DEVELOPMENT OF HYBRID DECISION-MAKING METHOD FOR PROJECT MANAGEMENT UTILIZING SCHEDULING AND LINE BALANCING RISK ASSESSMENT

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2022

FK 2022 122

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Mohd Khairol Anuar Mohd Ariffin, PhD
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This research focused on the uncertainty in the industrial project selection problem. In the real environment, several risk factors threaten the project's success which may lead to financial harm. However, such risk factors are not constant and may take various values depending on the project's environment. Therefore, the classic decision-making methods may fail to correctly address the actual risk factor values and select the best project among the alternatives. This research aims to find the critical risk factors that threaten a project through its life cycle and propose a decision-making method to select the best project with the lowest total risk factor in the presence of uncertainty. For this purpose, a multi-stage method is proposed where in the first stage, a Delphi method is used to determine influential factors that may affect project success through its life cycle. Then, a questionnaire is designed to find the opinion of the statistical society where project experts are considered as statistical society. The statistical analysis was then carried out to specify the variables' descriptions, find correlations between them, and determine their values in project success (as the dependent variable). Then, in the next stage, a new hybrid AHP and Dempster-Shafer (DS) Theory of Evidence is proposed, which was worked based on the uncertainty level of the risk factors. The proposed method could determine each alternative total risk level range and then report the best alternative with the lowest total risk level range. The findings showed that the risks could be divided into four main risk clusters, which are: Properties Risk Factors (Infrastructure, Machinery, Human Resource); Technology and Operational Risk Factors (Scheduling, Technology, Operational Risk, Management Systems); Financial Risk Factors (Evaluating projects, Profit, Costs, Money Value); Strategic Risk Factor (Competition, Market share, Marketing, Customer Satisfaction). In order to examine the performance of the proposed method, a Taguchi Method (L2^4) is designed for designing 24 experiments. The outcomes indicated that the proposed method could solve all small, medium, and large-scale experiments.

Moreover, it could find the project with the lowest total risk range in all cases. While solving time comes into consideration, the proposed method solved the Small-scale problems in [0.036 0.054], Medium scale problems in [0.033 0.088], and Large-scale problems in [0.062 0.557] seconds, depending on the nature of the project. It is also noticeable that the proposed method could solve all experiments (including large-scale experiments with 30 experts, 13 risk factors, 10 alternatives and 5 contract options) in less than one second. The outcomes showed that the proposed hybrid method could select projects with the lowest total risk factor up to 90.53% for small-scale studied cases, up to 94.45% for medium-scale studied cases and 19.61% for large-scale studied cases depending to the scale of the case studies.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KAEDAH MEMBUAT KEPUTUSAN HIBRID UNTUK PENGURUSAN PROJEK MENGGUNAKAN PENJADUALIAN DAN PENILAIAN RISIKO PENGIMBANGAN TALIAN

Oleh

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Kajian ini memberikan tumpuan kepada ketakpastian dalam masalah pemilihan projek industri. Dalam persekitaran sebenar, beberapa faktor risiko boleh mendatangkan ancaman kepada kejayaan projek yang mungkin menyebabkan kerugian kewangan. Namun, faktor risiko tersebut tidak tetap dan mungkin mempunyai pelbagai nilai bergantung pada persekitaran projek. Oleh itu, kaedah pembuatan keputusan klasik mungkin tidak dapat menangani nilai faktor risiko sebenar dengan betul dan memilih projek terbaik daripada alternatif yang ada. Matlamat kajian ini adalah untuk mengenal pasti faktor risiko penting yang mendatangkan ancaman kepada sesuatu projek sepanjang kitaran hayatnya dan mencadangkan kaedah pembuatan keputusan untuk memilih projek terbaik dengan faktor risiko keseluruhan terendah dalam situasi ketakpastian. Bagi tujuan ini, kaedah berbilang tahap yang dicadangkan menggunakan kaedah Delphi pada peringkat pertama untuk menentukan faktor berpengaruh yang boleh menjejaskan kejayaan projek sepanjang kitaran hayatnya. Seterusnya, satu soal selidik dirangka bagi mendapatkan pandangan kumpulan statistik dengan pakar projek dianggap sebagai kumpulan statistik. Analisis statistik kemudiannya dijalankan untuk menentukan jenis pemboleh ubah, mengenal pasti hubung kait antara pemboleh ubah berkenaan dan menentukan nilai pemboleh ubah tersebut dalam kejayaan projek (sebagai pemboleh ubah bersandar). Kemudian, pada peringkat seterusnya, Proses Hierarki Analisis (AHP) hibrid baharu dan Teori Pembuktian Dempster-Shafer (DS) dicadangkan, yang berfungsi berdasarkan tahap ketakpastian faktor risiko. Kaedah yang dicadangkan boleh menentukan julat tahap risiko keseluruhan bagi setiap alternatif dan kemudian melaporkan alternatif terbaik dengan julat tahap risiko keseluruhan terendah. Dapatan menunjukkan bahawa risiko boleh dibahagikan kepada empat kumpulan risiko utama, iaitu: Faktor Risiko Hartanah (Infrastruktur, Jentera, Sumber Manusia); Faktor Risiko Teknologi dan Operasi (Penjadualan, Teknologi, Risiko Operasi, Sistem Pengurusan); Faktor Risiko

Kewangan (Penilaian projek, Keuntungan, Kos, Nilai Wang); Faktor Risiko Strategik (Persaingan, Bahagian pasaran, Pemasaran, Kepuasan Pelanggan). Bagi menilai prestasi kaedah yang dicadangkan, Kaedah Taguchi (L2^4) digunakan untuk mereka bentuk 24 uji kaji. Hasil menunjukkan bahawa kaedah yang dicadangkan boleh menyelesaikan semua uji kaji berskala kecil, sederhana dan besar. Selain itu, kaedah yang dicadangkan dapat mengenal pasti projek dengan julat risiko keseluruhan terendah dalam semua kes. Apabila tempoh penyelesaian diambil kira, kaedah yang dicadangkan dapat menyelesaikan masalah berskala Kecil dalam [0.036 0.054] saat, masalah berskala Sederhana dalam [0.033 0.088] saat, dan masalah berskala Besar dalam [0.062 0.557] saat, bergantung pada jenis projek. Dapat diperhatikan juga bahawa kaedah yang dicadangkan dapat menyelesaikan semua uji kaji (termasuk uji kaji berskala besar yang melibatkan 30 pakar, 13 faktor risiko, 10 alternatif dan 5 pilihan kontrak) dalam tempoh kurang daripada satu saat. Hasil menunjukkan bahawa kaedah hibrid yang dicadangkan boleh memilih projek yang mempunyai faktor risiko keseluruhan terendah sehingga 90.53% bagi kes kajian berskala kecil, sehingga 94.45% bagi kes kajian berskala sederhana dan 19.61% bagi kes kajian berskala besar, bergantung pada skala kajian kes.

ACKNOWLEDGEMENTS

Firstly, all praise to Allah that He blesses me to complete my higher education. I dedicate my greatest love to all my family, including my mother and father, my wife, and my kids, who always bless me to fulfill the thesis requirements and gain the degree. Finally, I would like to take this opportunity to send my greatest regards to my government for all their help and support during my study.

I am also grateful for all the support and concerns my supervisor, Professor provided. Ir. Dr. Mohd Khairol Anuar Mohd Ariffin for chairing my committee. I want to express my sincere thanks for his whole-hearted support, enthusiasm and inspiration throughout my graduate study.

My greatest regards will go to Associate Professor Dr. Eris Elianddy Bin Supeni and Professor Ir. Dr. Kamarul Arifin Ahmad as my co-supervisors for the invaluable advice and suggestions that I provided, which helped me enrich the thesis level.

Finally, I would like to thank all faculty members at the Mechanical and Manufacturing Engineering Department at UPM for their help and support.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AHP	Analytic Hierarchy Process
AI	Alternative Index
ANP	Analytic network process
APP	Aggregate Production Planning
BN	Bayesian network
CLT	Central Limit Theorem
Coef	Coefficient
COPRAS	Complex Proportional Assessment
COS	cost of safety
CPM	Critical Path Method
CV	Coefficient of variation
d	domain
df	Degree Of Freedom
DOE	Design Of Experiments
DS	Dempster-Shafer Theory
ERP	Enterprise resource planning
FBBN	fuzzy Bayesian belief network
FDI	foreign direct investment
FMEA	Failure Modes and Effects Analysis
FTA	Fault tree analysis
GA	Genetic Algorithm
GDP	Gross Domestic Product
GIS	Geographic Information System
HR	Human Resource

HVAC	Heating, ventilation, and air conditioning
IT	Information Technology
L	Lower
LP	Linear Programming
M&As	Mergers and Acquisitions
MADM	multi-attributed decision-making model
MAGDM	multi-attribute group decision-making
MCDM	multi-criteria decision-making model
MODM	Multi-Objectives Decision-Making Model
MRCPSP	Multi-mode Resource Constrained Scheduling Problem
NSGA-II	Non-Dominated Sorting Genetic Algorithm II
PMBOK	Project Management Body of Knowledge
R&D	Research and development
RCPSP	Resource Constrained Scheduling Problem
RRI	Reduced Risk Indicator
SA	Simulated Annealing
SE Coef	standard error Coefficient
Sig.	Significant
SME	small and medium-sized enterprises
Std. Deviation	Standard Deviation
SWARA	Step-wise Weight Assessment Ratio Analysis
TOPSIS	Technique For Order Preference By Similarity To Ideal Solution
TS	Tabu Search
U	Upper
UK	United Kingdom
UPM	Universiti Putra Malaysia

UTM	Universiti Teknologi Malaysia
VI	Validating Index
VICOR	VlseKriterijumska Optimizacija I Kompromisno Resenje
VIF	Variance inflation factor
μ	Mean
σ	Sigma

CHAPTER 1

INTRODUCTION

1.1 Projects and their importance in the economy of a country

Cambridge Dictionary defines the term project as "a piece of planned work or an activity that is finished over a period of time and intended to achieve a particular purpose[1]." Projects are temporary efforts that do not follow the processing rules. A project usually has specific start and finish times. It is essential to schedule projects due to time, money, resources, and other limitations. Projects can be divided into several groups according to various points of view. Perhaps the most important one is categorizing them according to the nature of the activities associated with the project goal:

- Oil, Gas and Petrochemical Projects
- Civil Projects (Construction)
- Electrical and Mechanical Projects
- Manufacturing Projects
- IT Projects
- Management Projects
- Research Projects

The manufacturing industry plays a crucial role in each country's economy (Delgoshaei et al., 2017b). Developed countries mostly have better industries; therefore, investments in potential opportunities (manufacturing projects) accordingly. For example, Абдикеев et al. (2019) reported that in 2017, 30%, 28%, 20%, and 13.5% of the annual Gross Domestic Product (GDP) of China, South Korea, Germany and Russia belong to the manufacturing industry. Of this, a significant value belongs to manufacturing industries. For instance, Figure 1.1 indicates the value of net cross-border Mergers and Acquisitions (M&As) and announced greenfield Global foreign direct investment (FDI) projects, 2008–2017 (Dašić et al., 2019).

[1] https://dictionary.cambridge.org/dictionary/english/project- Retrieved in 10 September, 2020.

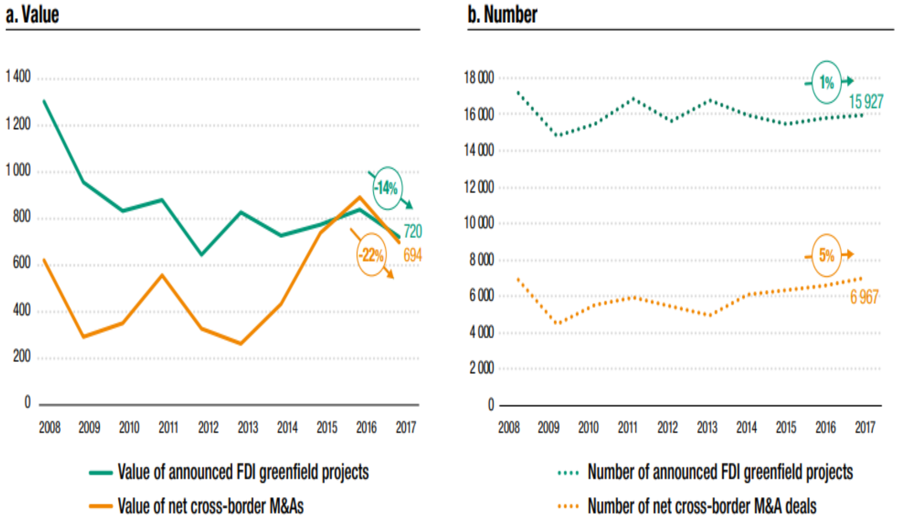

Figure 1.1 : Value of net cross-border M&As and announced greenfield Global foreign direct investment (FDI-Billions of dollars and numbers)

1.2 Project selection and reasons for project failures

In today's rivalry, choosing appropriate decisions plays a key role in manufacturing a firm's success. In most cases, choosing inappropriate choices will negatively affect a company or cause project failure (see section 1.3). Hence, selecting the correct project among the available alternatives is vital (de Souza et al., 2021).

As mentioned above, projects are risky in their nature, and many factors could threaten a project's success (Delgoshaei et al., 2018). The Project Master UK Co. introduced 15 major reasons that prevent projects from obtaining their predefined goals, no matter the project's scope[2]. These reasons are listed in Table 1.1:

[2] https://www.projectsmart.co.uk/15-causes-of-project-failure.php - Retrieved in 13 September, 2020.

Table 1.1 : Top 15 Major Reasons for Project Failures

Row	Reason
1	Poorly defined project scope
2	Inadequate risk management
3	Failure to identify key assumptions
4	Project managers who lack experience and training
5	No use of formal methods and strategies
6	Lack of effective communication at all levels
7	Key staff leaving the project and/or company
8	Poor management of expectations
9	Ineffective leadership
10	Lack of detailed documentation
11	Failure to track requirements
12	Failure to track progress
13	Lack of detail in the project plans
14	Inaccurate time and effort estimates
15	Cultural differences in global projects

1.3 Risk Management as an Important Part of the Project Management

Risks are an inseparable part of a project and thus should not be ignored. Each year, many projects have failed due to their harm. Risks attributed to projects can have various sources, but all have the same goal: to fail a project. Figure 1.2 depicts the correlations between the level of risks associated with a project and the amount at stake throughout the lifecycle of a project.

As shown by Figure 1.2, the level of the risks at the earlier phase of a project is significantly higher than is in the ending phases. Such a fact can reveal the importance of risk management in project selection. Sadeghiyan et al. (2022) also mentioned a significant correlation between the level of risk management taken by a project team and project success.

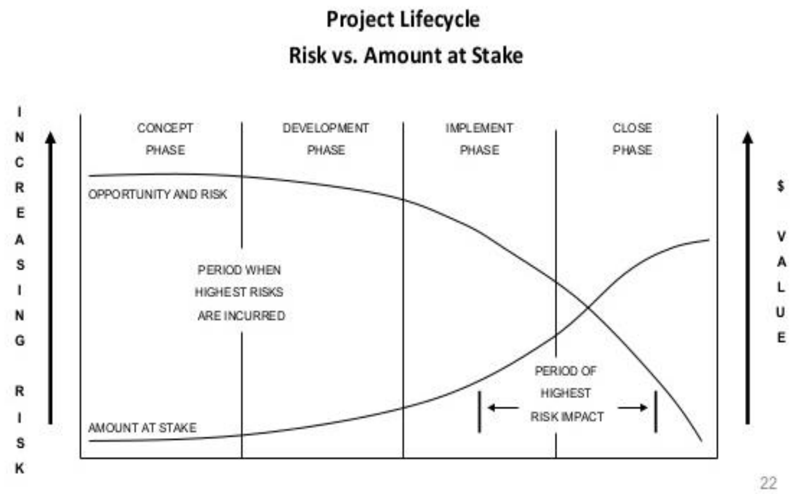

Figure 1.2 : Correlations Between the Level of Risks Associated with A Project and the Amount at Stake[3]

Various risks that can threaten a project will be explained to investigate more. Figure 1.3 shows some of the most important and common reasons for a project failure:

Figure 1.3 : Various types of risk factors for a project

Therefore, minimizing the risks of a project is a vital need. Subsequently, the more attention paid to risk identification, the less level of risk will be faced during the lifecycle of a project. For this purpose, as seen in chapter 2, exert efforts have been made during the last 2 decades to propose various decision-making

[3] https://slideplayer.com/slide/12927929/. Retrieved in 12 September, 2020.

methods to investigate different risk management problems (Figure 1.4). Of these, a noticeable share belongs to the project selection problem. Afterward, the shortcoming of the current research methods will be investigated. However, the problem will be explained in more detail in the literature review chapter.

Figure 1.4 : Reason for selecting Risk Management in Project Selecting Problem

The main question here is whether deterministic decision-making methods can satisfy all needs of Risk Management in Project Selecting Problem. In continue, this question will be answered.

1.4 Problem statement

During the last two decades, scientists came up with the idea that in most cases in the real world, parameters are not constant and may take different values according to the circumstance of surroundings (Rastegar et al., 2021). Such an idea increases the use of uncertainty in decision science as well. Cambridge dictionary defines the term uncertainty as "a situation in which something is not known, or something that is not known or certain[4]."

[4] https://dictionary.cambridge.org/dictionary/english/uncertainty- Retrieved in 10.09.2020.

1.4.1 One major problem in project selection

One common problem that usually emerges in a tender process for industrial projects is ignoring the risk factors in the project selection process Mols (2021; Rajala & Aaltonen (2021). A recent Survey that Universiti Teknologi Malaysia (UTM) scientists have conducted reveals that there is a wide range of risk factors that threaten a project[5]. Such factors can threaten a project throughout its life cycle.

Figure 1.5 : Jaya shopping mall collapsing that happened in May 2009

1.4.2 Results of failing to pay enough attention to the project risks

As a result, each year, many project failures will be observed. As a result, massive financial harm may happen to the project owners, constructors and society. Figure 1.5 indicates an image of the Jaya shopping mall that collapsed in May 2009 due to safety reasons.

[5] http://eprints.utm.my/id/eprint/30494/1/Pub9_Government_ICTProjectFailureFactors_amend.pdf-Retrieved in 08.26.2022

For example, there were ten mega project failures reported by nst.com[6]. Of this, three projects were supposed to save 285.04 million RM. Collapsing the Penang second bridge that happened in June 2013 could be considered another example of failing to pay enough attention to risk factors associated with a project[7].

1.4.3 The reasons for emerging the problem:

Classic methods usually do not consider uncertainty during the decision-making method. For example, the classic Analytic Hierarchy Process (AHP) considers constant values for alternatives and factors to choose the best alternative accordingly. While considering the term uncertainty, each cell in the AHP will not necessarily have a certain specific value. Instead, a range of values (confidence intervals) must be estimated by considering confidence levels (1-α).

Therefore, an optimum solution will not necessarily exist and could be changed over time by considering different confidence intervals (Figure 1.6).

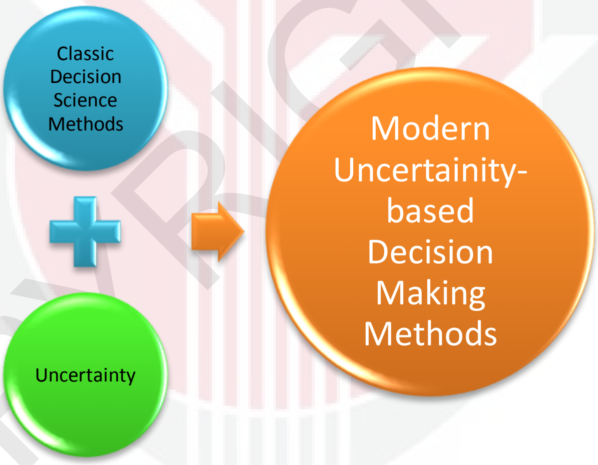

Figure 1.6 : Impacts of Uncertainty on Classic Decision-Making Methods

Using the facts mentioned above, ample evidence is available to consider uncertainty in selecting the best project among the available alternatives to minimize the project's risks in the executing phase (Figure 1.7).

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[6]https://www.nst.com.my/news/nation/2021/09/731646/ag-report-10-projects-failed-meet objectives- Retrieved in 08.26.2022.
[7] https://cilisos.my/6-most-epic-fail-and-deadly-malaysian-constructions/- Retrieved in 08.26.2022.

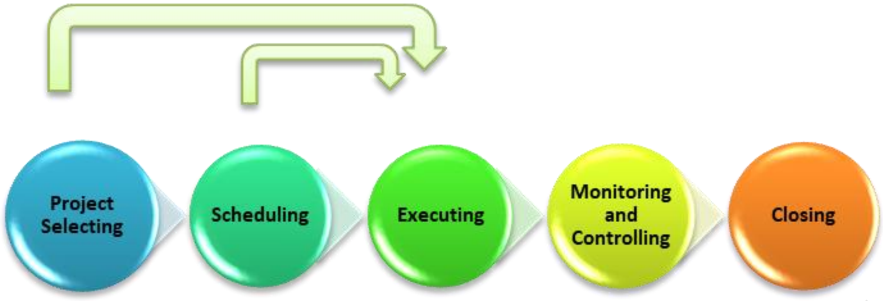

Figure 1.7 : Project Management Processes

Therefore, in this research, a new decision-making model will be proposed to select the best alternative while uncertainties exist regarding risk factors. The aim will be to minimize the risks associated with the company's capabilities, such as available money, human resource skills, machinery, documentation systems, and quality control level.

1.5 Importance of the study

This study can help industrial business owners to select appropriate projects according to their capabilities and strengths. Choosing the wrong project for construction can have detrimental effects on a business and impose irreparable financial harm. In each county, several failed projects can be found that remain unconstructed for years or even decades. The same phenomenon happens in the industry. After a quick search in each industrial zone, a series of unsuccessful projects can be found left alone for years. In some cases, this event happens because the managers believe they made a wrong decision in choosing projects and calculating the required budget for completing them due to not paying enough attention to selecting appropriate projects according to the money and resource availability. The following shows only a few examples of left projects in industrial zones due to failing to pay enough attention to choosing appropriate projects according to availably resources and money (Figures 1.8 to 1.11):

- Abandoned uncompleted buildings
- Uncompleted production lines in the manufacturing firms
- Purchased lands that were left alone for many years
- Unequipped laboratories
- Uncompleted industrial sheds in companies

Figure 1.8 : Purchased lands that were left alone for many years

Figure 1.9 : Uncompleted production lines in the manufacturing firms

Figure 1.10 : Uncompleted industrial sheds in companies

Figure 1.11 : Abandoned uncompleted buildings

For example, suppose a company needs to set up a new production line. Ignoring essential items like the volume of production, technology, available machinery, and market needs causes wrong decisions about the type of construction project and, consequently, the project's achievements.

Therefore, in this study, an effort will be made to develop a comprehensive method for selecting appropriate projects for manufacturing companies by giving special attention to the production factors that will affect the project in the future. Such an approach will prevent choosing the wrong project and wasting time and money.

1.6 Innovations of the Study

In this research, a new method will be proposed to involve uncertainty of available evidence in the process of selecting the best alternative among a list of available proposals for manufacturing projects in order to minimize the level of the risk factors associated with a project by utilizing scheduling and line balancing risk assessment.

1.7 Hypothesis, questions, and objectives

1.7.1 The hypothesis of the research

This research tries to prove the following hypothesis

$$\begin{cases} H_0: \text{There are uncertain risk factors that exist and can impose detrimentally effects the projects} \\ H_1: \text{The opposite side is true} \end{cases}$$

To continue, and if the above hypothesis is confirmed, a new decision-making method will be proposed to minimize the risk factors that can influence the project's success in the future.

1.7.2 Questions of the research

This research tries to answer the following questions according to the project's hypothesis. The questions are:

1. What are the main factors that can influence a manufacturing project's future success in terms of a manufacturing firm's capabilities?
2. Are these factors constant or uncertain in project management experts' minds?
3. To what extent can the risk factors influence the project selection?
4. Can an effective method help choose the best project among the available alternatives while uncertainties exist like the risks associated with the alternatives?
5. If the answer to the above question is "Yes," to what extent does scheduling positively impact minimizing the risks associated with a project in the future?

1.7.3 Objectives

According to the questions mentioned above, the following objectives will be defined:

1. To determine the main factors that influence the success of a manufacturing project, check if they are constant or uncertain.
2. To develop a decision-making method to effectively choose the best project among the available alternatives while risk factors are uncertain.

3. To validate the proposed decision-making method in choosing the best project among the available alternatives in uncertain risk factors.
4. To determine the impact of uncertain risk factors in selecting projects among the available alternatives.

1.8 Assumptions of the research

Several assumptions must be considered while doing this research, which are:

1. All project alternatives are known in advance and no other alternative can be added later.
2. In this research, it is assumed that managers are not 100% confident about the impact of the various factors while selecting a project in most cases. This reality which represents uncertainty is entirely rational and in accordance with reality.
3. In addition, it is assumed that a manufacturing company has clear capabilities such as workforce, equipment, money, time, and the project will not be financed from elsewhere such as the government or stock market after the project completion unless it was known in advance.

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