

**COMPRESSION OF PROJECT SCHEDULES USING ETRPOY- TOPSIS
AND THE BEST-WORST-METHOD**

BY

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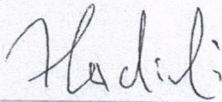
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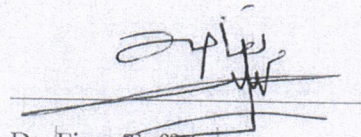


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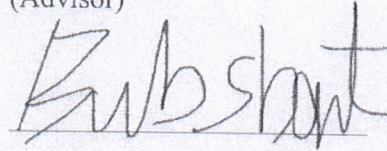


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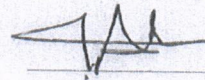
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[First of all, thank for Allah then thanks for everyone who helped me even in small advice
till I reached this stage in my life and completed this major milestone]

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LIST OF ABBREVIATIONS

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

BWM: Best-Worst-method

CP: Critical Path

Cs: Cost Slope

Ci: Cost before crashing.

Ca: Cost after crashing.

Ti: Time before crashing.

Ta: Time after crashing.

RII: The relative importance index.

|

ABSTRACT

Full Name : [A'sem Thabet Snoubar]

Thesis Title : [Compression of Project Schedules using Entropy-TOPSIS and the Best-Worst-method]

Major Field : [Construction Engineering and Management]

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In the construction industry there are many factors affecting the successful implementation of any project as for, but not limited to, design, cash flow, method of execution ... Etc., Among these factors, planning and the delivery time of the project is considered as the most important factors specially when the running project is expected to generate revenues, profits, or any other benefits to the owners. The time-cost trade off was the dominant criteria used in project acceleration. This trend is still seen in the literature despite some shy attempts reported by some researchers. Although the time-cost trade off is vital in project crashing, yet there are other factors that worth to be considered during the crashing process. In this thesis, the factors that have to be considered for activity selection and crashing will be addressed. At the same time, A multi-objective criteria model will be used to prioritize the activity selection for crashing. In particular, two different techniques will be used; the Entropy-TOPSIS method and the BWM-TOPSIS Model. In both, the TOPSIS will be used to provide the scores of the nominated activities for crashing, whereas the weights are generated either by the Entropy technique or through the BWM. Both methods are compared to the time-cost trade off method, and with respect to each other. The results indicated that both methods have a different behavior as compared to the traditional time cost trade off approach.

ملخص الرسالة

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عنوان الرسالة: ضغط جداول المشاريع باستخدام طريقه الانتروبي-توبسيس و طريقه الاسوء و الافضل

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في عالم المشاريع الإنشائية هنالك اسباب عده تساهم في نجاح المشروع من هذه الاسباب على سبيل المثال لا الحصر نذكر التصميم و توافر السيوله الماليه وطريقه الانشاء ... الخ, ومع ذكر هذه العوامل دائما يعتبر التخطيط للوقت الكلفه للمشروع من اهم العوامل خصوصا عندما يكزن المشروع ربحيا او له اهميه استراتيجيه او اي عوامل اخرى لدى المالك او المستفيد النهائي. لفتره زمني طويله كانت طريقه مقايضه الوقت بالتكلفه هي الطريقه الاكثر انتشارا واستخداما بالمشاريع الهندسيه في ضغط الجداول الزمنيه للتنفيذ وتقبل وقت تنفيذ المشروع, ولكن لا احد يستطيع ان ينكر ان هنالك عوامل اخرى تؤثر على اختيار النشاط بالمشروع لعملية ضغط الجدول الزمني وهذه العوامل جديره بان يتم دراستها واخذها بعين الحسبان. في هذه الرساله سيتم دراسته وتحديد العوامل التي يجب ان يتم اخذها بالحسبان وبنفس الوقت سيتم تطبيق التوبسيس وهي طريقه تعتمد على العوامل العده في اتخاذ بحيث يتم اعطاء درجه على مقياس درجات معين للعوامل التي تم اختيارها كمعامل مؤثره على ضغط الجدول الزمني للمشروع وسيتم اخذ هذه الدرجه من مره خلال تطبيق مبدأ انتروبي ومره اخرى من خلال طريقه الاسوء والافضل. و بعد تطبيق التوبسيس على الاوزان التي اخذت من الطريقتين سيتم مقارنة النتائج مع طريقه مقايضه الوقت بالتكلفه . في النهايه اظهرت النتائج اختلاف في سلوك الطريقتين عن الطريقه التقليديه وهي مقايضه الوقت بالتكلفه |

CHAPTER 1

INTRODUCTION

In the construction industry there are many factors affecting the successful implementation of any project as for, but not limited to, design, cash flow, method of execution ... Etc., Among these factors, planning and the delivery time of the project is considered as the most important factor specially when the running project is expected to generate revenues, profits, or any other benefits to the owners. The successful and proper planning for any project aids the contractor to deliver the project properly and within the time limitations. (Anderson, Shane, and Schexnayder 2011). Nevertheless, in the construction field there are several circumstances that surround the construction process. Therefore, there is always a chance for the original plan to be modified. And in some cases, the original plan goes through radical changes (Moselhi, Bakry, and Alshibani 2016). At the same time, project is bounded by risk and uncertain conditions also prevail, which will in turn impact the project execution and effect the project delivery date. Moreover, in many cases the owner/client or contractor is forced to terminate the project earlier than expected. Reasons behind this could be, but not limited to, the contractor is engagement with other projects which forces him to free some resources, or changes in the regulatory environment, and many others. Hence, the contractor/owner will be in immense need to expedite the project (Moselhi and Roofigari-Esfahan 2013a). In addition to the above, the appearance of unanticipated obstacles during the execution phase could lead to unfactored delays in the project execution and hence delaying the project delivery date. Besides, sometimes there are opportunities looming ahead that the contractor is willing to compete for. Under these circumstances and more, project expediting seems the proper solution. Project acceleration is one of the vital tools within the hands of the project manager that allows meeting deadlines, if needed, and capturing opportunities. project expediting is an important tool within the hands of the project manager that requires careful planning and management.

Traditionally, the cost slope method was the prominent tool used in projects acceleration. This technique relies on selecting the activity that enjoys the least cost per unit time to crash and expedite. Nevertheless, among the construction industry participants, there is an agreement that there are other factors that has to be taken into consideration, but unfortunately, those factors lack the appropriate technique and framework for application similar to the Time-Cost-Trade off method.

The first attempt to include other criteria in the crashing process is reported by (Moselhi and Roofigari-Esfahan 2013a). In their work, they used the “Analytical Hierarchy Process (AHP)” method to accelerate the project’s construction.

1.1 An overview of the two methods to be used:

1.1.1 TOPSIS

The TOPSIS “Technique for Order Performance by Similarity to Ideal Solution” was presented by Yoon and Hwang (1981) to solve multi-criteria decision-making (MCDM) problems depends on the idea that the selected option should be the nearest option to the optimum solution and the furthest from the negative solution. If every attribute has the “monotonically” swelling efficacy, then it is simple to put the “Ideal” answer that contains all best values of achievable qualities, and the “negative-ideal” answer contains all worst values of achievable qualities. One technique is to consider a substitute that has the shortest distance to the optimum answer in a “geometrical sense” and at the same time this substitute must be the farthest from the negative-optimum answer. According to Zavadskas, et.al (2006) TOPSIS is a compensative collecting method that compare a group of options or a set of solutions by assigning a weight for each one, “normalizing” score for each one and finding the geometric space between each solution and the optimal solution, the best answer is the nearest geometrically to the ideal solution and farthest from the negative-ideal solution. The steps of applying TOPSIS to a multi-criteria problem are: 1- Put all criteria’s in one matrix called “decision matrix” 2- Make the weight normalized “decision matrix” 3- Find the positive ideal and negative-ideal answer 4- Find geometric space between each alternative and the positive ideal and negative-ideal answer 5- Rank the alternatives as per the results in the step number 4.

1.1.2 Best-worst multi-criteria decision-making method

The best-worst method (BWM) was proposed by (Rezaei 2015) to solve multi-criteria decision-making (MCDM) problems. This method is quite simple and easy. The procedure of this method requires that the best (e.g. most desirable, most important) and the worst (e.g. least desirable, least important) criteria to be identified first by the decision-maker. Afterwards, a Pairwise comparisons are then conducted between each of these two criteria (best and worst) and the other criteria. After the terminations of the pairwise comparison phase, A maximin problem is then formulated and solved to determine the weights of the different criteria. The maximin problem is an optimization problem that requires the application of optimization software. Similar to the AHP process, both scores and weights are determined suing the same procedure. The final scores of the alternatives are derived

by aggregating the weights and scores almost in similar fashion to AHP process, and the best alternative with the highest overall score is identified. This method has a consistency ratio to check the reliability of the comparisons. In general; This method has some advantages compared to the existing methods, which are: (1) it requires less comparison data; (2) it easier to apply.

1.2 Problem Statement

In the literature, there are a few papers that discussed project acceleration and crashing using multi-objective criteria. Most of the work is mainly related to the “Time-Cost-Trade-Off” method. Yet, there are many factors that has to be considered during the crashing process. The purpose of this work is to consider those factors that are impacting activity selection and crashing and to propose a model that could be used to facilitate this task.

In this work, a multi-objective criteria model is proposed, this model will be used to prioritize the critical path activities, and hence, the activity with the highest priority shall be selected for expediting. The priorities are based on many factors of interest for the construction industry. Time-cost method is still also considered, but its role is not vital, its role depends on its priority relative to the other factors of interest.

These factors are taken from the literature, and yet, more refined through interviews and surveys to match the realities of the Saudi construction industry.

1.3 Objective

This research will introduce and present a new method for construction projects acceleration and crashing by using the Entropy weighing method and a TOPSIS model which will give the decision maker a strong support system to select the optimum activity for crashing based on this model outcomes and results. At the same time, the BWM will also be examined and applied in the same token.

1.4 Significance of this Work

This research will provide a method using the Entropy-TOPSIS and the BWM models to help the decision maker in selecting the optimal activity for the crashing process by

incorporating multiple factors rather than the cost slope criterion alone. Using the Entropy-TOPSIS model or the BWM will present a numerical technique that allows the decision makers to factor in additional variables in the activity selection for crashing and hence it will allow the selection of the activity that most fit their interest. In other words, the project manager will have the confidence when selecting activities for crashing. Also, this technique will present an excellent tool to the contractors that allow meeting the client's requirements and expectations in a better way.

Moreover, this research could be referred to as a reference for future research related to the development and application of different models in the activity selection and nomination for the crashing process.

1.5 Thesis Scope and Limitation

The most important purpose of this research is to give the decision maker a solid and helpful support system to select the activities for project crashing and acceleration process. However, the thesis limitations are as follows:

- A- The factors will be considered based on the construction expert's judgement
- B- Factors will be taken according to construction projects nature in the Kingdom of Saudi Arabia.
- C- The model is only based on the building construction projects and this research will not consider other sectors like Repetitive project or administrative projects, production line projects Etc. |

CHAPTER 2

LITERATURE REVIEW

In the following, the literature during the last ten years has been examined thoroughly. And through the following sections, the literature is outlined in almost three different sub sections.

2.1 Multi objective criteria method

According to the survey conducted by (Moselhi and Roofigari-Esfahan 2012), for project acceleration project managers often consider more than one factor in this process. Unfortunately, the lack of the proper framework that can enable admitting more one factor into event selection and crashing hinders the ability of the project managers to move in that direction. To circumvent this limitation, the authors proposed using the analytical hierarchy process (AHP) for schedule compression of construction projects. Where in their method, a multi-objective decision environment is utilized, in which activities are queued for crashing based on the priorities established in that environment. The factors of interest are gathered through surveys, and the authors presented a numerical example to illustrate the applicability of their method. In another attempt by the same authors, (Moselhi and Roofigari-Esfahan 2013b) the authors attempted to model the schedule compression process as a multi-attributed decision-making problem. For this purpose, they proposed a modified format of the Multiple Binary Decision Method (MBDM) along with iterative crashing process. The method was implemented in MATLAB, with a dynamic link to MS-Project to facilitate the needed iterative rescheduling. The applicability of the developed method was demonstrated through a numerical example. (Moselhi, Bakry, and Alshibani 2016) addressed project acceleration issue faced by repetitive projects, and for that concern, they proposed Fuzzy sets theory to model uncertainties associated with acceleration costs to prioritize activities for acceleration. At the same time, contractors' judgement is utilized to account for other influential factors. Once again, a case study was analyzed to demonstrate the method's applicability for repetitive projects.

2.2 Time-Cost and its variants

Construction projects acceleration is more than often required by contractors/ or owners. Contractors objectives behind acceleration may include, but not limited to, the existence of contractual bonus, to avoid penalties, to recover from delays, and to avoid bad anticipated weather conditions. Owners, on the other side, may want to capture business and operational opportunities. (Bakry, Moselhi, and Zayed 2014) presented an algorithm for schedule updating, dynamic rescheduling and optimized acceleration of repetitive construction projects. Where, optimized acceleration is s an optimized time–cost trade-off algorithm that is tailored for repetitive projects. Moreover, schedule updating and Dynamic scheduling aims at capturing the exact progress of the project and fine-tuning the remaining portion of the project. The optimized acceleration procedure divided each activity into smaller units, and identified the units that would shorten project duration if accelerated. For those identified units, the ones with the least cost slope are selected and queued for acceleration. Along with those identified units for acceleration, the algorithm attempts to study and allocate additional acceleration resources. Different acceleration strategies are utilized, as for, working overtime, working double shifts, working weekends, and adding more man power. The developed algorithm is applied to a case study drawn to illustrate its applicability. (Abuwarda and Hegazy 2016) proposed a model that determines the optimum combination of activity crashing and overlapping decisions that minimizes project cost without violating the resource constraints. To achieve this target, they studied the flexible relationships between activities. To capture this flexibility, they introduced a generic logical formalization of activity relationships. Using this representation, the activity start and finish time computations are modified and used with the schedule-crashing model. (Feylizadeh et al. 2018) introduced a model for compression of total project’s duration given different competing factors; which are time, cost, quality, and risk. In their work, project crashing and fast tracking are employed first, then a fuzzy multi objective model is applied to deal with the ambiguity and uncertainty. By applying the proposed method on an actual project as case study it has been found that the cost of compression was reduced. Besides this, the authors were able to determine which activities have to be crashed or fast tracked in order to achieve the target.

scheduling in repetitive construction projects (RCPs) is unique and complex due to the segregation of work into many segments, and the involvement of resources for activates completion. For these types of projects, (Heravi and Moridi 2019) introduced a scheduling method that enables managers to consider resources along with their associated shortages. To account for practical concerns surrounding these types of problems, the authors not only considered the direct and indirect cost of the resource, but the resource idle cost is also considered as a cost element within the total cost of the project. To search for optimal solution, they used a time variant multi-objective particle swarm. Finally, a numerical

example is presented to illustrate the model applicability. (Come and Kustamar 2019) studied the application of a typical time-cost methods on project acceleration. They applied this method on construction project of West Sumba. The project initially was subject to delays due to man power problems. The government declared the applicability of a project due date extension by an additional 50 days. The managers used time-cost analysis to crash activities over the critical path the has the lowest slope. After four rounds of compression, the managers managed to reduce the project duration to match up with the new set deadline, yet the increment in cost was not that much significant.

2.3 Impact of project acceleration

There is often a lack of agreement between various parties over is the suitable method that has to be used in acceleration claims on construction projects. (Maritz and Schutte, n.d.) conducted a survey in the South African construction industry to assess the application of various methods for activity crashing and project acceleration. The findings indicate that there are significant differences on a number of aspects regarding the calculation of acceleration costs on construction projects according to the parties being involved. However, majority of the respondents pointed out that the time impact analysis is the most frequently applied, but the modified total cost approach is the method that should mostly be adopted whenever there is a significant increase in the scope of work. Highway projects acceleration according to (Anderson, Shane, and Schexnayder 2011) has not received much attention. Therefore, the National Cooperative Highway Research Program has initiated an action to gather information in this regard. Based over the gathered information and on the successful project's acceleration reported in four different projects (Anderson, Shane, and Schexnayder 2011) presented a paper in which they synthesized the gathered information into fundamentals that can support successful planned accelerated highway project delivery. These fundamentals include detailed planning, design for project acceleration, collaborative environment, and the existence of incentives to motivate contractors. Zaini, Hidayat and Santosa (2017) conducted a real-life analysis over n library building project of State Islamic Institute of Samarinda, Indonesia. The authers indicated that using fast-track method to accelerate the project can save project time by "15%" without incurring substantial increase in cost through savings in the in-direct cost but it required a high level of management and coordination process. Also, it requires hiring a skilled and high experience staff and labor to get the maximum results of using this method, as well as close control of the work implementation. (Venugopal, Harsha, and Balaji 2017) analyzed the impact of project acceleration on the project's overall performance and success. In particular, they emphasized the acceleration impact on project quality, profitability, and resource utilization. On the other hand, Semwogerere (2018) studied the performance of Construction industry in Uganda. According to the author, the industry faces the problem of delay in completion of

projects. The research methodology used by the author included surveys, face to face interviews and survey results analysis. According to the author, most of the contractors are willing to accelerate rather than asking for an extension. This can be attributed to the benefits behind meeting the project delivery date and time. Crashing, in general, involves allocating additional resources to predetermined activities in order to reduce its duration. Time-cost relationships has often been assumed to be linear. Only a few studies have suggested that this should not be the case. (Ballesteros-Pérez, Elamrousy, and González-Cruz 2019) proposed two non-linear theoretical models which assume either collaborative or non-collaborative resources. According to the authors, these cases are the two most common situations that happen during construction projects. The proposed theoretical models allow for both discrete, continuous, deterministic, and stochastic configurations. To show the applicability of the method, a comparison has been conducted between this method and a recent method from the literature. Also (Mahardika et al. 2019) introduced “labor analysis” method to calculate the effect of the crashing process by using critical path method on the project labor cost by applying the method on real project, the result was savings in labor cost by 15%. Based on the study the project planner should take note to the relations between the activities from the beginning in the schedule which will reduce the cost of any crashing process in the future.

2.4 Using Entropy-TOPSIS in the construction

The Entropy weighting method and TOPSIS model have been used in the construction industry issues, in a recent study, (Dehdasht et al. 2020) studied the drivers related to the successful implementation of lean construction in the Malaysian industry. In their paper, they presented a list of all essential drivers and proposed a methodology to rank these drivers and identify the key drivers. They used the entropy weighted Technique coupled with TOPSIS in this regard. In summary, the authors identified of 63 important drivers in total; among these, 22 were considered as key drivers.

According to the literature above, and according to the authors best knowledge, neither the method of TOPSIS nor the BWM have been used in the project crashing and acceleration. Hence, examining the application of both methods or even each one alone for activity selection and crashing, as the subject of this research, is justified.

After examining the literature, only (Moselhi and Rofigari-Esfahan 2012) have examined this topic closely. And in their work they identified the set of factors impacting the compression of project schedules. Therefore, in this work we will adopt the factors cited by (Moselhi and Rofigari-Esfahan 2012). In the following; the factors and their descriptions are listed; The Factors are: 1- Resources availability 2- Risk 3- complexity and logistics 4- sub-contractor 5- cost slope 6- Number of successors 7- Cash flow constrain. Other factors also could be

considered like: Weather, Change Order and Bonus / Penalty. The following will explain the relation of each factor with compression of project schedules in the construction industry.

- Resources availability; The availability of resources is vital and essential to start and complete any project. As per (Elkabalawy and Al-Sakkaf 2021) in construction industries increasing the resources will result in a shorter execution period but decently it will increase the cost. So, the main concern for most of researchers is to find the optimal number of resources at the least budget impact.
- Risk; projects are always surrounded by risk. As per (Barker et al., n.d.) the foremost important issues to mitigate risks related to project are to remove any confusion, prevent any possibility to repeat the work and reduce the uncertainties.
- Complexity and the activity logistics; as per Gidado (2016) one of the biggest challenges that are encountered during project planning and execution phase is the degree of complexity the activity has. At the same time, Referring to (Tunji-Olayeni et al. 2017), activity logistics is a crucial part in the construction industry and it impacts the execution of any project. Activity logistics comprises the following typical activities; sourcing, procurement, shipment, receiving and warehousing of materials. Any delays to any part of the processes earlier will lead definitely to delay of the project submission date.
- Sub-contractors; Most of the projects requires a wide spread of activities and expertise. this mandate handing over various tasks to subcontractors. Hence, selecting proper subcontractor is significant to the project success (Albino and Garavelli 1998).
- The cost time trade-off; As per (Eirgash et al. 2019) the cost time trade-off is the most common method in project compression. The cost slope (Cs) of an activity could be defined as the deference between the cost before crashing (Ci) and the cost after crashing (Ca) divided by the deference in time before crashing (Ti) and after time after crashing (Ta). That is:

$$Cs = (Ca - Ci)/(Ti-Ta) \quad (1)$$

This will give a numerical tool for the planner, or the project manager to calculate the cost of compression for an activity. As per (Feng, Liu, and Burns 2000) the cost slope of an activity is considered as unknown and could not be measured before the activity start so in solving or applying any compression problem the doubt about time and cost must be taken into consideration

- Number of successors; The number of successors for the activity that will be crashed.
- Cash flow; As per (Al-Joburi, Al-Aomar, and Bahri 2012), cash flow is vital and important for each step in the constriction process, it affects all features and phases during the execution of the construction project. Any lack of cash for an activity or a set of activities will cause a delay in the completion and delivery of this activity/ activities. As per (Zayed and Liu 2014) construction projects are often characterized by various degrees of complexity, uncertainty and difficulty. Therefore, construction projects are often risky, and a proper cash flow administration is required to avoid any unnecessary delays in the project completion and delivery.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

In this work, as shown in Figure 1 the following research methodology is followed: -From the literature, the factors affecting activity selection for acceleration are determined (already finished). These factors gathered from the literature will be refined more through expert's feedback. This step is essential as it shapes the factors to match with the Saudi construction realities. A survey will be developed to assess the importance of each factor over a Likert scale of 7, where 1 stands for extremely not important, and 7 is extremely important. The remaining scale numbers are in between. The importance of each factor is measured via the RII or by any other convenient mean. The most important factors will be stressed over and passed to the TOPSIS and BWM models. Using TOPSIS/BWM methods, a model will be built. The model will be used to prioritize activities along the critical path according to the factors gathered. The activity with the highest priority should be selected for crashing. Crashing activities is an iterative procedure. It requires timely update to the construction schedule, the respective cost of each activity, resource availability, and the emergence of other critical paths. Hence, rules regarding activity selection and crashing will be developed, if not covered properly by the literature. Validate the model application through a numerical example, and afterwards we conclude.

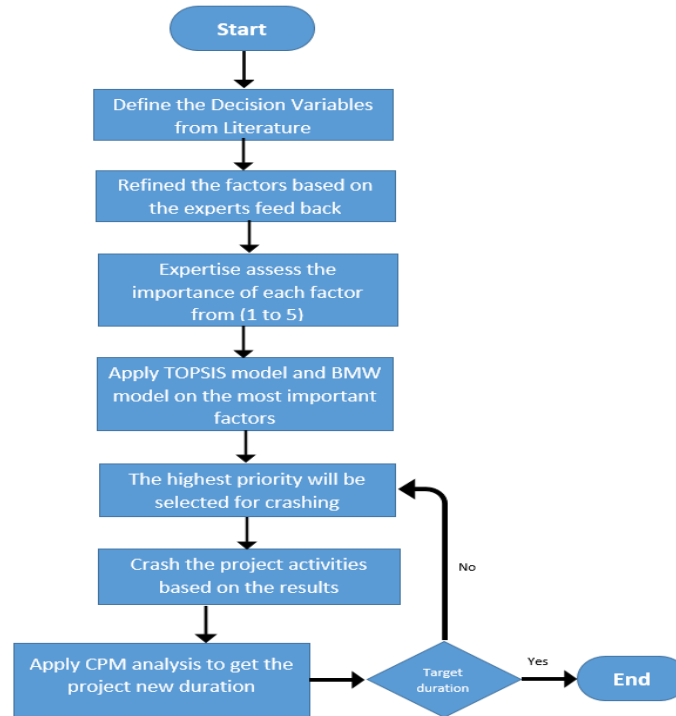


Figure 1 Flowchart for the proposed method

3.2 Expert's Meeting

In For more validation, interviews with experts in the construction industry have been conducted to get the experts opinion and judgment. The selection of those experts was based on their experience in the projects planning and control in the construction industry in KSA. Four interviews, in total, have been conducted. The following shows the demographics of the experts selected; The first expert has a master's degree in engineering management with 25 years of experience in the construction and currently he is project control director working with well-known pioneered construction company. The second expert has a Bachelor of science in Civil engineering with 19 years of experience in the construction, infrastructure and substations. Currently he is a Senior planner working with well-known company it is pioneer in construction industry. The third expert is a Civil engineer with 15 years of experience as senior planning engineer in the construction, infrastructure and water industry. Currently he is a Senior planner working with well-known company. He is preparing and monitoring the plans for mega and landmark projects. The fourth expert is a Civil engineer with 20 years of experience as a planning manager in the construction industry. Currently he is a planning manager working with a big and pioneer construction company. He is preparing and monitoring the plans for mega and landmark projects.

After the interviews, the experts dropped two factors (subcontractor, and contractor judgement), and approved the remaining factors but yet they added more. Table 1 shows the feedback of the experts.

Table 1 Experts meeting results.

No.	Factors	Expert 1	Expert 2	Expert 3	Expert 4	Selected
1	Resources availability (R1)	✓	✓	✓	✓	✓
2	Risk (R2)	✓		✓	✓	✓
3	complexity and logistic (R3)	✓	✓	✓	✓	✓
4	Cost Slope (R4)	✓	✓	✓	✓	✓
5	sub-contractor					Not selected
6	Number of successors (R9)		✓	✓		✓
7	Cash flow constrain (R5)	✓	✓	✓	✓	✓
8	Contractor Judgment	✓				Not selected
Factors added by the experts						
9	Availability of materials	✓				Not selected
10	logistics	✓				Not selected
11	Penalty / Bonus (R7)	✓	✓	✓	✓	✓
12	Indirect cost (R13)	✓		✓		✓
13	logic in the schedule (R14)	✓		✓		✓
14	Buffer time (R16)	✓			✓	✓
15	Weather (R6)	✓	✓		✓	✓
16	Activity location (Inside/outside)		✓			Not selected
17	Flexibility of the activity for compression (R10)		✓	✓		✓
18	Readiness of activity (R15)			✓	✓	✓
19	Rules and Laws (labor law, traffic, pol.... etc.) (R8)		✓		✓	✓
20	Required authorities to get approval (R11)		✓	✓	✓	✓
21	The quality constrains (R12)	✓			✓	✓

3.3 Factors based on the expert's judgment

In conclusion, sixteen (16) factors have been selected and ready to be used in the survey. Those factors are as follows:

Resources availability (R1), Risk (R2), Complexity (R3), Cost Slope (R4), Cash Flow Constrain (R5), Weather (R6), Penalty/ Bonus (R7), Rules and Laws (labor law, traffic, pol.... etc.) (R8), Number of Successors (R9), Flexibility of the activity for compression (R10), Required authorities to get approval (R11), Quality (R12), Indirect cost (R13), Logic in Schedule (R14), Readiness of activity (R15), and Buffer Time (R16)

3.4 Sample Size

3.4.1 Introduction

Sample size is an important consideration in research, as it impacts the validity and reliability of research results. Choosing an appropriate sample size is crucial for obtaining statistically significant results that accurately represent the population being studied.

3.4.2 Methods

Researchers use various methods to determine an appropriate sample size for their study. These include statistical power analysis, sample size calculation, and minimum sample size requirements. Statistical power analysis is a commonly used method that calculates the minimum sample size required to achieve a certain level of statistical power. Sample size calculation involves determining the sample size needed to detect a certain effect size or difference between groups. Minimum sample size requirements are set by some journals or funding agencies, and researchers must meet these requirements to have their study published or funded (Hulley et al., 2013).

3.4.3 Factors influencing sample size

Several factors influence the selection of an appropriate sample size, including the study design, research question, effect size, variability, and resources available. The study design, such as whether it is a randomized controlled trial or observational study, can affect the required sample size. The research question also plays a role, as some questions may require larger sample sizes than others. The effect size, or the magnitude of the difference or relationship being studied, can also impact sample size, with significance effects requiring larger sample sizes. Variability within the sample population can increase the required sample size, as larger sample sizes are needed to accurately capture the range of values. Finally, the resources available to conduct the study can also influence the selection of sample size, with larger studies requiring more time, money, and personnel (Polit & Beck, 2004).

3.4.4 How to Calculate Sample Size?

As we have defined all the necessary terms, let us briefly learn how to determine the sample size using a sample calculation formula known as Andrew Fisher's Formula.

A- Determine the population size (if known).

B- Determine the confidence interval.

C- Determine the confidence interval.

D- Determine the confidence level.

E- Determine the standard deviation (a standard deviation of 0.5 is a safe choice where the figure is unknown)

F- Convert the confidence level into a Z-Score. This table shows the z-scores for the most common confidence level.

Confidence level	z-score
80%	1.28
85%	1.44
90%	1.65
95%	1.96
99%	2.58

G- Put these figures into the sample size formula (Equation 2) to get your sample size the.

$$\text{Sample size} = \frac{Z^2 \cdot \sigma(1-\sigma)}{CI^2}; \quad (2)$$

where; Z: Z-score, σ : Standard deviation and CI: Confidence interval.

The below is sample size required our research:

Considering 95% as confidence level so the Z-score is 1.96, a standard deviation of 0.5, and a confidence interval (margin of error) of $\pm 10\%$, you just need to substitute the values in the formula:

$$\text{sample size} = \frac{1.96^2 \times 0.5 (1-0.5)}{0.1^2} = 96.04$$

Our sample size should be 97.

3.5 Survey distribution

In total, ninety-nine (99) responses were collected which is comparable to the required sample size ($n=96$). The responses have been collected from various practitioners in the field, the sample included Contractors, Clients, and Consultants. 78% of the participants have experience more than ten years in the management and control of construction projects. The full survey questions are available in the Append. I. All the respondents are well positioned within the construction industry

The survey contained sixteen factors for participants ranking and evaluation. The respondents are asked to assess the importance of the factors, as per their best knowledge and practice, over a Licker scale of 7, where 1 stand for extremely not important, and 7 is extremely important, and the remaining are in between.

3.6 Survey Data

The targeted sample were various professionals in construction who assume various managerial and engineering positions and have good experience in the construction field. The survey data showed that 23% of the participants are project managers, 14% are planners, 9% are project controllers, 8% are construction managers, 7% are consultants, 4% are contracts specialists, whereas the remaining specialist assume different positions in the construction companies. Also, the data showed that the participant types of business are 55.6% from contractor's companies, 20.2% from client's companies, 20.2% from consultant's companies. Fig 2 shows the participants various types of business distribution.

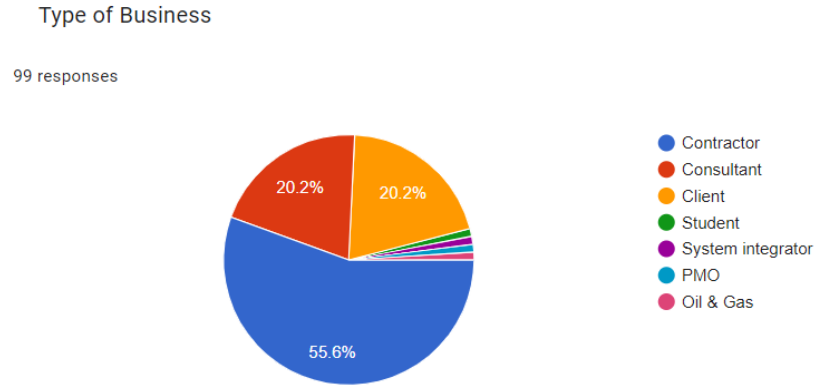


Figure 2 Participant types of business distribution

In terms of the project size the participants are involved with: 42.4% of the projects are more than 1 Billion SAR, 27.3% are between SAR 500 Million and 1 Billion, 9.1% are between SAR 200 – 500 Million, 11.1% are between SAR 50-200 Million. This information is shown in Figure 3. The survey data showed that 81% are using Primavera as software for project acceleration and 17.2% are using MS projects (see Figure 4).

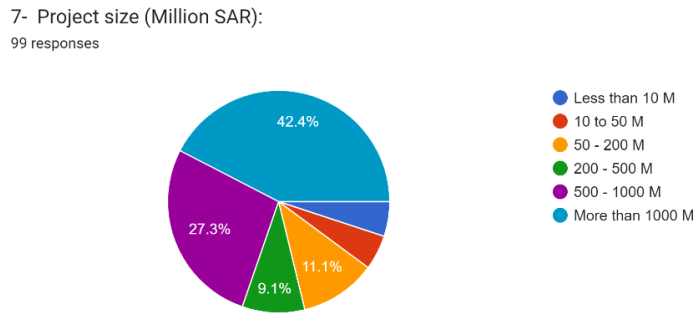


Figure 3 Projects size distribution

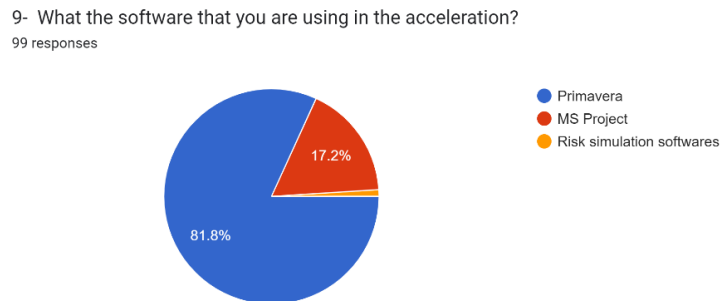


Figure 4 Software that used for acceleration.

3.7 Survey Results

After analyzing the responses, the relative importance index (RII) along with the mean of the data were analyzed. The RII equation can be calculated as: -

Equation 1 RII

$$RII = \frac{\sum_{i=1}^5 a_i n_i}{A * N} \quad (3)$$

Where:

a_i :- Is the categories used in the Likert scale of the survey, that is $a_1 = 1, a_2 = 2$ and so on

n_i : Number of responses reported at each level $i, i = 1, 2, \dots, 5$

A :- Is the highest weight (i.e., 7 in this case)

N :- Total number of responses

Table 3.2 summarizes the results of the Factors' RII along with their mean values in a descending order. The mean value indicates whether a factor has received a sufficient level of significance to be deemed important. All factors that has a mean value higher than 4 are considered to be important and hence admitted for further analysis. According to Table 3.2, the following are the highest important six factors (factors with a mean higher than value of 4): Cash Flow Constrain (R5), Resources availability (R1), Quality (R12), Flexibility of the activity for compression (R10), Readiness of activity (R15), Cost slope (R4). Although the cost slop is among the selected ones, yet, its rank is an indication that the current practices are considering other factors other than the cost slope whenever a project expedition is required.

Table 2 Survey Results and analysis.

	Factor	RII	Mean	Rank
R5	Cash flow constrain	0.7	5.63	1
R1	Resource availability	0.7	5.57	2
R12	Quality	0.69	5.51	3
R10	Flexibility of the activity for compression	0.64	5.09	4
R15	Readiness of activity	0.63	5.05	5
R4	Cost slope	0.63	5.01	6

R2	Risk	0.59	4.76	7
R3	Complexity	0.57	4.59	8
R14	Logic in schedule	0.56	4.49	9
R11	Required authorities to get approval	0.54	4.32	10
R9	Number of successors	0.54	4.29	11
R8	Roles and Laws	0.49	3.96	12
R13	Indirect cost	0.49	3.89	13
R7	Penalty / Bonus	0.48	3.82	14
R16	Time buffer	0.47	3.8	15
R6	Weather	0.47	3.74	16

3.8 Expert judgment for the survey result

Based on the survey results, it is evident that there are several factors that are considered important in selecting the activity for the crashing process. Out of the 16 factors that were assessed, six factors received an important rating of more than 5. These factors are Cash Flow Constrain (R5), Resources availability (R1), Quality (R12), Flexibility of the activity for compression (R10), Readiness of activity (R15), and Cost slope (R4).

However, upon consulting the experts, it was advised to reduce the number of factors to four. This is because some of the factors are highly related with each other. Hence, some can be compensated for by others. For example, Cash Flow Constrain is a sub component of cost slope factor, while Readiness of activity is a result of resource availability. Hence both factors were taken out as they are represented by the other two factors. In conclusion, the following four factors will be used for activity selection through the entropy-BMW/TOPSIS model, where the project managers can make informed decisions and take appropriate actions in selecting the activity for crashing.

The four remaining factors that are considered for project crashing are:

1. Resources availability (R1) This refers to the availability of necessary resources, including personnel, materials, and equipment, for the successful completion of a project. Having access to adequate resources can help ensure that a project is completed on time and within budget.

To assess the resources availability attribute, a scale of 1 to 5 will be used, where 1 stands for very low, and 5 is for very high. The activities having higher resources will have a higher score value reflecting the number of resources available. The activity scores will be assigned as per the expert's feedback.

2. Quality (R12) This factor emphasizes the importance of delivering a high-quality product or service. Quality is essential for building customer loyalty and maintaining a positive reputation in the industry.

The quality assessment model has been performed using “probability impact matrix” shown in Table 3.2. where for each activity selected for crashing, the impact on quality is assessed on a two-dimensional scale. The impact on quality if the activity has been expedited which is measured on a scale from 1 to 5, and the likelihood of that impact which is also measured on a scale from 1 to 5. The aggregate overall impact on quality is measured by calculating α (eq. 3.8) , where $0 \leq \alpha \leq 1$. The lower the α values the lower the impact on quality.

$$\alpha = \frac{\text{Activity Probability} \times \text{Activity Impact}}{25} \dots\dots\dots (3.8)$$

Table 3 probability impact matrix

		VL	L	M	H	VH	
Probability	5	5	10	15	20	25	VH
	4	4	8	12	16	20	H
	3	3	6	9	12	15	M
	2	2	4	6	8	10	L
	1	1	2	3	4	5	VL
		1	2	3	4	5	
		Impact					

3. Flexibility of the activity for compression (R10) This factor refers to the ability to compress or shorten the duration of a project activity without affecting the overall project schedule. A high level of flexibility can help project managers adapt to unforeseen circumstances and make changes to the project plan when necessary.

Flexibility of the activity for compression will be defined using a scale of 1 to 5 similar to the scale used for the resource availability attribute. In a similar fashion, activities with a score of 1 are activities that possess limited flexibility for compression. Whereas, activities with a score of 5 are the activities that enjoys the highest flexibility for compression. Expert’s judgment will be used to assign each a score for each activity.

- Cost slope (R4) This factor is related to the rate at which costs increase as the duration of a project decreases. It is important to monitor cost slope throughout the project to

ensure that the project stays within budget and does not exceed the available cost. The attributes of the cost slope will be calculated from the project given cost data and information, the cost slope (C_s) of an activity could be defined as the deference between the cost before crashing (C_i) and the cost after crashing (C_a) divided by the deference in time before crashing (T_i) and after time after crashing (T_a).

CHAPTER 4

Model Implementation

4.1 Entropy model:

The application of the TOPSIS method requires the availability of a predetermined set of weights w_j to be used. These weights can be determined subjectively using any convenient approach such as the AHP or the Delphi method etc. In general, these approaches are subject to bias due to human subjectivity. On the contrary, the entropy approach can lead to more objective assessment as it explores the internal indexes inherent variation within the data. The smaller the disorder degree of the system is, the smaller the value of entropy will be. And vice versa. Thus, the entropy method examines and reflects the natural amount of disorder within a system as an objective weight for that system. The entropy method works as follows.

- Standardization of indexes

Given that there are m activities to crash, and n criteria for evaluation, let x_{ij} be the index value at the i th activity and j th criterion. In order to eliminate the impact of the index's values over the weights, the indexes have to be standardized using equations (4) and (5) below. For benefit indexes the x_{ij} 's can be standardized using (Eq. 4), besides, for the cost indexes, the x_{ij} 's can be standardized using (Eq. 5).

Activity/Factors	1		j		n
Act1	x_{11}	x_{12}	.	.	x_{1n}
Act2	x_{21}	x_{22}	.	.	x_{2n}
i	.	.	x_{ij}	.	.
.	.	.	.	.	.
Act m	x_{m1}				x_{mn}

$$r_{ij} = \frac{x_{ij}}{\max_j x_{ij}}; (i=1, \dots, m; j=1, \dots, n) \quad (4)$$

Where x_{ij} the attribute value of the j factor in the activity i .

$$r_{ij} = \frac{\min_j x_{ij}}{x_{ij}}; \min_j x_{ij} \neq 0; (i=1, \dots, m; j=1, \dots, n) \quad (5)$$

After transforming the Indexes to their Standard format, the standardized matrix $R = [r_{ij}]_{m \times n}$ is formed.

- Calculation of the Entropy weights

The Entropy weights of the j th factor can be calculated by the equation (6), (7) and (8) below. First the factor f_{ij} is calculated using equation (7), then the H_j values and the factor weights w_j are calculated using equations (6) and (8).

$$H_j = \frac{\sum_{i=1}^m f_{ij} \ln f_{ij}}{\ln m}; (i=1, \dots, m; j=1, \dots, n) \quad (6)$$

Where:

$$f_{ij} = \frac{r_{ij}}{\sum_{i=1}^m r_{ij}}; (i=1, \dots, m; j=1, \dots, n) \quad (7)$$

If $f_{ij} = 0$, then let $\ln f_{ij} = 0$

Now we can calculate the Entropy Weight Indexes (w) from equation (5)

$$w_j = \frac{1-H_j}{n - \sum_{j=1}^n H_j}; \sum_{j=1}^n w_j = 1, (j=1, \dots, n) \quad (8)$$

4.2 TOPSIS model:

TOPSIS stands for “Technique for Order Preference by Similarity to Ideal Solution”, and it is abbreviated as Ideal Solution. The basic idea is to define the ideal solution and negative ideal solution for the decision-making problem first, then find a feasible solution and rank the selected activities for crashing according to their closeness to the ideal solution and spacing away from the negative ideal solution. In conclusion, the activities that have higher rankings are those that are closer on average to the ideal solution and furthest away on

average from the worst ideal solutions. The steps for applying the TOPSIS method are as follows:

- Build the decision matrix:

Given that there are m activities to crash, and n criteria for evaluation, let x_{ij} be the index value at the i th activity and j th criterion, then the decision matrix is $X = [x_{ij}]_{m \times n}$. To cancel the effect of index size and value on the results, all indexes have to be normalized to form the matrix $R = [r_{ij}]_{m \times n}$ by the following equation

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}}, (i=1, \dots, m; j=1, \dots, n)$$

Next, the weighted decision matrix is formed by multiplying the indexes weights with the normalized matrix as shown by (9)

Equation 2 V_{ij}

$$V_{ij} = w_j r_{ij}, (i=1, \dots, m; j=1, \dots, n) \quad (9)$$

The weights for the TOPSIS method are predetermined using either the Entropy method, an AHP, or through using the BWM.

The ideal solution is coming from the optimum result of every aspect from the matrix V_{ij} and illustrated by equation (10), as well the negative ideal solution is coming from the worst result of every aspect from the matrix V_{ij} and illustrated by equation (11).

$$V^+ = (V_1^+, V_2^+, \dots, V_m^+) \quad (10)$$

$$V^- = (V_1^-, V_2^-, \dots, V_m^-) \quad (11)$$

So, the ideal result and negative ideal result could be obtained from equations (12) & (13).

$$V_j^+ = \begin{cases} \max V_{ij}, & \text{for the benefit indexes} \\ \min V_{ij}, & \text{for the cost indexes} \end{cases} \quad (12)$$

$$V_j^- = \begin{cases} \min V_{ij}, & \text{for the benefit indexes} \\ \max V_{ij}, & \text{for the cost indexes} \end{cases} \quad (13)$$

Now, we need to calculate the distance of each answer from the ideal solution and the negative ideal solution by using equations (14) & (15)

$$S_i^+ = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^+)^2}, \quad (i=1, \dots, m; j=1, \dots, n) \quad (14)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^-)^2}, \quad (i=1, \dots, m; j=1, \dots, n) \quad (15)$$

To calculate the relative degree of approximation, we use equation (16)

$$P_i = \frac{S_i^-}{(S_i^+ + S_i^-)}, \quad (0 \leq P_i \leq 1; i = 1, 2, \dots, m); \quad (16)$$

The activities will be ranked according to their P_i values in descending order. The activity that is ranked first i.e. has the highest P_i value, is selected for crashing.

4.3 Best Worst Method:

(Rezaei 2015) introduced a new method of multi criteria decision-making, called the Best-Worst (BWM) method. The method assumes that individuals can more easily identify the best and worst options from a set of alternatives than rank them in order of preference. The BWM method involves asking individuals to identify the best and worst options from a set of alternatives based on a set of criteria, firstly. Then, the individuals are asked to assess the relationship between the best alternative with respect to the remaining options forming the vector best to others (BO). At the same time, the others are compared to the worst option forming the vector of others to worst (OW). All comparisons are conducted using a scale of 1 to 9 similar to the AHP process. To calculate the weights of the factors/alternatives, the following linear program is solved.

min ξ

s.t.

$$|w_B - a_{Bj}w_j| \leq \xi w_j, \quad \text{for all } j$$

$$|w_j - a_{jw}w_w| \leq \xi w_w, \quad \text{for all } j$$

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

$$w_j \geq 0, \quad \text{for all } j$$

Where

w_B , w_w , and w_j are the weights of the best, worst, and remaining options, respectively.

a_{Bj} , and a_{jw} are the scores (over a scale from 1 to 9) between the best option to other options, and the other options to the worst option.

Similar to the AHP, the BWM has a consistency assessment based on a_{Bj} , and a_{jw} values. After the decision maker carries out the pairwise assessments, an input-based consistency ratio(CR^i) can be calculated. If CR^i value is less than a specific threshold level, the decision maker assessment is deemed acceptable, otherwise, the decision maker is asked to reassess again ((Liang, Brunelli, and Rezaei 2020)). The BWM offers some advantages over the AHP process. It requires fewer pairwise comparisons. For n criteria, a total of $2n-3$ comparisons are required compared to $n(n-1)/2$ comparisons needed by the AHP. At the same time, the consistency assessment is directly related to the inputs and guides the decision maker on which assessments he has to change to be more consistent. Whereas although the AHP has a consistency ratio, but it doesn't provide guidance for the decision maker on where to pay attention to adjust his consistency.

4.4 Numerical Example:

To illustrate the application of TOPSIS-Entropy, and TOPSIS BMW methods for activity selection and project crashing, the model presented by Feng et.al. (1995) will be adopted and used. Which is the same case referred to by (Moselhi and Roofigari-Esfahan 2013b) in their work.

The case presented and used is for a construction project with seven activities. The indirect cost is \$1500 per day. Figure 5 shows the project network of this case and the data of the project is shown by figure 6 including the direct cost and cost slope for all project activities as taken from (Moselhi and Roofigari-Esfahan 2013b).

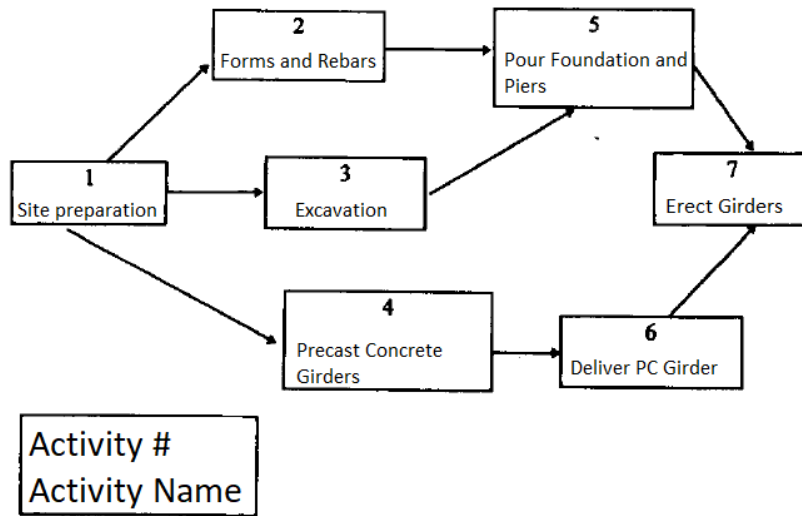


Figure 5 Case study project network

Activity	Duration	Direct cost(\$1000)	Cost slope
1	14	23.0	1.100
	20	18.0	
	24	12.0	
2	15	3.0	0.200
	18	2.4	
	20	1.8	
	23	1.5	
	25	1.0	
3	15	4.5	0.070
	22	4.0	
	33	3.2	
4	12	45.0	1.875
	16	35.0	
	20	30.0	
5	22	20.0	1.250
	24	17.5	
	28	15.0	
	30	10.0	
6	14	40.0	2.20
	18	32.0	
	24	18.0	
7	9	30.0	0.890
	15	24.0	
	18	22.0	

Figure 6 Project data including the direct cost and cost slope (Moselhi and Esfahan (2013))

4.4.1 Applying Entropy-TOPSIS model:

As shown in Table 4 the project activities matrix for the whole project with the decision factors and attributes that have been gathered from the survey and experts' judgement, as well Figure 5 shows the project plan and duration in addition to the critical path activities

using MS project. The critical path activities are activities 1, 3, 5 and 7. With these activities being used as the set of alternatives we have, in addition to the selection criteria developed earlier the initial iteration of the entropy-TOPSIS can commence.

Table 5 shows the matrix of the critical path activities that will be used in the first iteration along with the scores of the activities at each criterion. The criteria have been partitioned into beneficial criteria and cost criteria. For the beneficial criteria (highlighted in green) we opt for the higher the better, whereas for the cost criteria (highlighted in red) the lower is the best. Figure 9 Also shows the reference max/min that will be used as an input to equations (1) and (2).

Table 4 Project activity matrix for the whole project with the decision factors and attributes

#	Activity/ Factor	RA	Flexibility	Quality	Cost slope	Duration	Crushable days
1	Site preparation	5	5	0.04	1.1	24	10
2	Forms and Rebars	3	4	0.6	0.2	25	10
3	Excavation	3	1	0.8	0.07	33	18
4	Precast Concrete Girders	2	1	1	1.875	20	8
5	Pour Foundation and Piers	3	2	0.6	1.25	30	8
6	Deliver PC Girder	3	4	0.24	2.2	24	10
7	Erect Girders	1	3	0.8	0.89	18	9

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names	s
1			Site Preparation	24 days	Mon 3/6/23	Thu 4/6/23			
2			Form and Rebars	25 days	Fri 4/7/23	Thu 5/11/23	1		
3			Excavation	33 days	Fri 4/7/23	Tue 5/23/23	1		
4			Precast Concrete Girder	20 days	Fri 4/7/23	Thu 5/4/23	1		
5			Pour Foundation and Piers	30 days	Wed 5/24/23	Tue 7/4/23	2,3		
6			Deliver PC Girder	24 days	Fri 5/5/23	Wed 6/7/23	4		
7			Erect Girders	18 days	Wed 7/5/23	Fri 7/28/23	6,5		

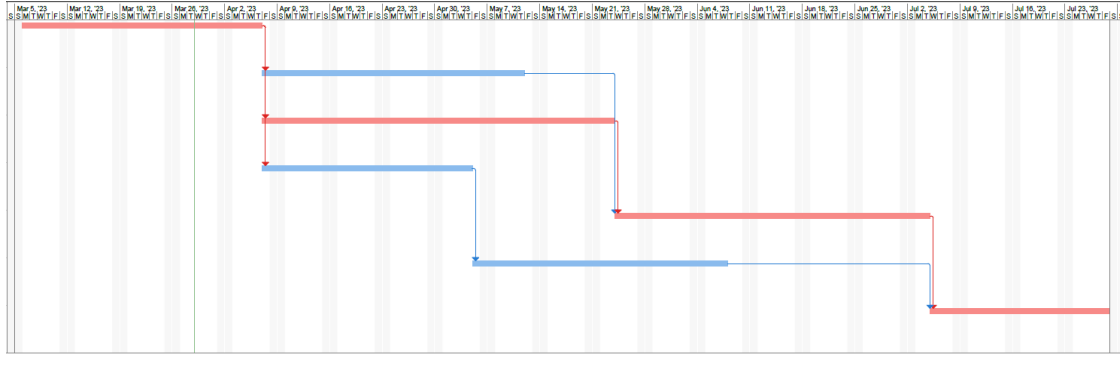


Figure 7 Project plan using MS project

Table 5 Matrix for Critical Path activities 1st iteration

#	Activity/ Factor	RA	Flexibility	Quality	Cost slope	Duration	Crushable days
1	Site preparation	5	5	0.04	1.1	24	10
3	Excavation	3	1	0.8	0.07	33	18
5	Pour Foundation and Piers	3	2	0.6	1.25	30	8
7	Erect Girders	1	3	0.8	0.89	18	9
	Max or Min	5	5	0.04	0.07	105	

Using equations (4) and (5), table 5 can be transformed to the R matrix, $R = [r_{ij}]_{m \times n}$ shown in the table 6

Table 6 The standardized matrix $R = [r_{ij}]_{(m \times n)}$

#	Activity/ Factor	r_{ij}			
		RA	Flexibility	Quality	Cost slope
1	Site preparation	1.000	1.000	1.000	0.064
3	Excavation	0.600	0.200	0.050	1.000
5	Pour Foundation and Piers	0.600	0.400	0.067	0.056
7	Erect Girders	0.200	0.600	0.050	0.079

Using equation (7) the f_{ij} matrix is developed as shown in Table 7.

Table 7 The f_{ij} matrix

#	Activity/ Factor	f_{ij}			
		RA	Flexibility	Quality	Cost slope
1	Site preparation	0.41667	0.454545	0.857143	0.053106
3	Excavation	0.25	0.090909	0.042857	0.834524
5	Pour Foundation and Piers	0.25	0.181818	0.057143	0.046733
7	Erect Girders	0.08333	0.272727	0.042857	0.065637

Lastly, the H_j , and w_j values can be derived using Table 7. and through equations (6) and (8), the results are shown in table 8.

Table 8 Entropy Wight Indexes (w_j)

Factors	RA	Flexibility	Quality	Cost slope	
H_j	0.91251	0.894965	0.408047	0.453568	
w_j	0.066	0.079	0.445	0.411	1

With the weights of the criteria being established (w_j), the first iteration of the TOPSIS method can start.

Now, the following steps will be applied to implement the TOPSIS model:

- 1- With the scores identified along with the activities as shown in Table 4 or 5. After normalizing the matrix using eq.(9), the following normalized matrix will be developed as shown by Table 10.

Table 9 critical activities vs factors matrix including weights.

	Benf.	Benf.	N Benf.	N Benf.
weights	0.066	0.079	0.445	0.411
Activity/Criteria	RA	Flexibility	Quality	Cost slope
Site preparation	5	5	0.04	1.1
Excavation	3	1	0.8	0.07
Pour Foundation and Piers	3	2	0.6	1.25
Erect Girders	1	3	0.8	0.89

Table 10 Normalized matrix

Activity/Criteria	RA	Flexibility	Quality	Cost slope
Site preparation	0.7537784	0.800641	0.03122	0.5822
Excavation	0.452267	0.160128	0.62439	0.0371
Pour Foundation and Piers	0.452267	0.320256	0.46829	0.6616
Erect Girders	0.1507557	0.480384	0.62439	0.4711

- 2- The weighted normalized matrix is calculated by applying equation 11. then the ideal solutions (both positive and negative) are found at every criterion by using equations (12) and (13), respectively. Using equations (1-6) and (17), the Euclidean distance from the ideal best solution (S_i^+) as well as the Euclidean distance from the ideal worst solutions (S_i^-) are determined. To determine the activities' rank, the relative degree (P_i) is determined using equation 14. The activities are ranked according to their P_i values, where the activity that has the highest P_i value is ranked first, and so on. Figure 15 shows the final matrix. As per Table 11, site preparation (1) is ranked first and will be selected for crashing.

Table 11 Final TOPSIS matrix

Activity/Factor	RA	Flexibility	Quality	Cost slope	Si+	Si-	Pi	Rank
Site preparation	0.050	0.063	0.014	0.239	0.224	0.273	0.550	1
Excavation	0.030	0.013	0.278	0.015	0.269	0.257	0.488	2
Pour Foundation and Piers	0.030	0.025	0.208	0.271	0.325	0.073	0.184	4
Erect Girders	0.010	0.038	0.278	0.193	0.322	0.082	0.203	3
V+	0.050	0.063	0.014	0.015				
V-	0.010	0.013	0.278	0.271				

Project crashing and expediting is an iterative process. After selecting an activity to crash, the project schedule and plan is modified and the critical path is reassessed to determine if new activities will show up or not. At any new iteration, and for selecting an activity to crash, the same set of steps outlined above will be repeated again. After running the Entropy-TOPSIS for activity selection and crashing the final and crashed project schedule using the Entropy-TPOSIS model is shown in Table 12 and Fig 9.

Table 12 Final crashing result

Iteration #	CP Activities	Crashed Act	Crashed time	New selected activity duration	New duration Project
0	1 3 5 7				105
1	1 3 5 7	1	10	14	95
2	1 3 5 7	3	8	25	87
3	12357	2,3	10	15	77
4	12357	5	1	29	76
5	12357 1467	6,5	7	5=22 6=17	69
6	12357 1467	6	1	16	69
7	12357	7	9	9	60

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			Site Preparation	14 days	Mon 3/6/23	Thu 3/23/23		
2			Form and Rebars	15 days	Fri 3/24/23	Thu 4/13/23	1	
3			Excavation	15 days	Fri 3/24/23	Thu 4/13/23	1	
4			Precast Concrete Girder	20 days	Fri 3/24/23	Thu 4/20/23	1	
5			Pour Foundation and Piers	22 days	Fri 4/14/23	Mon 5/15/23	2,3	
6			Deliver PC Girder	17 days	Fri 4/21/23	Mon 5/15/23	4	
7			Erect Girders	9 days	Tue 5/16/23	Fri 5/26/23	6,5	

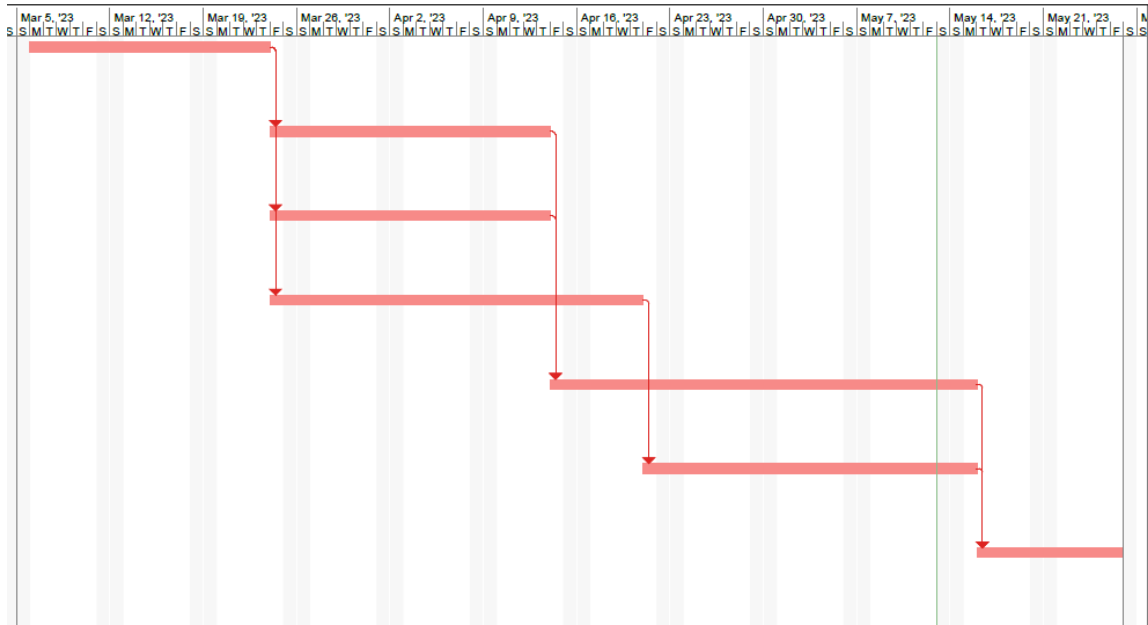


Figure 8 Crashed project schedule using Entropy-TPOSIS model.

4.4.2 Applying Best Worst Method- TOPSIS Model

As mentioned in section 4.3 the Best Worst Method will be used to determine the weights that will be used in normalized matrix in the TOPSIS model. Firstly, experts are consulted to identify the best factor and Worst factor. According to the expert's feedback, Quality (3) is selected as the best factor, whereas the Cost Slope (R4) is the worst factor. Secondly, the experts were asked to determine the scores (on a scale from 1 to 9) between the best and others to form the BO vector. At the same time, they were asked to assign scores between others and the worst to form the OW vector. Tables 13 and table 14 shows the expert feedback.

Table 13 Best to other attributes

Best to Others	RA (1)	Flex (2)	Quality (3)	Cost Slope (4)
Quality (3)	7	6	1	4

Table 14 Others to worst.

Others to the Worst	Cost Slope (4)
RA (1)	2
Flex (2)	2
Quality (3)	4
Cost Slope (4)	1

To determine the criteria weights, the following linear program is formed.

$$\min \xi$$

s.t.

$$|w_3 - a_{31}w_1| \leq \xi w_1,$$

$$|w_3 - a_{32}w_2| \leq \xi w_2$$

$$|w_3 - a_{34}w_4| \leq \xi w_4$$

$$|w_1 - a_{24}w_4| \leq \xi w_4$$

$$|w_2 - a_{24}w_4| \leq \xi w_4$$

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

$$w_j \geq 0, \text{ for all } j$$

Where $a_{31} = 7$, $a_{32} = 6$, $a_{34} = 4$, $a_{14} = 2$, $a_{24} = 2$ (Tables 4.1, and 4.2)

Through using Excel solver the following weights were obtained (see the Table below).

Weights	RA	Flex	Quality	Cost Slope	Fact Sum
	0.1106	0.1290	0.6359	0.1244	1

To determine the input-based constituency ratio CR^i), the equation (0) has been used

Once the weights are determined, the TOPSIS model will be applied by using the weights values obtained from the BWM.

Table 15 shows the critical activities vs factors matrix including the weights from BWM model

Table 15 Critical activities vs factors including BWM weights

weights	0.111	0.129	0.636	0.124
Activity/Factor	RA	Flexibility	Quality	Cost slope
Site preparation	5	5	0.04	1.1
Excavation	3	1	0.8	0.07
Pour Foundation and Piers	3	2	0.6	1.25
Erect Girders	1	3	0.8	0.89

Table 16 shows the final TOPSIS matrix including V_j^+ , V_j^- , S_i^+ , S_i^- , P_i and the activities ranking. As shown by Table 16, site preparation (1) is selected for crashing in the first iteration,

Table 16 Final TOPSIS matrix including V^+ , V^- , S_i^+ , S_i^- , P_i

Activity/Factor	RA	Flexibility	Quality	Cost slope	Si+	Si-	Pi	Rank
Site preparation	0.083	0.103	0.020	0.072	0.068	0.392	0.852	1
Excavation	0.050	0.021	0.397	0.005	0.388	0.085	0.179	3
Pour Foundation and Piers	0.050	0.041	0.298	0.082	0.297	0.107	0.264	2
Erect Girders	0.017	0.062	0.397	0.059	0.389	0.048	0.109	4
V+	0.0834	0.1033	0.0199	0.0046				
V-	0.0167	0.0207	0.3971	0.0823				

Like the Entropy-TOPSIS earlier, the steps are repeated at each crashing activity selection step. Nevertheless, only the TOPSIS matrix has to be revisited as the scores do change from iteration to iteration. but since the criteria will not change, the weights are determined only once using the BWM.

After running the BWM-TOPSIS for activity selection and crashing, the following crashing schedule is developed (Table 17). besides, Figure 10 shows the final and crashed project schedule using BWM-TOPSIS model.

Table 17 Final crashing results using BWM-TOPSIS

Iteration #	CP Activities	Crashed Act	Crashed time	New selected activity duration	New duration Project	Remarks
0	1 3 5 7				105	
1	1 3 5 7	1	10	14	95	
2	1 3 5 7	5	8	22	87	
3	1357	3	8	25	79	
4	12357	2,3	3	22	76	
5	12357 1467	6	1	23	76	Will not decrease the CP period
6	12357	2,3	1	21	75	
7	12357 1467	6,2,3,	6	2,3=15 6=17	69	
8	12357 1467	6	1	16	69	Will not decrease the CP period
9	12357	7	9	9	60	

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		Site Preparation	14 days	Mon 3/6/23	Thu 3/23/23		
2		Form and Rebars	15 days	Fri 3/24/23	Thu 4/13/23	1	
3		Excavation	15 days	Fri 3/24/23	Thu 4/13/23	1	
4		Precast Concrete Girder	20 days	Fri 3/24/23	Thu 4/20/23	1	
5		Pour Foundation and Piers	22 days	Fri 4/14/23	Mon 5/15/23	2,3	
6		Deliver PC Girder	17 days	Fri 4/21/23	Mon 5/15/23	4	
7		Erect Girders	9 days	Tue 5/16/23	Fri 5/26/23	6,5	

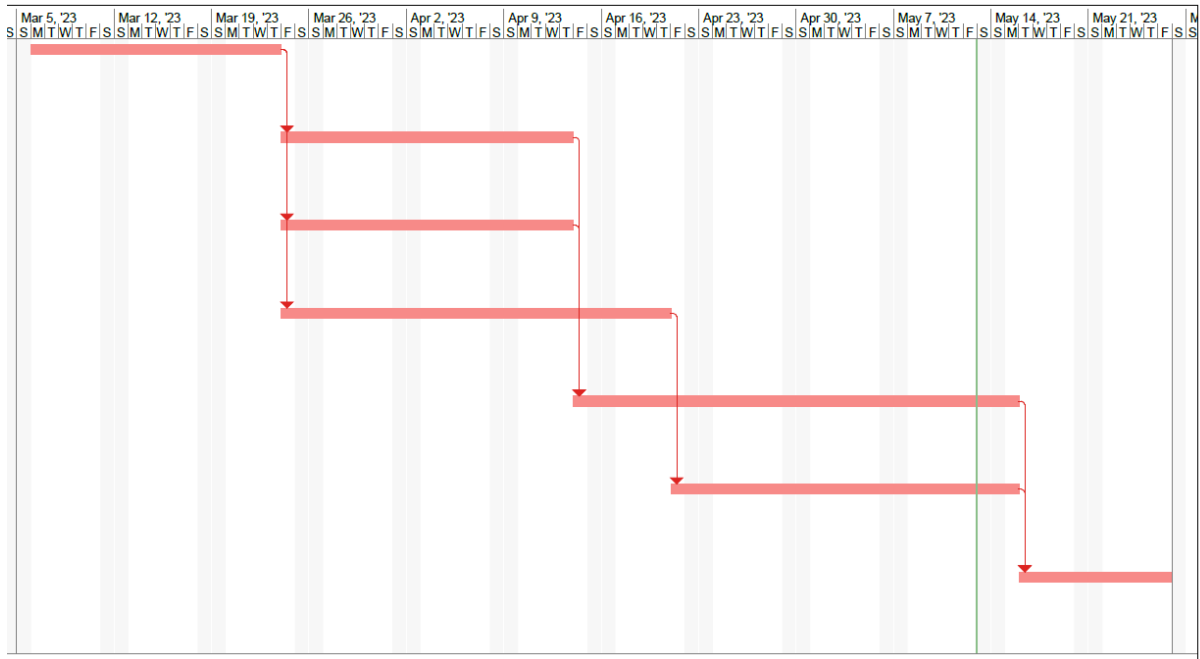


Figure 9 Final crashed schedule using BWM-TOPSIS

4.4.3 Entropy-TOPSIS results and discussion:

The result of applying Entropy-TOPSIS model provides a new method for selecting activities for the crashing process as well as providing a new path and scenarios for the crashing process, Table 18 shows the summary of crashing iterations including the direct cost, indirect cost, and the total cost. Also, Figure 11 shows a comparison between the crashing results reported by (Moselhi and Roofigari-Esfahan 2013b), and Entropy-TOPSIS model that has been implemented in this study. Where both are compared to the time cost trade-off method. At a glance, the crashing curve is decreasing by all three methods and at

the duration between 70 and 80 days it reverses direction and starts to increase. This is attributed to the daily indirect cost impact. As it is more advantageous to reduce project duration and incur some additional costs which are balanced by the reduction of indirect daily costs. This feature continues till the project duration is between 70 and 80 days and afterward, it ceased to exist. Besides this remark, Fig. 11 shows that the Entropy-TOPSIS model is closer to the time-cost trade off method than the AHP approach. This can be explained by the fact that the weights derived by the entropy method reflect the high variation within the scores. The highest variation within the scores was attributed to the cost slope and the quality criteria. Hence the activities selected were somehow closer to the cost slope method.

Table 18 Summary of crashing iterations including the direct cost, indirect cost, and the total cost for Entropy-TOOSIS.

Iteration #	CP Activities	Crashed (selected) Act	Crashed time	New selected activity duration	New duration Project	Direct cost \$	Indirect cost \$	Total Cost \$
0	1 3 5 7				105	96,200.00	157,500.00	253,700.00
1	1 3 5 7	1	10	14	95	107,200.00	142,500.00	249,700.00
2	1 3 5 7	3	8	25	87	107,781.81	130,500.00	238,281.81
3	12357	2,3	10	15	77	110,500.00	115,500.00	226,000.00
4	12357	5	1	29	76	113,000.00	114,000.00	227,000.00
5	12357 1467	6,5	7	5=22 6=17	69	136,500.00	103,500.00	240,000.00
6	12357	7	9	9	60	144,500.00	90,000.00	234,500.00

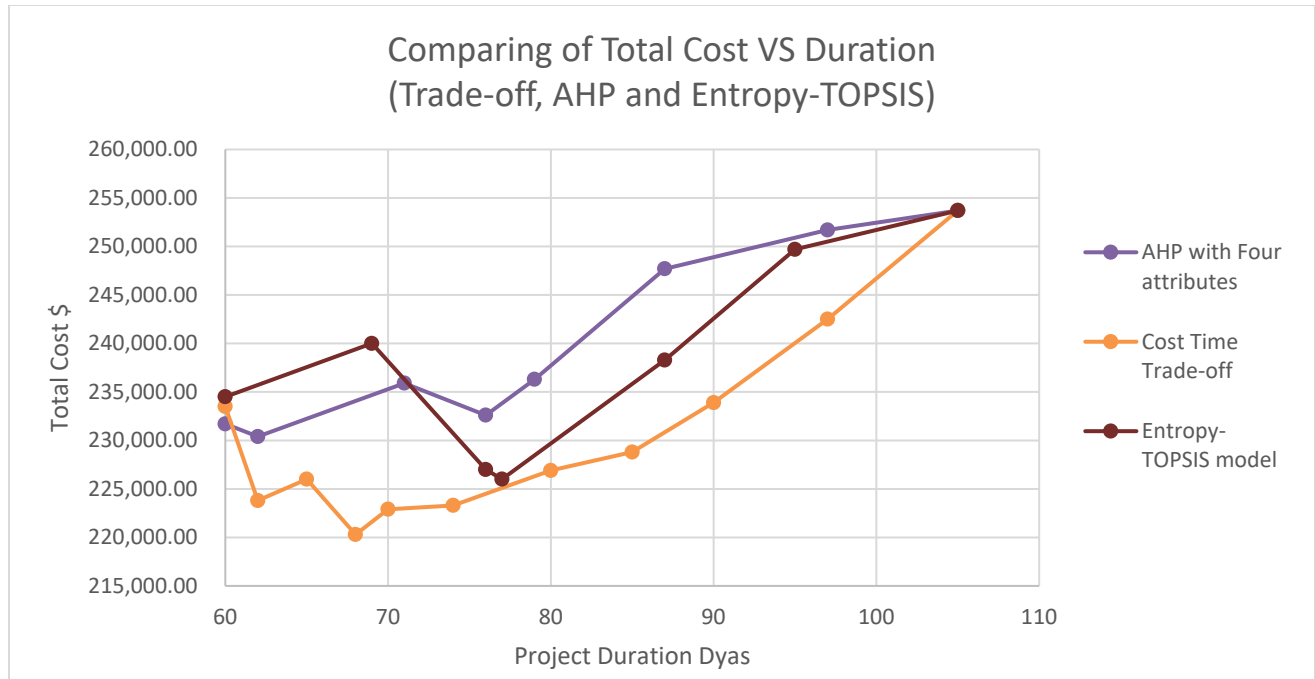


Figure 10 Comparing of Total Cost VS Duration - Trade-off, AHP and Entropy-TOPSIS

4.4.4 BWM-TOPSIS results and discussion:

The BWM-TOPSIS is a model that has been used to make the selection of activities in the crashing of construction projects. This method is integrated with TOPSIS model, as the first provides the weights for the latter. Whereas the latter is used for the selection. Table 19 shows the summary of crashing iterations including the direct cost, indirect cost, and the total cost. Also, Fig. 12 compares the crashing schedule cost results between time cost trade-off, the AHP results by (Moselhi and Roofigari-Esfahan 2013b), and BWM-TOPSIS model that has been implemented in this work. The same decreasing then increasing phenomena of the crashing cost function is seen once again in this Figure which is also attributed to advantages gained by reducing the project cost relative to the additional costs incurred from crashing. Besides, The Figure shows that the results of the BWM-TOPSIS model are very close to the AHP that had been used by (Moselhi and Roofigari-Esfahan 2013b). This is explained by the fact that BMW methods are close in nature to the AHP but they offer more advantages in terms of time and number of comparisons.

Table 19 Summary of crashing iterations - direct cost, indirect cost, and the total cost - BWM-TOPSIS.

Iteration #	CP Activities	Crashed (selected) Act	Crashed time	New selected activity duration	New duration Project	Direct cost \$	Indirect cost \$	Total Cost \$
0	1 3 5 7				105	96,200.00	157,500.00	253,700.00
1	1 3 5 7	1	10	14	95	107,200.00	142,500.00	249,700.00
2	1 3 5 7	5	8	22	87	117,200.00	130,500.00	247,700.00
3	1357	3	8	25	79	117,781.81	118,500.00	236,281.81
4	12357	2,3	3	22	76	118,600.00	114,000.00	232,600.00
5	12357	2,3	1	21	75	118,771.42	112,500.00	231,271.42
6	12357 1467	6,2,3,	6	2,3=15 6=17	69	134,500.00	103,500.00	238,000.00
7	12357	7	9	9	60	142,500.00	90,000.00	232,500.00

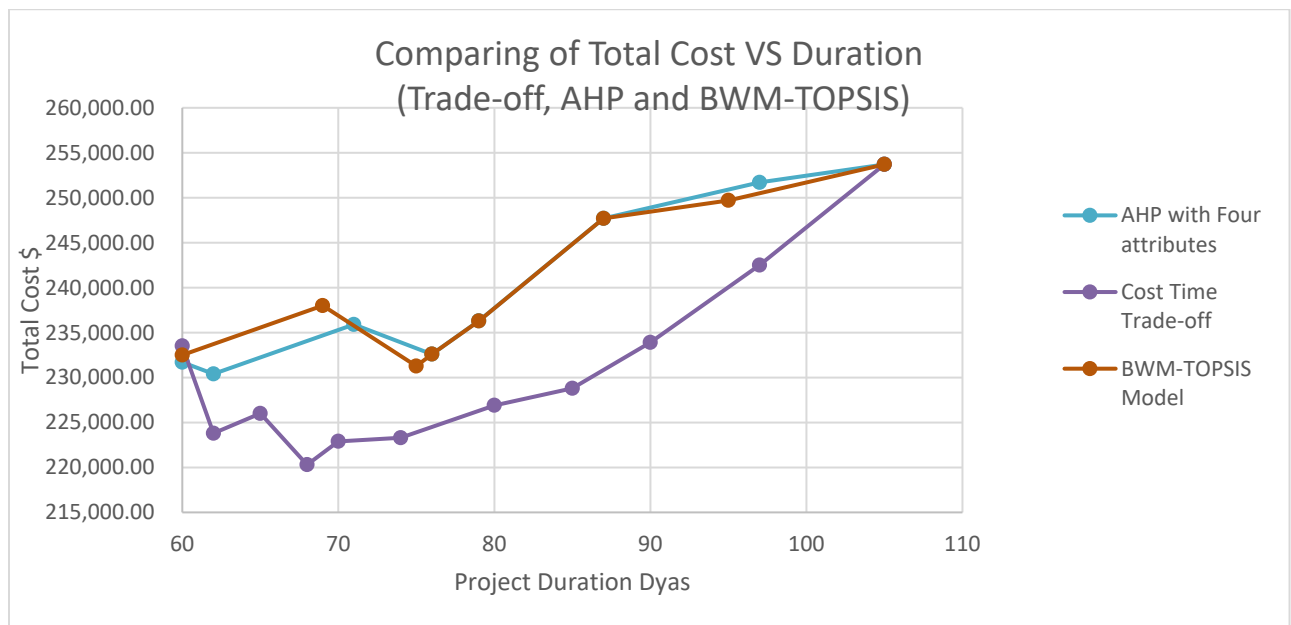


Figure 11 Comparing of Total Cost VS Duration - Trade-off, AHP and BWM-TOPSIS

4.4.5 Entropy-TOPSIS VS BWM-TOPSIS results and discussion

Figure 13 compares the results of both methods used in this work. Entropy-TOPSIS offers a lower crashing cost schedule as compared to the BWM-TOPSIS. This is an indicative that Entropy-TOPSIS offers a selection process closer to the best crashing method in terms of cost and time, i.e. The cost slope method.

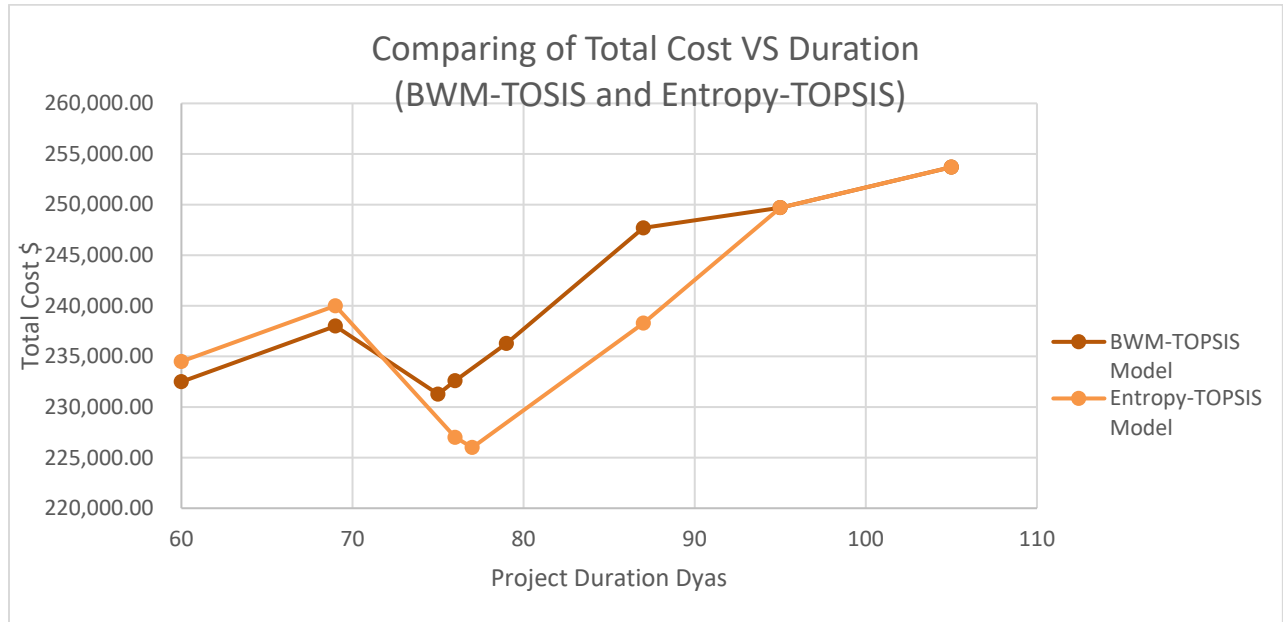


Figure 12: Comparing of Total Cost VS Duration - BWM-TOPSIS and Entropy-TOPSIS

4.4.6 Model Validation

Both model results were shown to the experts to gain some insights on the application of both methods. The feedback was that the choice of the method for crashing is situation dependent. To crash a project or not is based on the project context, surroundings, circumstances, and the project manager or controller assessment of the whole situation. Does the situation call for crashing, and under what reason? Is it for time reduction, or cost savings? ... Etc.

The proposed models are considered as tools that are available for the decision maker to based on the situation or target.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

This research proposed and presented two methods for the selecting of activities in the construction project crashing process. Two models have been applied. Entropy-TOPSIS, and BWM-TOPSIS. TOPSIS alone cannot be used for selection. It requires criteria weights to be generated externally. Hence, the integration of other methods with TOPSIS is the norm. In this work, Entropy and BMW have been integrated with TOPSIS as a means for activity selection for project crashing.

Both models have been applied over the same case study used by (Moselhi and Roofigari-Esfahan 2013b). The results show that the Entropy-TOPSIS cost behavior is closer to the cost slope model, whereas the BMW-TOPSIS shape is closer to the AHP model used in (Moselhi and Roofigari-Esfahan 2013b). This can be explained by the fact that Entropy-TOPSIS has a selection criterion that is comparable to the cost slope. Where the weights generated by the entropy model reflect the variation that exists between the score matrices. The higher the variation, the higher the degree of disorder, and hence the higher the weight. In this work, the variation between quality and the cost slope were the highest, hence more weights have been given to both quality and cost slope. The reason why the BMW-TOPSIS is closer to the AHP model results reported by (Moselhi and Roofigari-Esfahan 2013b) is due to the fact that the BWM is close in nature to the AHP. But it offers more advantages in terms of application time and number of pair-wise comparisons needed.

One last point that is worth attention is that in all models addressed by this work either applied or referenced, it is evident that although the cost slope model offers the best cost advantage yet in practice experts have their own criteria to use for selection other than the cost slope. In all the methods applied, the cost slope was one of the criteria for activity selection, nevertheless, the selected activity was not the one nominated by the cost slope alone, it was different based on a compromise set of criteria. The divergence of the crashing cost curve away from the cost slope curve is real evidence for that.

5.2 Research Limitation:

- 1- This research is for Building project in the construction industry, and it is not applicable to the repetitive or linear projects, infrastructure projects and marine projects.

- 2- The value of the objective attributes is totally dependent on the expert's judgment.
- 3- The selected factors were based on the survey that has been performed on the building projects in the construction industry in the Kingdom of Saudi Arabia. So, maybe these factors will not be valid or applicable in other countries.

5.3 Recommendations and Future work:

- 1- The application of the two models to the other types of projects in the construction industry like linear projects.
- 2- Using new methods as for neural network and machine learning algorithms and exploring their applicability to project crashing and scheduling

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