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# Sustainable Survival Pyramid Model to Balance Four Factors of Cost, Quality, Risk and Time Limitation in Project Management under Uncertainty

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**Abstract**

The final agreement on the timing of project completion is one of the obvious problems between project managers and their clients. There have been numerous reports of customers requesting shorter completion times than previously announced. This request will affect the three project factors of overall cost, final quality of the project, and risk of implementation. This paper proposes a multipurpose cumulative complex linear programming to minimize "project overhead," "increase projects total risk" and "increase overall project quality" due to “time constraints." In other words, the proposed study is fully implemented among the four goals mentioned to shorten the project duration. Computational experiments have also been used to evaluate the performance of the proposed model. The main objective of this paper is to optimize the integration of the four factors of the survival pyramid (time, cost, quality, and risk) in industrial projects simultaneously under uncertainty. An innovative solution approach based on the multi-objective genetic algorithm (NSGA-II) is presented. This model is then used to solve a problem in another study and its results, strengths, and weaknesses compared to the previous model are evaluated. The results show the performance of the proposed model in all four factors is better than the previous models.

**Key Words:** Sustainable decision making; Model development; NSGA-II; Survival pyramid.

**Mathematical Subject Classification:** 90B06; 68W50

## 1. Introduction

Today, starting an investment plan is a way to get into the business world. Therefore, to survive and succeed in the complex world of global business, steps must be taken firmly and optimally. A project involves an organization of individuals that utilize a set of resources to achieve a specific purpose (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011). The project management base is also defined as planning, directing and controlling resources to achieve specific project goals (Fan, Lin, & Sheu, 2008). And over time, the traditional approach to optimization has been to solve the problems of time and cost balance and in the last decade, time, cost and quality (Afshar, Kaveh, & Shoghli, 2007). And in recent years, time, cost, quality, and risk have been the focus of construction projects. The emergence of new contracts that consider enhancing the quality of project execution while reducing their time, cost and risk, requires the development of models that take into account quality, in addition to time, cost and risk, in evaluating and optimizing project execution procedures. Reducing risk, cost, and execution time, as well as enhancing their quality, are different goals for managers that do not align. Therefore, it is the task of the management accountant to assist production engineers in solving the problem of time, cost, risk, and quality in investment plans and development projects. A good investment strategy is based on risk reduction, minimizing trading volume and reducing transaction and tax costs (Bahr al-Alum, Tehrani, & Hanifi, 2011).

Accordingly, one of the tasks of project managers is project planning. The planning phase begins after the project is properly defined and approved. During this time, the project is divided into several manageable activities that must be performed to achieve the desired goals. At this stage, the duration of the activities should be estimated and the requirements and the amount of access to resources as well as the prerequisite relationships between the activities should be determined. The timing of each activity begins and ends so that the project goals, the minimum time and cost, and the quality of the project are maximized, is accomplished in the scheduling phase. This topic, namely project scheduling that ultimately leads to optimum adherence to project goals, has been addressed in the project management literature as project scheduling issues, one of the most commonly used issues in operational research and one of the familiar areas in the latest optimization techniques (Baptiste & Demassey, 2004). The main purpose of the project scheduling phase is to create a feasible operational schedule. At the time the start and end of each activity are specified, resource constraints and prerequisite relationships must be observed, and as far as possible, a step towards the set goals (Singh & Ernst, 2011).

In project scheduling, it is often possible to speed up project completion time by reducing the time spent on some activities and incurring additional costs. Also, some project managers implemented recourse leveling for tradeoff between time and cost of project completion. PMBOK guide defines as "A technique in which start and finish dates are adjusted based on resource limitation with the goal of balancing the demand for resources with the available supply." (Project Management Institute, 2013). Nasrollahi et al. proposed a hybrid model for resource-leveling by multi-criteria differential evolution algorithm and ELECTRE method. The purpose of their model was to reduce the time and cost of project completion simultaneously (Nasrollahi, Mina, Ghodsi, & Iranmanesh, 2016).

In the past, decisions to accelerate the project included time and cost considerations. But recently it has been suggested that the quality of the project be taken into account as well (Iranmanesh, Skandari, & Allahverdiloo, 2008). The issue of quality and attention to it is one of the goals of the project that is explicitly stated in the body of project management knowledge (Babu & Suresh, 1996). Triangle of time - cost - quality is continually followed by project managers throughout the project life cycle. Different stakeholders' expectations of the project and what is happening throughout the project may force the manager to make changes to these goals. According to the time-cost-quality triangle, the change over time and its compression will certainly lead to changes in cost and quality (Kerzner, 2017). Therefore, this paper will also develop a cost-risk-quality balance model concerning the time factor.

The structure of the article is as follows: After the introduction and necessity of this research, the literature of the research will be reviewed. In this section, the story of the formation of the research problem will be examined, and the research gap will be expressed. Then, in the third section, the methodology and expression of the model and its implementation in the case study are discussed. In the following, the results have been analyzed and finally summarized in the conclusion.

## 2. Literature review

There have been several studies on the cost-risk-quality balance model, the most important of which are the following: Mohammadipour and Sadjadi (Mohammadipour & Sadjadi, 2016), did research entitled "Cost-Quality-Risk Analysis at a Time-Limited Financing" for a project. One of the main issues in planning any project is the difficulty of convincing the customer throughout the project duration. There are numerous cases where the customer informs the contractor that the program should be shortened. This can lead to increased overall cost and risk and may also reduce the quality of the project. This paper proposes a multifunctional cumulative complex linear programming to minimize "additional project total cost", "increase project total risk" and "reduce overall project quality" due to time constraints. In other words, the proposed study is fully implemented among the three goals mentioned to shorten the project duration. The Pareto approach is used to achieve the goals of solving the multipurpose model and obtaining optimal solutions. Computational experiments have also been used to evaluate the performance of the proposed model.

Jeang (2015), researched project management for uncertainty with multiple goals of optimizing time, cost, and reliability. This study adopts a method that utilizes computer simulation and statistical analysis of adverse activity time, cost of operation, expiration date and project budget to address the quality and process of learning related to project planning. Since the learning process affects the scheduling, from the Cobb-Douglas Verbal Power Model is used to illustrate the relationship between the dependent variable is the standard deviation of activity time, independent variables that calculate the cumulative and mean average activity time, and standard deviations for randomly used activity time for project planning analysis (Fuleky, 2006).

The response level methodology (RSM) is used to create a logic of cost-time-cost issues. The solutions in RSM have been optimized for one purpose only, such as project completion time, total project cost, probability of complete occurrence and probability of total cost. Therefore, multiple objectives are necessary for further optimization and a limited project budget, limited completion time, probable total cost probability, and probability of "acceptance" should be considered at the same time as the learning effect. Using the response functions of the RSM, compromise planning is adopted to approve the proposed project planning problems for multipurpose optimization.

Hebert and Deckro (2011) explored present and past management tools for solving project planning problems (Hebert & Deckro, 2011). In this study, they investigated a construction project that involved the building of large concrete skeletons for three office complexes. Priority relationships Finish to Start (FS) as well as Start to Start (SS) and Finish to Finish (FF) exist among all project activities. The initial project schedule is prepared using the Microsoft project and manually validated the results using the priority description method. When the client informs that the program should be shortened, if the project Microsoft is unable to solve its specific time/cost issues in this case, the traditional approach is to solve the project time/cost equations. And a basic linear programming formula is developed for the time/cost problem when designing a project as a forward diagram. By combining contemporary projects (Microsoft Project) and traditional (a linear scheduling/cost modeling) project management tool, the ability to solve planning issues related to a construction project is created. Also, the anomalous effects of the FF (T) start-to-finish (SS) and Finish to Finish (T) relationships are illustrated by the example of a construction project where the solution to the problem of shortage of time/cost requires specific activities for short It's time to do the project.

Herroelen et al (1999) in a study developed a classification scheme for project planning problems. The wide range of project planning problems motivates the introduction of a systematic cue that can be used as the basis for a classification scheme. The broad classification scheme introduced in their research is similar to the standard classification method used in machine planning research. It consists of three areas. The first field describes the characteristics of the problem sources. The second field describes the characteristics of the project activities, and the third field represents the performance measure (s). The combination of the different contexts and the exact meaning of the parameters are assigned to the project planning domain. Based on the potential use of the classification scheme, the description of the most important project scheduling plans presented in developing research is shown. In the project, discussed the close relationships between different scheduling problems by providing diagrams showing different relationships between different values of specific classification parameters (Herroelen, Demeulemeester, & De Reyck, 1999).

Gembicki, Haimes (1975) optimized multi-objective performance and sensitivity: goal attainment method. This short article is about computational methods for solving optimization problems with a vector index function (vector optimization). It uses vector optimization as a tool for analyzing static control problems with performance indices and parameter sensitivity. The first part of this short article introduces the new computational approach to the goal approach that removes some of the limitations and disadvantages of the current methods. The second part is to present a comprehensive multifunctional treatment optimizing performance and sensitivity based on a vector index approach. A numerical example in electrical power system control involves the analysis and results of using the goal approach and applying the approach to performance and sensitivity optimization (Gembicki & Haimes, 1975).

Feylizadeh and Mahmoudi (2018), surveyed projects crashing based on the elements containing cost, time, quality, risk and the rule of lessening yields. To this end, a grey linear programming model proposed. So far, this has been one of the most complete models presented in the subject literature. But this model is not considered under uncertainty, and all parameters are constant (Mahmoudi & Feylizadeh, 2018).

Investigations in the literature and evaluation of the valuable models presented, despite all efforts made, still leave a gap to eliminate the concern of project managers by presenting a model that can simultaneously strike a balance between all four factors of the project pyramid (Cost, quality, risk and time), under uncertainty, is felt. In this study, it is attempted to cover this research gap.

## 3. Methodology

The categorization of this research, in terms of the type of purpose it pursues, falls into the category of "applied research," and from the strategic perspective, it falls into the category of "numeric analysis and modeling research." numeric calculus or numerical analysis regulates, studies, and applies approximate computational methods to solve continuous mathematics problems against discrete mathematics that cannot be solved by precise analytical methods. The method used in this study is as follows:

- Collect resources and articles related to the topic and categorize them
- Problem Modeling
- Case study review
- Analysis of results

In this study, to solve the proposed model, the multi-objective model is transformed into a uniform equivalent problem using the goal-attainment method. This method is introduced by Gembicki and Haimes (1975) and then used to apply several real-world multipurpose problems in different domains (Gembicki & Haimes, Approach to performance and sensitivity multiobjective optimization: The goal attainment method, 1975). The optimal solution obtained by this technique is the Pareto optimal solution, which is very sensitive to both the purpose and the weighting provided by the decision-maker. The need for fewer variables than interactive techniques, and rapid one-step model solving, are considered to be advantages of the goal- attainment approach compared to other multi-objective techniques.

This paper attempts to optimize the components of the pyramid of survival, including time, cost, quality and risk in industrial projects and investment plans. The novelty of this study, compared to previous studies, is that these targets are simultaneously investigated under uncertainty using the Nondominated Sorting Genetic Algorithm II (NSGA-II). Moreover, in the previous articles, these four objectives have either been studied separately or analyzed in the "conditions of certainty." The modeling of this paper is based on a study in 2018 by Filyzadeh et al. (Filyzadeh, Mahmoudi, Bagherpour, & Li, 2018), Who investigated the project by considering four items of cost, time, quality and risk using fuzzy multi-objective modeling under certain conditions. In Figure 1, the survival pyramid is shown, according to which the goals are linked.

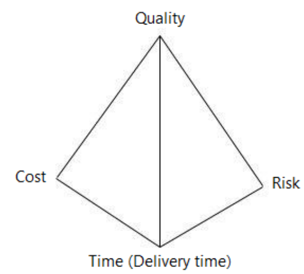


Figure 1: Survival pyramid

Table 1 shows the list of parameters and variables used in this study.

Table 1: Parameters and Variables

| Parameters/ Variables | Explanation |
|---|---|
| $E$ | Activities |
| $S$ | A set of risky activities |
| $H$ | A set of activities that can be done quickly |
| $M$ | A set of activities that depend on the previous activity |
| $b$ | Expresses activity before other activity |
| $j$ | Expressing activity |
| $a$ | Expresses activity after activity j |
| $n$ | Number of project activities |
| $y_j$ | It takes time for j to reach the end of the project |
| $c_j$ | Cost per unit decrease in operating time j |
| $yy_{bj}$ | Increased or decreased time caused by lag/lead in relation bj |
| $v_{bj}$ | The duration of the feasibility that can be reduced in relation bj |
| $q_j$ | Impact of the quality of activity j on overall project quality |
| $d_j$ | The initial time required to complete the activity j |
| $w_j$ | Is a binary variable that is equal to 1 if the activity quality level is lower than the target level, otherwise it is zero |
| $ww_{bj}$ | Is a binary variable that if the relation activity bj is less than the desired level equals 1, otherwise it is zero |
| $Xlf_j$ | Last Activity j |
| $Xes_j$ | First, start time j |
| $lag/lead_{bj}$ | Lag/lead between activities b and j for end-to-end communication (FS) |
| $q_{f-threshold}$ | The fast delivery quality threshold between activities |
| $q_{c-threshold}$ | The quality threshold for low limit |
| $u_j$ | Possible Time Reduction Activity j |
| $M$ | A big number |

The objective functions investigated in this study are discussed separately in the form of Z1 to Z4 functions. Accordingly, the Z5 objective function determines the relationship of these 4 objective functions to each other.

$$Min\ Z_1 = \sum_{j=1}^{n} y_j \times C_j \qquad j \in S \tag{1}$$

$$Min\ Z_2 = \sum_{j=1}^{n} \frac{yy_{bj}}{v_{bj}} \times (P_{bj} \times I_{bj}) \quad j \in H \tag{2}$$

$$Min\ Z_3 = X_{es_1} - Xlf_n \tag{3}$$

$$Max\ Z_4 = \sum_{j} q_{cj} \times \left(\frac{d_j - y_j}{d_j}\right) \qquad j \in S \tag{4}$$

In the above equations, equation (1) represents the lowest cost, relationship (2) expresses the least amount of risk, the objective function (3) expresses the least overall project time, and relationship (4) maximizes project delivery quality. Hence, in relation (5) the simultaneous consideration of these objective functions is considered under uncertainty conditions.

$$F(x) = \frac{Z_3 - T_{min}}{T_{max} - T_{min}} + \frac{Z_1 - C_{min}}{C_{max} - C_{min}} + \frac{Z_2 - R_{min}}{R_{max} - R_{min}} + \frac{Z_4 - Q_{min}}{Q_{max} - Q_{min}} \tag{5}$$

In relation (5), the first component contains duration, the second component costs, the third component quality, and the fourth component executes risk to calculate the objective function value for each response. Since the units of measurement of the components of the pyramid of survival are not the same, their values are set between zero and one and are scaled (their values are normalized) to be comparable or additive. In the technical issue of this study, the lowest time (T_min) and maximum time (T_max) were 150 and 403 days, the lowest cost (C_min) and the highest cost (C_max), respectively, at $ 96,200 and $ 165,500, the lowest quality. (Q_min) and highest quality (Q_max) are 60.5% and 97% and lowest risk (R_min) and highest risk (R_max) are 20% and 45%, respectively. The constraints of this study are as follows:

$$Xlf_n \le T_{max} \tag{6}$$

$$Xlf_j - Xes_j \ge d_j - y_j \qquad j \in E \tag{7}$$

$$Xes_j - Xes_b \ge (d_b - y_b) + \left(\frac{lag}{leadb_j} - yy_{bj}\right) \qquad j \in E \tag{8}$$

$$Xlf_a - Xlf_j \ge (d_a - y_a) + \left(\frac{lag}{leadj_a} - yy_{ja}\right) \qquad j \in E \tag{9}$$

$$y_j \le v_j \qquad j \in S \tag{10}$$

$$yy_{bj} \le v_{bj} \qquad j \in H \tag{11}$$

$$q_{f-threshold} \le \frac{v_{bj} - yy_{bj}}{v_{bj}} + ww_{bj} \times M \qquad j \in U\ .\ \ j \in H \tag{12}$$

$$q_{c-threshold} \le \frac{d_j - y_j}{d_j} + w_j \times M \qquad j \in U. \quad j \in S \tag{13}$$

$$yy_{bj} \ge 0. \quad j \in H \tag{14}$$

$$y_j \ge 0. \quad j \in S \tag{15}$$

$$ww_j = \{0.1\} \qquad . \qquad j \in U \tag{16}$$

$$w_j = \{0.1\} \qquad . \qquad j \in U \tag{17}$$

When specifying the target function, a sample project must be evaluated to be evaluated using the NSGA-II algorithm. NSGA-II is one of the most popular multi-objective evolutionary algorithms developed by Deb et al. (2002) based on a genetic algorithm (Nasrollahi & J, 2019). Like other evolutionary algorithms, in the first step, NSGA-II generates random solutions with a population of μ. Also, each solution is evaluated by fitness functions and based on this evaluation, the Pareto fronts are created by non-domination sorting. In the next step, each solution receives a rank equal to the level of the front that it belongs to. Then the crowding distance between the solutions on each front is measured. The selection procedure is the binary tournament method. The winner is the solution with the highest rank and if there is a tie in the highest rank, the winner is the one amongst the highest rank members with higher crowding distance (Nasrollahi, Razmi, & Ghodsi, 2018). The rest of the NSGA-II procedure is the same as the genetic algorithm as explained in (Nasrollahi, Razmi, & Shamekhi Amiri, 2015). The specifics of project activities are presented in Table 2.

Table 2: Project Activity Specifications

| Activity Number | Prerequisites | Run Option | Time (Day) | Cost ($) | Percent Impact | Quality | Risk |
|---|---|---|---|---|---|---|---|
| 1 | - | 1 | 14 | 23000 | 8 | 98 | 0.45 |
| | | 2 | 20 | 18000 | | 89 | 0.30 |
| | | 3 | 24 | 12000 | | 84 | 0.25 |
| 2 | 1 | 1 | 15 | 3000 | 6 | 99 | 0.25 |
| | | 2 | 18 | 2400 | | 95 | 0.20 |
| | | 3 | 20 | 1800 | | 85 | 0.23 |
| | | 4 | 23 | 1500 | | 70 | 0.22 |
| | | 5 | 25 | 1000 | | 59 | 0.10 |
| 3 | 1 | 1 | 15 | 4500 | 14 | 98 | 0.60 |
| | | 2 | 22 | 4000 | | 81 | 0.25 |
| | | 3 | 33 | 3200 | | 63 | 0.15 |
| 4 | 1 | 1 | 12 | 45000 | 19 | 94 | 0.30 |
| | | 2 | 16 | 35000 | | 76 | 0.28 |
| | | 3 | 20 | 30000 | | 64 | 0.22 |
| 5 | 2, 3 | 1 | 22 | 20000 | 17 | 99 | 0.30 |
| | | 2 | 24 | 17500 | | 89 | 0.28 |
| | | 3 | 28 | 15000 | | 72 | 0.22 |
| | | 4 | 30 | 10000 | | 61 | 0.20 |
| 6 | 4 | 1 | 14 | 40000 | 19 | 100 | 0.43 |
| | | 2 | 18 | 32000 | | 79 | 0.30 |
| | | 3 | 24 | 18000 | | 68 | 0.27 |
| 7 | 5, 6 | 1 | 9 | 30000 | 17 | 93 | 0.44 |
| | | 2 | 15 | 24000 | | 71 | 0.31 |
| | | 3 | 18 | 22000 | | 67 | 0.25 |

Genetic algorithm settings are as follows:

Table 3: Genetic Algorithm Model Settings

| Parameter | Value |
|---|---|
| Initial population | 500 |
| Number of genes | 150 |
| Mutation | 2-Point |
| Crossover | Gene Location Based |
| Rate of Mutation ($P_m$) | 0.3 |
| Rate of Crossover ($P_c$) | 0.8 |

## 4. Results

Finally, the results of the simulation are presented. The results for 10 different models are shown in Table 4.

Table 4. Simulation results

| Sample | Number of Activities | Highest Delivery Time (Days) | Delivery Time (Days) | Cost (USD) | Quality | Risk (Percent) |
|---|---|---|---|---|---|---|
| 1 | 4 | 350 | 175 | 985,521,000 | 0.2435 | 0.865 |
| 2 | 4 | 356 | 179 | 999,635,100 | 0.2136 | 0.86 |
| 3 | 4 | 374 | 181 | 1,118,714,205 | 0.2433 | 0.749 |
| 4 | 5 | 379 | 189 | 1,259,800,200 | 0.2533 | 0.81 |
| 5 | 5 | 385 | 195 | 1,387,958,000 | 0.2374 | 0.825 |
| 6 | 6 | 385 | 200 | 1,391,695,120 | 0.2441 | 0.833 |
| 7 | 6 | 390 | 209 | 1,400,140,175 | 0.2357 | 0.849 |
| 8 | 6 | 400 | 227 | 1,486,855,140 | 0.2491 | 0.831 |
| 9 | 7 | 403 | 257 | 1,534,338,200 | 0.2341 | 0.836 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 8 | 403 | 296 | 1,610,172,000 | 0.2359 | 0.85 |

The results presented in the table above can be presented for each model in Figure 2:

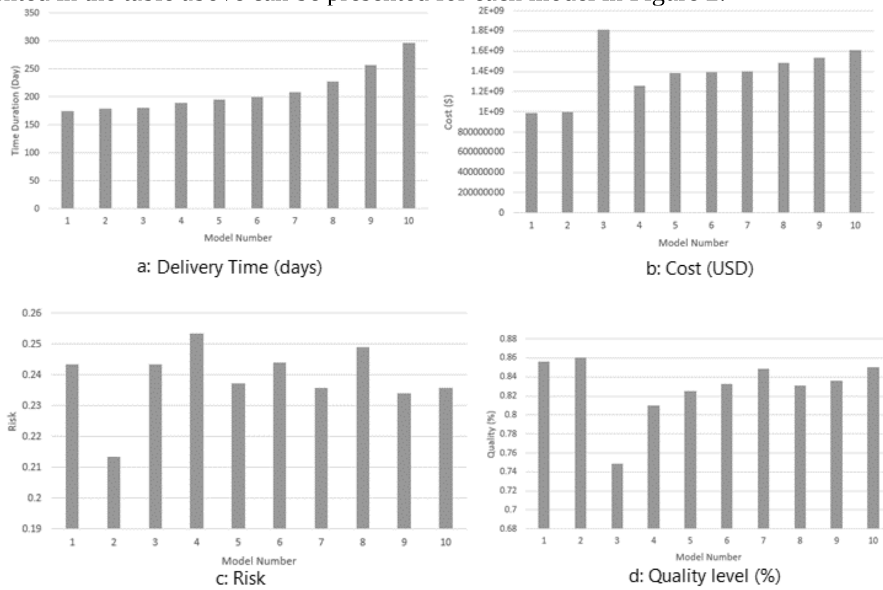


Figure 2: Results from each model, in terms of delivery time, cost, risk and quality level,

Furthermore, to compare the proposed model and evaluate its validity, its results were compared with the results presented in "Filyzadeh et al.", for delivery time and total cost. It should be noted that the sample considered had a delivery time of 403 days.

Table 5: Comparison of the results of the two models

| Model | Cost ($) | Time (day) |
|---|---|---|
| Filyzadeh et.al. model | 16892060000 | 303 |
| The presented model | 16101720000 | 296 |

The comparison results can be presented in the following diagrams (Figure. 3).

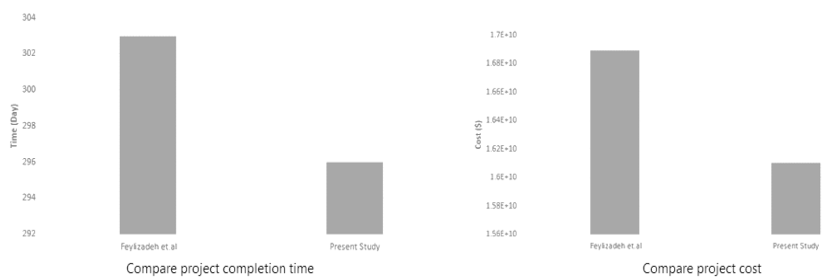


Figure 3: Compare project time and cost

## 5. Conclusion

In this study, the components of the industrial project were analyzed and modeled based on what was done in previous researches. The main objective was to investigate the four factors of cost, time, quality and risk simultaneously under uncertainty. A multi-objective mathematical programming model was developed to optimize these four factors simultaneously. Then the proposed model was solved using Genetic Multipurpose Algorithm (NSGAII). For this purpose, after modeling, data from an existing project were used and the results of each pyramid component in different samples were obtained.

The results showed that the average project risk was 21%, and the quality of production was 85%. The results also showed that the proposed model reduced the completion time from 403 days to 296 days, which resulted in a 26.04% improvement. Finally, by comparing the model with the article "Filyzadeh et al .", they investigated this issue in 2018 using a multi-objective fuzzy model, it was also shown to save about 4.6 percent in cost, and 2.3 percent in project completion time.

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