project knowledge database as the organizational asset, will allow the model to be improved as the number of projects under review and feedback on results grows. The accuracy of the model can be increased by modifying the structure of the model or feeding more data to the model.

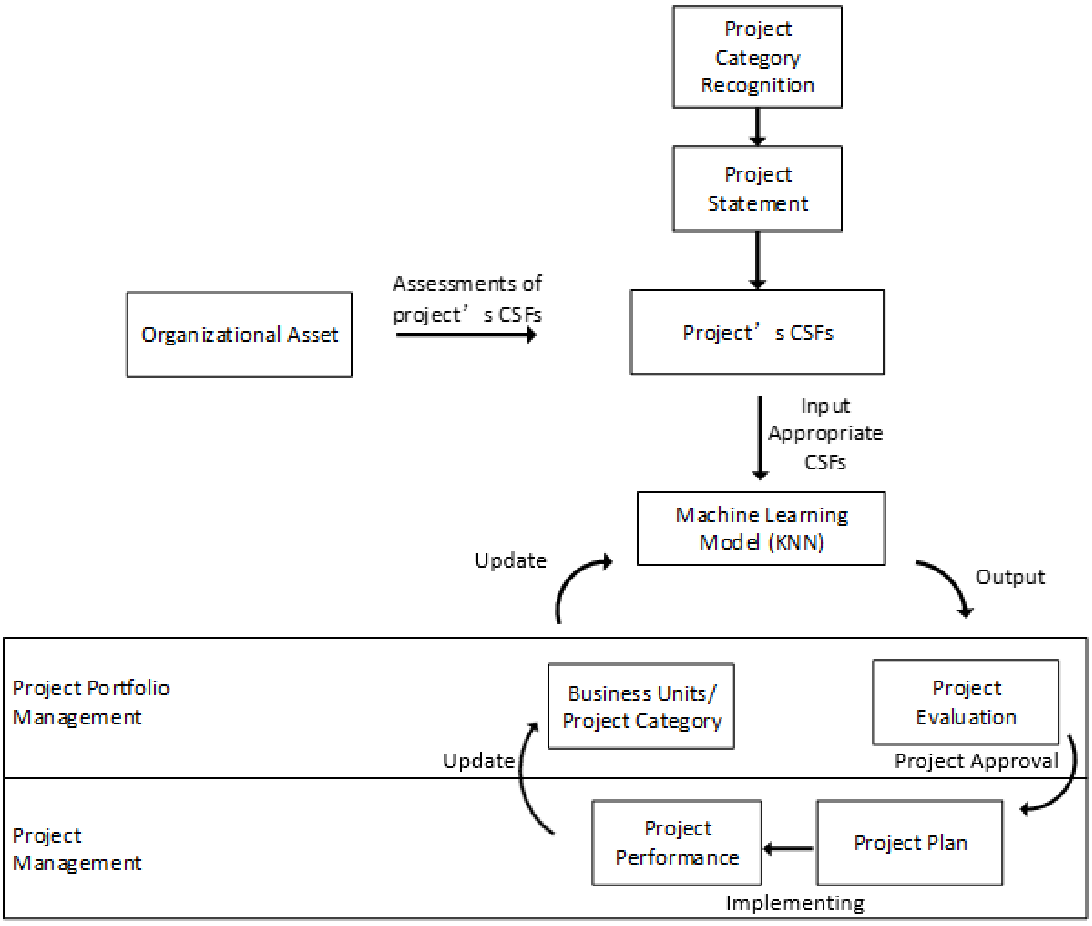

Figure 13. Mechanism for project selection

5 Summary and Conclusion

5.1 Summary of the study

This research set out to use survey data to verify the difference of CSFs among project categories using fuzzy TOPSIS. Though the data collected only from three respondents who had similar work experience and worked in the same industry, it is shown that the change of the CSFs in different project category was in accordance with the core concept using to define four project categories, which is the level of product change and process change. The research found that project success requires PM action and procedure more at the low level of change. When the level of change increased, the project success trended to reply on the capability of the project manager and project team. Besides, the resource factor also varied significantly. This factor had more influence on the project having the higher level of change. This finding can offer a meaningful strategy to portfolio managers. For the project having a low level of change, portfolio managers need to concrete the PM procedure to increase the project administration efficiency for the project manager. For the high level of change project, portfolio managers should choose an appropriate project manager, build a strong project team, and guarantee the extra resource available.

Though Many studies acknowledge the importance of early project assessment evaluating the CSFs in project selection, a systematic method to support the assessing the project is still lacking. This paper proposed a novel approach to assess the project. According to company practice, CSFs are immediately linked to project performance during the design, validation, and testing of a KNN classification model. The model serves as a decision support tool for the project selection process, identifying early indicators of failure by considering a project's compatibility with organizational policy and the riskiness of accepting the project.

Finally, it's worth noting that the study aimed to develop a standardized approach for early project evaluation that could be applied to any CSF platform currently available. The defined process, in particular, are not a normal linguistic evaluation widely used nowadays concerning the correlation among CFSs, project category and project selection decision, but rather an indicator made by both qualitative and quantitative methods showing the early project assessment meets the requirements of a particular contractor since its CSFs profile shows an important and accurate connection to project performance.

Table 14 summarize how the research findings answer the research questions and the recommendation to the portfolio managers.

Table 14. Summary of research findings

Research Questions	Research Findings
Do CSFs vary according to the project category?	1. CSFs vary among the project category, especially the factors in specific 4 CSFs groups.
	2. When the level of product and process change increases, scope management and resource management is required more while the PM efficiency becoming less important. Besides, the importance of policy factor also increases gradually along with the increasing of project change.
	3. The human related factor shows extreme importance constantly among 4 project categories.

How can a supportive method be established to help project managers to select the project for portfolio?	The KNN classification algorithm can identify the best practices from previous data and predict the result for project assessment in early stage.

These findings have important implications for bringing new insight into PM, portfolio management, and project selection. Regardless of the project category, organizations and managers related to PM have priority to improve the project manager's managerial ability as well as the project team's relevant skills and enhance the relationship with the customer. Meanwhile, Portfolio managers and project managers need to pay attention to the different CSFs for different project categories to ensure project success. The concentration on the CSFs should adjust corresponding to the level of product change and process change. For projects having a low level of product and process change, portfolio managers need to focus on the PM action and procedure. When the change increases, the focus turns to scope management, policy analysis, availability, and resource allocation. Furthermore, by using the KNN classification model, portfolio managers will only need to focus on the scoring project according to the CSFs instead of investing substantial time and cost on the traditional linguistic evaluation, which can get more efficient and rational results support portfolio managers to make decision.

5.2 Conclusion, limitation and future research

The findings of this paper can practically become a powerful tool for the company, not only for project selection, but also for project-self assessment. Portfolio managers can assess the project in early stage with lower invested resource and obtain the optimal and rational result by identifying the best practice from previous projects and knowledge. Project managers can also utilize the approach to assess the project and get a holistic picture regarding CSFs. To ensure the project success, project managers should enhance the weak CSFs to mitigate the risk of failure and strengthen the strong CSFs to increase the opportunity of the success.

The most critical limitation of this research is the number of the survey. Although more respondents can provide an accumulated insight about differentiation of CSFs among the project categories, qualification of the respondents needs to be considered carefully. The respondents should understand the project category and CSFs both theoretically and practically so that they can evaluate the CSFs rationally.

The research's another drawback is that the analytical study is limited to a sample of projects due to the time limitation and confidential issue. Despite the fact that the sample size was important in terms of the number of projects from various areas. As a result, our future efforts will be focused on achieving a larger sample size in order to improve the generalizability of the findings or to validate the results' relevance only to particular contexts.

In addition, future researches can follow one of two paths. To begin, the research team will continue to produce, implement, and validate improved KNN algorithms on other CSF systems. Second, the methodology of the thesis can be strengthened by closely linking CSFs to KPIs and analyzing experts'/project managers' descriptions of project business cases in order to strengthen risk analysis capability and move from a classification to a regression approach. To that end, an analytical mathematical structure must be created, as well as dedicated filters to deal with results that contradict expert decisions (and vice versa), as well as to avoid incorrect comparisons between CSFs and performance levels.

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Appendices

Appendix 1. Fuzzy TOPSIS Code

```
function W=aggregatew(WD,k,n)

for i=1:n
    tmp1=[];    tmp2=[];    tmp3=[];    tmp4=[];
    for j=1:k
        tmp1=[tmp1 WD{j}{i}(1)];
        tmp2=[tmp2 WD{j}{i}(2)];
        tmp3=[tmp3 WD{j}{i}(3)];
        tmp4=[tmp4 WD{j}{i}(4)];
    end
    Wj1a(i)=min(tmp1);
    Wj2a(i)=1/k*sum(tmp2);
    Wj3a(i)=1/k*sum(tmp3);
    Wj4a(i)=max(tmp4);
end

W=[Wj1a;Wj2a;Wj3a;Wj4a];

for i=1:n
    Wv(i,:)=W(:,i)';
end
W=Wv;

function FDM=aggregateFDM(FDM,z,k,n)


for i=1:n
        tmp1=[];    tmp2=[];    tmp3=[];    tmp4=[];
    for j=1:k
        tmp1=[tmp1 FDM{j}{z,i}(1)];
        tmp2=[tmp2 FDM{j}{z,i}(2)];
        tmp3=[tmp3 FDM{j}{z,i}(3)];
        tmp4=[tmp4 FDM{j}{z,i}(4)];
    end
   Wj1a(i)=min(tmp1);
   Wj2a(i)=1/k*sum(tmp2);
   Wj3a(i)=1/k*sum(tmp3);
   Wj4a(i)=max(tmp4);

end
FDMtmp=[Wj1a; Wj2a; Wj3a; Wj4a];
for i=1:n
    FDM2{:,i}=FDMtmp(:,i)';
end
```

```
FDM=FDM2;

function [Simil] = fsimil1(A,B)

P_A=sqrt((A(1)-A(2))^2+A(5)^2)+sqrt((A(3)-A(4))^2+A(5)^2)+(A(3)-
A(2))+(A(4)-A(1));
P_B=sqrt((B(1)-B(2))^2+B(5)^2)+sqrt((B(3)-B(4))^2+B(5)^2)+(B(3)-
B(2))+(B(4)-B(1));

minmax=(min(P_A,P_B)+min(A(5),B(5)))/(max(P_A,P_B)+max(A(5),B(5)));
S1=1-sum(abs(A(1:4)-B(1:4)))/4;
Simil=S1*minmax;

VL=[0 0 0.1 0.2 1];
L=[0.1 0.2 0.2 0.3 1];
ML=[0.2 0.3 0.4 0.5 1];
M=[0.4 0.5 0.5 0.6 1];
MH=[0.5 0.6 0.7 0.8 1];
H=[0.7 0.8 0.8 0.9 1];
VH=[0.8 0.9 1.0 1.0 1];


VP=[0,0,1,2, 1];
P=[1,2,2,3, 1];
MP=[2,3,4,5, 1];
F=[4,5,5,6, 1];
MG=[5,6,7,8, 1];
G=[7,8,8,9, 1];
VG=[8,9,10,10,1];


function Sstar=fuzzysimveca(FDMNW,FPIS,n,simi)

for i=1:n
    if simi==1
        Sstar(i)=fsimil3([FDMNW{i}(1:4) 1],[FPIS{i}(1:4) 1]);
    elseif simi==2
        Sstar(i)=fsimil4a([FDMNW{i}(1:4) 1],[FPIS{i}(1:4) 1]);
    elseif simi==3
        Sstar(i)=fsimil1([FDMNW{i}(1:4) 1],[FPIS{i}(1:4) 1]);
    elseif simi==4
        Sstar(i)=fsimil2([FDMNW{i}(1:4) 1],[FPIS{i}(1:4) 1]);
    end
end
```

```
function[CCS,Sstar,Sneg,Order]=Stopsis(WD,FDM,k,m,n,ideal,criteria,si
mi)


Wagg=aggregateW(WD,k,n);

for i=1:m
    FDMA(i,:)=aggregateFDM(FDM,i,k,n);
end


for j=1:n
    for i=1:m
        matrixB(i,j)=FDMA{i,j}(4);
        matrixC(i,j)=FDMA{i,j}(1);
    end
end


    dividerB=max(matrixB);
    dividerC=min(matrixC);


for i=1:m
    for j=1:n
        if criteria(j)==1
            FDMN{i,j}(1:4)=FDMA{i,j}(1:4)./dividerB(j);
        elseif criteria(j)==2
            FDMN{i,j}(1:4)=dividerC(j)./FDMA{i,j}(4:-1:1);
        end
    end
end


for i=1:m
    for j=1:n
        FDMNW{i,j}(1:4)=FDMN{i,j}(1:4).*Wagg(j,:);
    end
end



if ideal==1
```

```
 for i=1:m
        for j=1:n
            maxi(i,j)=FDMNW{i,j}(4);
            mini(i,j)=FDMNW{i,j}(1);
        end
    end
    FPIStmp=max(maxi);
    FNIStmp=min(mini);
    for i=1:n
        FPIS{i}(1:4)=FPIStmp(i)*ones(1,4);
        FNIS{i}(1:4)=FNIStmp(i)*ones(1,4);
    end
elseif ideal==2

    for i=1:n
        FPIS{i}(1:4)=ones(1,4);
        FNIS{i}(1:4)=zeros(1,4);
    end
elseif ideal==3
    for j=1:n
        for i=1:m
            maxi2(i,:)=FDMNW{i,j}(1:4);
        end
        FPIS{j}(1:4)=max(maxi2);
        FNIS{j}(1:4)=min(maxi2);
    end
end


for i=1:m
    Sstar(i,:)=fuzzsimveca(FDMNW(i,:),FPIS,n,simi);
end

SstarAgg=sum(Sstar,2)/n;
Sstar=SstarAgg';


for i=1:m
    Sneg(i,:)=fuzzsimveca(FDMNW(i,:),FNIS,n,simi);
end
SnegAgg=sum(Sneg,2)/n;
Sneg=SnegAgg';
```

```
for i=1:m
    CCS(i)=SstarAgg(i)/(SstarAgg(i)+SnegAgg(i));
end
[Y,I]=sort(CCS,'descend');
Order=I';

clear all
close all
k=10;
n=6;
criteria=[1 1 1 1 1 1 ];

m=16;

ideal=1;

simi=1;

lingvar

WD1={MH H   H   ML  H   H};
WD2={H  H   H   L   ML  H};
WD3={MH VH  VH  M   M   H};
WD4={H  H   H   L   MH  MH};
WD5={H  H   H   ML  H   H};
WD6={MH H   MH  L   MH  H};
WD7={H  H   H   M   H   H};
WD8={MH VH  VH  L   H   H};
WD9={MH MH  MH  L   H   H};
WD10={H H   H   M   H   H};

WD={WD1;WD2;WD3;WD4;WD5;WD6;WD7;WD8;WD9;WD10};
W=aggregateW(WD,k,n);


FDM1={G F   F   P   VG  M
VG  F   F   VP  F   MG
VG  VG  VG  VP  VG  VG
G   F   F   F   F   VG
F   F   MG  VP  F   F
F   MG  G   MG  MG  MG
MG  F   F   VP  MG  MG
F   VP  P   VP  MG  VP
```

```
P   P   P   VP  F   MG
MG  F   MG  VP  F   F
VP  F   VP  MG  VP  VP
VP  VP  VP  F   MG  MG
VP  VP  VP  F   VP  VP
F   F   F   VP  F   MG
VP  MG  VP  G   VP  VP
VP  MG  VP  G   VP  VP
};


FDM2={MG    F   F   VP  G   M
VG  MG  F   VP  P   MG
VG  G   G   VP  G   VG
MG  MG  MG  MP  F   VG
MG  F   MP  VP  F   F
MG  MG  G   F   MG  G
MG  F   P   VP  F   MG
MG  P   F   VP  MG  P
VP  VP  VP  VP  VP  VP
F   MP  G   VP  G   MG
VP  F   VP  MG  VP  VP
F   P   F   MG  MG  G
F   P   G   P   P   VP
MG  F   F   VP  F   G
VP  G   VP  G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM3={VG    F   MG  P   G   VG
VG  F   MP  P   MP  MG
VG  G   G   VP  G   VG
MG  MG  MP  F   MG  VG
G   MG  F   P   F   MG
F   F   F   MG  MG  F
F   F   P   VP  F   G
F   VP  F   VP  F   VP
VP  VP  P   VP  VP  VP
MG  P   G   VP  VG  MG
P   MG  P   F   VP  VP
VP  VP  P   MG  F   F
P   F   VP  F   P   VP
MG  F   F   VP  F   MG
VP  MG  VP  G   VP  VP
```

```
P   P   P   VP  F   MG
MG  F   MG  VP  F   F
VP  F   VP  MG  VP  VP
VP  VP  VP  F   MG  MG
VP  VP  VP  F   VP  VP
F   F   F   VP  F   MG
VP  MG  VP  G   VP  VP
VP  MG  VP  G   VP  VP
};


FDM2={MG    F   F   VP  G   M
VG  MG  F   VP  P   MG
VG  G   G   VP  G   VG
MG  MG  MG  MP  F   VG
MG  F   MP  VP  F   F
MG  MG  G   F   MG  G
MG  F   P   VP  F   MG
MG  P   F   VP  MG  P
VP  VP  VP  VP  VP  VP
F   MP  G   VP  G   MG
VP  F   VP  MG  VP  VP
F   P   F   MG  MG  G
F   P   G   P   P   VP
MG  F   F   VP  F   G
VP  G   VP  G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM3={VG    F   MG  P   G   VG
VG  F   MP  P   MP  MG
VG  G   G   VP  G   VG
MG  MG  MP  F   MG  VG
G   MG  F   P   F   MG
F   F   F   MG  MG  F
F   F   P   VP  F   G
F   VP  F   VP  F   VP
VP  VP  P   VP  VP  VP
MG  P   G   VP  VG  MG
P   MG  P   F   VP  VP
VP  VP  P   MG  F   F
P   F   VP  F   P   VP
MG  F   F   VP  F   MG
VP  MG  VP  G   VP  VP
```

```
MG  F   MG  VP  MG  F
F   F   G   F   F   F
G   F   P   VP  MG  MG
F   VP  MG  VP  F   P
P   VP  F   VP  VP  VP
MG  MP  G   VP  MG  G
P   MG  F   MG  MG  P
VP  VP  VP  VP  MG  F
F   F   MG  P   P   VP
MG  F   G   P   F   G
P   G   VP  G   VP  VP
P   F   VP  G   VP  VP
};

FDM7={VG    F   VG  P   VG  MG
VG  F   F   VP  F   MG
VG  MG  G   VP  G   VG
MG  MG  MG  P   F   VG
MG  F   MP  VP  F   MG
G   MG  G   F   MG  G
G   F   P   P   F   MG
F   P   F   VP  MG  P
VP  VP  P   VP  VP  MG
MG  MG  MG  P   VG  F
VP  MG  VP  MG  VP  P
VP  P   P   VG  G   G
F   P   VP  F   P   VP
MG  MG  F   VP  G   G
VP  MG  VP  VG  F   VP
VP  MG  P   VG  VP  VP
};

FDM8={VG    F   MG  P   G   MG
VG  MG  MP  P   P   MG
MG  G   G   VP  MG  VG
MG  MG  G   P   G   G
MG  F   MG  VP  MG  F
F   MG  MG  F   MG  F
MG  F   F   VP  MG  G
F   VP  F   VP  MG  VP
F   F   VP  P   F   P
MG  MG  MG  VP  F   MG
VP  F   VP  MG  VP  VP
F   VP  VP  MG  F   G
```

```
F   VP  G   F   VG  VP
MG  F   G   P   F   G
P   G   P   VG  VP  VP
VP  MG  VP  G   VP  VP
};

FDM9={VG    F   VG  P   VG  M
VG  F   MP  P   MG  MG
MG  MG  G   VP  G   VG
MG  F   MG  MP  G   VG
MG  F   F   VP  F   F
G   F   MG  MG  F   G
MG  F   F   VP  F   G
F   VP  F   VP  MG  VP
P   F   F   VP  F   MG
MG  P   G   VP  G   G
VP  F   F   MG  VP  P
F   VP  F   MG  F   F
F   VP  VG  F   VP  VP
MG  F   MG  P   G   G
VP  MG  VP  G   F   VP
VP  MG  VP  VG  VP  VP
};

FDM10={G    F   VG  P   VG  VG
VG  F   MP  VP  F   MG
MG  VG  F   P   VG  VG
G   MG  MP  F   G   VG
MG  MG  MP  VP  MG  F
F   F   MG  F   MG  F
MG  F   F   VP  F   G
F   VP  F   VP  MG  VP
P   VP  MG  VP  VP  P
MG  P   G   VP  VG  MG
P   F   F   MG  VP  P
VP  P   P   F   MG  G
F   VP  VG  F   VG  VP
MG  MG  G   VP  G   MG
P   MG  VP  VG  VP  VP
VP  MG  VP  G   F   P
};
```

```
FDM={FDM1;FDM2;FDM3;FDM4;FDM5;FDM6;FDM7;FDM8;FDM9;FDM10};


[CCS,Sstar,Sneg,Order]=Stopsis(WD,FDM,k,m,n,ideal,criteria,simi);

disp('Similarities w.r.t. attribute and FPIS:')
Sstar
disp('Similarities w.r.t. attribute and FNIS:')
Sneg

disp('Order of the attributes:')
Order
disp('Closeness values with similarity for choosing attributes:')
CCS

%Platform project
clear all
close all
k=10;
n=6;
criteria=[1 1 1 1 1 1 ];
m=16;

ideal=1;

simi=1;

lingvar

WD1={MH H   H   ML  H   H};
WD2={H  H   H   L   ML  H};
WD3={MH VH  VH  M   M   H};
WD4={MH H   MH  L   H   H};
WD5={MH H   H   M   H   MH};
WD6={M  H   M   L   MH  H};
WD7={MH H   MH  M   MH  MH};
WD8={MH H   H   ML  H   H};
WD9={MH MH  MH  L   MH  H};
WD10={MH    H   H   L   MH  H};

WD={WD1;WD2;WD3;WD4;WD5;WD6;WD7;WD8;WD9;WD10};


FDM1={G F   F   P   VG  M
```

```
VG  F   F   VP  F   MG
VG  VG  VG  VP  VG  VG
G   MG  MG  F   F   VG
MG  F   MG  VP  F   F
F   MG  G   MG  MG  MG
MG  F   F   VP  MG  MG
F   VP  P   VP  MG  VP
F   P   F   VP  F   MG
G   F   MG  VP  F   MG
VP  F   VP  MG  VP  VP
VP  VP  VP  F   MG  MG
VP  VP  VP  F   VP  VP
MG  F   MG  VP  F   MG
VP  MG  VP  G   VP  VP
VP  MG  VP  G   VP  VP
};


FDM2={MG    F   F   VP  G   M
VG  MG  F   VP  P   MG
VG  G   G   VP  G   VG
MG  MG  MG  MP  F   VG
G   MG  F   VP  F   F
MG  MG  G   F   MG  G
MG  F   P   VP  F   MG
MG  P   F   VP  MG  P
MP  MP  MP  VP  VP  MP
MG  MG  G   VP  G   MG
VP  F   VP  MG  VP  VP
F   P   F   MG  MG  G
F   P   G   P   P   VP
MG  MG  MG  VP  F   G
VP  G   VP  G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM3={VG    F   MG  P   G   VG
VG  F   MP  P   MP  MG
VG  G   G   VP  G   VG
MG  MG  MP  F   MG  VG
G   MG  MG  P   F   MG
F   F   F   MG  MG  F
F   F   P   VP  F   G
F   VP  F   VP  F   VP
```

```
F   F   F   VP  VP  F
MG  P   G   VP  VG  MG
P   MG  P   F   VP  VP
VP  VP  P   MG  F   F
P   F   VP  F   P   VP
MG  F   MG  VP  F   MG
VP  MG  VP  G   VP  VP
VP  F   VP  G   VP  VP
};


FDM4={VG    F   VG  P   VG  MG
VG  F   MP  VP  MG  MG
MG  MG  F   VP  G   G
MG  MG  MG  VP  G   G
G   F   MG  VP  MG  MG
P   P   F   P   MG  P
MG  MG  MG  F   MG  F
MG  F   F   P   MG  MG
MP  MP  MG  P   MG  F
MP  P   MG  P   MP  MG
MG  MG  G   P   MG  G
F   P   P   VG  F   MG
F   VP  VG  F   F   VP
MG  F   G   P   G   G
P   G   P   VG  F   P
P   G   P   VG  F   P
};

FDM5={G F   F   P   G   MG
VG  F   F   P   MG  MG
F   MG  F   P   MG  F
G   G   G   P   G   G
MG  MG  G   P   MG  MG
G   F   G   MG  F   F
G   MG  G   P   MG  G
F   VP  MG  VP  MG  VP
MG  MG  MG  VP  MG  MG
G   MG  G   VP  G   G
P   F   F   MG  MG  P
VP  VP  VP  VP  G   F
F   VP  MG  F   VG  VP
MG  MG  MG  P   G   MG
VP  MG  VP  VG  F   VP
```

```
VP  MG  VP  VG  F   VP
};

FDM6={VG    F   F   P   VG  VG
VG  MG  F   VP  P   MG
MG  MG  G   P   VG  VG
MG  MG  MG  F   F   VG
MG  MG  MG  VP  MG  MG
F   MG  G   MG  MG  P
F   F   G   P   F   G
F   VP  MG  VP  F   MG
MP  MP  MP  P   MG  MG
MG  F   G   VP  MP  MG
P   F   P   MG  MG  VP
VP  P   VP  VP  MG  MG
P   P   G   F   VG  VP
MG  F   MG  VP  G   G
P   MG  VP  G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM7={G F   F   VP  G   MG
VG  MG  F   VP  MG  MG
VG  MG  VG  VP  MG  VG
MG  MG  MG  P   G   G
MG  MG  G   VP  MG  F
P   MG  F   MG  F   F
G   F   P   VP  MG  G
F   P   F   P   MG  VP
F   P   MG  VP  VP  F
MG  F   G   VP  MP  G
MG  MG  VP  F   MG  G
VP  VP  VP  VP  MG  MG
VP  VP  VG  F   F   VP
MG  F   MG  VP  F   G
VP  G   P   G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM8={G F   F   P   VG  MG
VG  MG  MP  VP  MG  MG
F   MG  G   VP  MG  G
G   G   MG  P   G   VG
G   MG  F   VP  F   F
```

```
G   F   G   P   MG  MG
MG  MG  G   VP  F   G
MG  VP  F   VP  MG  VP
MG  P   F   VP  MG  MP
G   MG  G   P   G   MG
MG  F   F   F   VP  VP
F   VP  P   VP  MG  F
VP  F   VG  F   P   VP
MG  F   MG  P   F   G
VP  G   VP  VG  VP  VP
VP  G   VP  VG  VP  P
};

FDM9={MG    F   F   P   G   VG
VG  F   MP  VP  MP  MG
VG  G   VG  VP  G   VG
MG  MG  MG  F   MG  VG
G   F   G   VP  F   F
P   MG  F   F   MG  P
MG  F   G   P   MG  G
MG  VP  MG  VP  MG  VP
MP  F   MG  VP  F   F
MP  P   MG  P   MP  G
VP  MG  VP  MG  VP  P
F   VP  P   F   MG  F
P   VP  VG  F   F   VP
MG  MG  MG  P   G   MG
VP  MG  VP  G   VP  P
VP  MG  VP  VG  VP  VP
};

FDM10={VG   F   F   P   G   MG
VG  F   MP  P   P   MG
VG  MG  G   VP  G   F
MG  MG  G   F   MG  VG
MG  MG  F   P   MG  MG
F   F   G   MG  MG  MG
MG  F   F   VP  MG  MG
F   F   F   VP  MG  P
MG  P   MP  VP  MG  MG
G   MG  G   VP  F   MG
VP  F   VP  MG  VP  VP
VP  VP  P   VP  G   MG
F   VP  VP  F   VP  VP
```

```
MG  F   G   VP  F   G
P   G   VP  VG  F   VP
VP  MG  VP  G   VP  VP
};



FDM={FDM1;FDM2;FDM3;FDM4;FDM5;FDM6;FDM7;FDM8;FDM9;FDM10};


[CCS,Sstar,Sneg,Order]=Stopsis(WD,FDM,k,m,n,ideal,criteria,simi);

disp('Similarities w.r.t. attribute and FPIS:')
Sstar
disp('Similarities w.r.t. attribute and FNIS:')
Sneg

disp('Order of the attributes:')
Order
disp('Closeness values with similarity for choosing attributes:')
CCS



%Breakthrough project
clear all
close all
k=10;
n=6;
criteria=[1 1 1 1 1 1 ];

m=16;

ideal=1;

simi=1;

lingvar

WD1={MH H   H   M   H   M};
WD2={M  MH  H   MH  H   MH};
WD3={MH H   H   H   H   M};
WD4={M  MH  MH  M   MH  MH};
WD5={M  MH  MH  M   MH  M};
```

```
WD6={M  MH  MH  MH  H   MH};
WD7={M  M   MH  M   MH  MH};
WD8={M  MH  M   M   MH  MH};
WD9={MH MH  MH  M   MH  MH};
WD10={M MH  H   M   MH  MH};

WD={WD1;WD2;WD3;WD4;WD5;WD6;WD7;WD8;WD9;WD10};


FDM1={MG    MG  G   VP  VG  G
VG  MG  F   VP  VG  VG
VG  G   F   VP  MG  VG
VG  VG  VG  F   F   G
G   G   G   VP  VG  MG
VG  G   G   VP  MG  VG
VG  F   F   VP  VG  F
VG  VG  VG  F   G   G
F   G   G   F   G   G
VG  VG  VG  VP  G   G
F   F   MP  VG  P   P
F   F   MP  VG  P   P
F   F   MP  VG  P   P
VG  F   F   VP  F   F
G   G   VP  VP  P   P
P   G   P   VG  P   P
};


FDM2={G G   G   VP  VG  VG
VG  G   F   VP  G   F
VG  VG  MG  VP  G   VG
VG  VG  VG  P   VG  VG
G   G   G   G   MG  G
MG  F   F   P   G   G
P   VP  MG  VP  P   VP
VG  G   VG  VP  VG  F
VP  F   G   MG  F   MG
VG  VG  VG  VP  VG  VG
VP  F   F   F   P   VP
VP  F   VP  G   F   MG
P   VP  VP  F   F   VP
MG  MG  MG  F   MG  MG
VP  MG  VP  VG  MG  VP
VP  MG  P   VG  P   VP
```

```
};

FDM3={MG    M   M   VP  G   MG
VG  MG  MG  VP  MG  MG
G   G   MG  VP  MG  VG
VG  VG  VG  VP  VG  VG
F   F   MG  G   G   MG
MG  F   F   VP  F   G
F   VP  P   VP  VG  VP
G   G   G   F   G   F
MG  MG  G   MG  F   F
G   G   G   P   G   G
P   P   P   G   F   P
F   P   F   MG  F   G
P   G   P   P   MG  VP
G   F   MG  P   G   G
VP  VG  MG  VG  MG  VP
VP  VG  F   VG  F   VP
};


FDM4={VG    F   VG  P   VG  MG
VG  F   MP  VP  MG  F
MG  F   F   VP  MG  MG
MG  MG  MG  VP  G   G
G   G   VG  VP  G   MG
MG  MG  MG  MG  G   MG
G   F   G   P   G   G
P   P   F   P   MG  P
G   G   G   P   G   G
G   G   G   P   G   VG
P   F   G   MG  MG  P
F   P   P   VG  F   MG
F   VP  VG  F   F   VP
MG  MG  G   P   G   G
P   G   P   VG  F   P
P   G   P   VG  F   P
};

FDM5={G F   F   P   G   MG
VG  F   P   P   F   F
MG  F   MP  P   F   F
G   G   G   P   G   G
VG  G   VG  P   G   VG
```

```
G   G   G   MG  G   G
G   G   G   P   G   G
F   VP  MG  VP  MG  VP
VG  MG  VG  VP  G   G
G   G   G   VP  G   VG
P   F   F   MG  MG  P
VP  VP  VP  VP  G   F
F   VP  MG  F   VG  VP
G   MG  VG  P   G   MG
VP  MG  VP  VG  F   VP
VP  MG  VP  VG  F   VP
};

FDM6={G MG  M   VP  VG  VG
VG  MG  MG  VP  MG  F
MG  VG  MP  VP  F   F
VG  G   G   P   G   G
G   G   G   VP  G   MG
VG  G   F   VP  MG  G
P   VP  F   P   VG  G
VG  P   G   VP  G   VP
G   MG  G   MG  G   G
VG  VG  G   VP  VG  G
P   F   MP  VG  P   P
VP  F   VP  MG  G   MG
P   VP  VP  F   P   VP
G   F   VG  VP  G   MG
VP  G   MG  VG  MG  VP
VP  MG  F   VG  P   VP
};

FDM7={G MG  VG  VP  G   MG
VG  MG  F   P   MG  F
MG  G   MG  VP  MG  MG
VG  MG  G   VP  VG  VG
VG  G   VG  G   G   VG
MG  F   G   MG  MG  VG
G   G   F   VP  VG  G
VG  VG  MG  P   MG  G
MG  G   G   MG  G   G
G   VG  G   VP  G   VG
VP  F   P   MG  MG  VP
F   P   VP  VP  F   P
F   F   P   F   F   P
```

```
MG  F   F   VP  G   MG
G   VG  VP  VP  MG  VP
VP  VG  P   VG  P   P
};

FDM8={G F   G   VP  G   MG
VG  G   F   VP  VG  F
G   F   F   VP  MG  VG
VG  VG  G   P   F   G
F   F   VG  VP  VG  G
MG  F   G   P   F   VG
G   G   P   VP  VG  VP
F   VG  F   F   MG  F
VG  G   G   VP  G   MG
VG  G   G   P   G   G
P   F   G   G   MG  P
F   P   VP  MG  F   MG
F   F   P   P   VG  VP
G   MG  G   F   F   G
VP  MG  VP  VG  P   VP
P   MG  F   VG  F   P
};

FDM9={G F   G   VP  VG  VG
VG  G   F   VP  G   F
MG  G   F   VP  MG  VG
G   MG  G   VP  F   G
G   G   G   VP  G   MG
MG  G   F   VP  MG  MG
G   VP  G   P   P   VP
VG  VP  VG  F   MG  F
G   G   G   MG  F   F
VG  G   G   VP  G   VG
P   P   F   VG  MG  P
F   F   VP  VG  P   P
P   VP  VP  P   P   VP
G   MG  VG  P   MG  MG
VP  MG  VP  VG  F   VP
P   G   F   VG  F   VP
};

FDM10={MG   M   M   VP  G   G
VG  F   F   VP  VG  F
MG  F   F   VP  MG  VG
```

```
VG  VG  MG  F   VG  G
G   G   VG  VP  G   MG
MG  F   G   MG  G   G
G   VP  P   P   G   VP
F   VP  MG  P   MG  F
VP  G   G   MG  F   G
G   G   VG  VP  G   VG
P   P   G   MG  P   VP
VP  F   VP  VP  F   F
F   VP  MG  F   F   P
MG  MG  G   VP  G   G
VP  MG  P   VG  MG  VP
P   MG  P   VG  P   P
};



FDM={FDM1;FDM2;FDM3;FDM4;FDM5;FDM6;FDM7;FDM8;FDM9;FDM10};


[CCS,Sstar,Sneg,Order]=Stopsis(WD,FDM,k,m,n,ideal,criteria,simi);

disp('Similarities w.r.t. attribute and FPIS:')
Sstar
disp('Similarities w.r.t. attribute and FNIS:')
Sneg

disp('Order of the attributes:')
Order
disp('Closeness values with similarity for choosing attributes:')
CCS



%R&D project
clear all
close all
k=10;
n=6;
criteria=[1 1 1 1 1 1 ];

m=15;

ideal=1;
```

```
simi=1;

lingvar

WD1={ML ML  H   M   VH  ML};
WD2={M  M   MH  M   VH  L};
WD3={ML L   H   M   VH  M};
WD4={ML M   MH  M   VH  ML};
WD5={M  ML  H   MH  VH  ML};
WD6={ML M   M   M   H   ML};
WD7={L  L   H   MH  MH  L};
WD8={ML M   H   MH  H   L};
WD9={M  ML  MH  MH  VH  ML};
WD10={L L   H   MH  H   L};

WD={WD1;WD2;WD3;WD4;WD5;WD6;WD7;WD8;WD9;WD10};


FDM1={G F   F   P   VG  M
VG  F   F   VP  F   MG
VG  VG  VG  VP  VG  VG
G   VG  VG  F   VG  VG
VG  VG  VG  MG  VG  VG
VG  VG  G   MG  VG  MG
G   MG  G   VP  G   MG
VG  VG  VG  F   VG  F
VG  VG  VG  F   VG  VG
VP  F   VP  MG  VP  VP
VP  VP  VP  F   MG  MG
VP  VP  VP  VP  VP  VP
VG  VG  VG  F   VG  VG
VP  MG  VP  G   VP  VP
VP  MG  VP  G   VP  VP
};


FDM2={MG    F   F   VP  G   M
VG  MG  F   VP  P   MG
VG  G   G   VP  G   VG
MG  MG  MG  MP  F   VG
VG  VG  VG  F   VG  G
MG  MG  G   F   MG  G
MG  F   P   VP  F   MG
VP  VP  VP  VP  VP  VP
```

```
F   MP  G   VP  G   MG
VP  F   VP  MG  VP  VP
F   P   F   MG  MG  G
VP  VP  VP  VP  VP  VP
MG  F   F   VP  VG  G
VP  G   VP  G   VP  VP
VP  MG  VP  G   VP  VP
};

FDM3={VG    F   MG  P   G   VG
VG  F   MP  P   MP  MG
VG  G   G   VP  G   VG
G   G   G   F   VG  VG
VG  VG  VG  F   VG  F
G   F   G   MG  G   F
G   F   G   VP  G   F
VG  VG  VG  F   VG  F
G   G   G   VP  VG  G
P   MG  P   F   VP  VP
VP  VP  P   MG  F   F
VP  VP  VP  VP  VP  VP
G   G   G   VP  G   G
VP  MG  VP  G   VP  VP
VP  F   VP  G   VP  VP
};


FDM4={VG    F   VG  P   VG  MG
VG  F   MP  VP  MG  MG
F   MP  MP  VP  F   G
G   G   G   F   G   G
VG  VG  VG  MG  VG  VG
F   G   G   G   G   F
MG  MG  G   P   G   G
G   G   VG  P   VG  G
VG  MG  VG  P   G   VG
P   F   G   MG  MG  P
F   P   P   VG  F   MG
F   VP  VG  F   F   VP
G   VG  VG  P   G   G
P   G   P   VG  F   P
P   G   P   VG  F   P
};
```

```
FDM5={G F   F   P   G   MG
VG  F   F   P   MG  MG
MP  MP  F   P   MG  MP
G   G   G   P   G   G
VG  VG  VG  F   VG  VG
G   F   G   MG  F   F
G   G   G   P   G   VG
VG  VG  VG  VP  VG  VG
G   G   G   VP  G   VG
P   F   F   MG  MG  P
VP  VP  VP  VP  G   F
F   VP  MG  F   VG  VP
G   MG  VG  P   G   G
VP  MG  VP  VG  F   VP
VP  MG  VP  VG  F   VP
};

FDM6={MG    F   F   VP  G   M
VG  F   MP  VP  MG  MG
F   MP  MP  VP  G   G
G   G   G   F   VG  G
VG  VG  VG  F   VG  VG
MG  G   G   MG  G   F
G   F   G   VP  G   VG
VG  VG  VG  P   VG  VG
G   G   G   VP  VG  VG
P   MG  F   MG  VP  VP
VP  VP  F   VG  G   F
F   VP  VP  F   VP  VP
G   F   VG  VP  VG  G
VP  G   VP  G   VP  P
P   F   VP  G   VP  P
};

FDM7={G F   F   P   VG  M
VG  F   MP  VP  MG  MG
VG  G   G   VP  G   G
G   MG  VG  P   F   G
VG  VG  VG  F   VG  VG
MG  VG  G   F   F   G
G   F   G   P   G   MG
VG  VG  VG  F   VG  VG
G   MP  VG  VP  G   MG
P   MG  P   MG  VP  VP
```

```
F   VP  F   VP  F   F
F   VP  MG  F   F   VP
MG  VG  G   P   VG  G
VP  MG  VP  G   VP  VP
VP  MG  P   G   VP  VP
};

FDM8={G F   F   P   G   M
VG  F   F   P   F   MG
VG  VG  G   VP  G   VG
MG  G   MG  F   G   VG
VG  VG  VG  MG  VG  VG
MG  MG  G   MG  F   MG
G   G   G   VP  G   MG
G   G   VG  F   VG  VG
VG  MP  G   VP  VG  VG
VP  F   P   MG  VP  P
VP  P   P   MG  F   G
VP  VP  VP  VP  VP  VP
VG  MG  VG  VP  G   G
VP  G   P   G   VP  VP
VP  MG  VP  VG  F   VP
};

FDM9={G F   F   P   VG  MG
VG  F   F   VP  MP  MG
VG  VG  MP  P   G   VG
G   G   G   F   G   VG
VG  VG  VG  F   VG  F
G   MG  G   MG  VG  F
MG  MG  G   VP  G   VG
VG  G   VG  VP  VG  G
VG  MG  VG  F   VG  MG
VP  F   VP  MG  VP  P
VP  VP  VP  VP  F   F
VP  VP  MG  VP  VP  VP
VG  G   F   P   G   G
P   MG  VP  G   F   VP
VP  MG  VP  G   VP  VP
};

FDM10={G    F   F   P   G   MG
VG  F   F   P   MP  MG
F   G   F   VP  F   VG
```

```
MG  G   G   MP  G   VG
VG  VG  VG  F   VG  F
MG  VG  G   F   F   F
G   F   G   P   G   G
VG  VG  VP  F   VG  VG
G   MG  G   VP  G   VG
VP  F   VP  MG  VP  P
F   VP  P   F   F   G
F   VP  VG  VP  VP  VP
G   MG  VG  P   VG  G
VP  G   VP  VG  VP  VP
VP  MG  P   G   VP  P
};


FDM={FDM1;FDM2;FDM3;FDM4;FDM5;FDM6;FDM7;FDM8;FDM9;FDM10};


[CCS,Sstar,Sneg,Order]=Stopsis(WD,FDM,k,m,n,ideal,criteria,simi);

disp('Similarities w.r.t. attribute and FPIS:')
Sstar
disp('Similarities w.r.t. attribute and FNIS:')
Sneg

disp('Order of the attributes:')
Order
disp('Closeness values with similarity for choosing attributes:')
CCS
```

Appendix 2. KNN Code

```
function [] = knn(train_data, test_data, train_target, test_target, k)
    classification_accuracy = 0;
    for i = 1:size(test_data, 1)

        D = test_data(i, :) - train_data(: , :);
        D = D.^2;
        dist_mat = sum(D, 2);
        dist_mat = sqrt(dist_mat);
        dist = [dist_mat train_target];

        dist = sortrows(dist, 1);

        if k == 1
            k_neighbours = dist(k, :);
            predicted = k_neighbours(1, 2);
            true = test_target(i, 1);
            if true == predicted
                accuracy = 1;
                classification_accuracy = classification_accuracy +
accuracy;
            else
                accuracy = 0;
            end
            fprintf('ID=%5d, predicted=%3d, true=%3d, accuracy=%4.2f
\n', i, predicted, true, accuracy)

        else
            k_neighbours = dist(1:k, :);
            if size(unique(k_neighbours(:, 2))) == 1
                predicted = unique(k_neighbours(:, 2));
            elseif size(unique(k_neighbours(:, 2))) == k
                predicted = k_neighbours(1, 2);
            else
                predicted = mode(k_neighbours(:, 2))
            end
            true = test_target(i, 1);
            if true == predicted
                accuracy = 1;
                classification_accuracy = classification_accuracy +
accuracy;
            else
```

```
nd

end


k=10;
    training_data = load('train_data.txt');
    testing_data = load('test_data.txt');
    train_target = training_data(:, end);
    test_target = testing_data(:, end);
    train_data = training_data(:, 1: end-1);
    test_data = testing_data(:, 1: end-1);


    mean_of_dimension = mean(train_data);
    std_deviation = std(train_data, 1);

    train_data = normalise(train_data, std_deviation,
mean_of_dimension);
    test_data = normalise(test_data, std_deviation,
mean_of_dimension);

    knn(train_data, test_data, train_target, test_target, k);
```