



Measuring the Effects of Different Factors on Activity Times in Wind Power Projects under Fuzzy Set Theory

Pınar KAYA SAMUT*

*Akdeniz University, Faculty of Economics and Administrative Sciences, Department of Econometrics, 07070, Antalya, Türkiye*

Highlights

- This paper aims to obtain a realistic estimation of the project completion time.
- Fuzzy set theory by including the risk factors is applied to a real wind power project.
- CPM and F-PERT are also applied for robustness.

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Abstract

In this study, it is aimed to determine the project completion time in a more realistic way by analyzing the effects of uncertainties experienced in wind power projects. For this purpose, a method was applied to calculate the project completion time under fuzzy set theory by including the risk factors in the relevant activity durations of an international company's wind power project. CPM and F-PERT methods were also applied to show the robustness of the applied method, and these three methods' results were benchmarked against the actual time of the project. The result of the study showed that a more realistic estimate of the project completion time can be determined with the applied method, in which all the factors affecting the duration of the activities are included, experts' opinions are taken into consideration, and historical data is used. In this study, in which the risk factors for wind power projects are examined in detail and suggestions for improvement are put forward, a customized roadmap for the management of all types of projects, particularly wind power projects, is intended to serve decision makers.

1. INTRODUCTION

Project management is defined as the application of knowledge, skills, tools, and techniques in project activities to meet the requirements thereof, and it is of great importance in business management [1]. In this context, optimization is achieved with project scheduling, taking into account the relevant activity priorities and resource constraints. Many network techniques have been developed to define the critical path in project scheduling. The most well-known of these, i.e., the Critical Path Method (CPM) [2], assumes durations to be deterministic. CPM cannot meet conditions where activities are uncertain and volatile as it requires the existence of clearly defined time periods for each activity [3,4]. On the other hand, a statistical approach that takes variability into account, the Project Evaluation and Review Technique (PERT), was developed by [5]. In the PERT technique, three estimates of the activity duration are suggested: Optimistic, most likely and pessimistic times, and the beta distribution is used to calculate the mean and variance [6]. PERT has been a preferred model owing to its ease of use arising from its being a transformed deterministic model, and its allowing estimations of probabilities of completion times of activities or projects [7]. However, in the PERT model, even though times are expressed as independent random variables, finding the distribution of project completion time is often problematic due to dependencies across the entire network [8]. In addition, it is criticized for reasons such as neglecting variability in the definition of Critical Path (CP), calculating variability lastly by adding the random times of the CP after the entire project completion time has been calculated, and the unreliability of the probability distribution of the activity times obtained by subjective judgments [3, 9]. Since modeling an unknown time with a probability distribution requires a large amount of information and little information is available about the processing time of each task of the project in real-life problems, researchers turned to fuzzy PERT instead of classical

*e-mail: pinarsamut@akdeniz.edu.tr

PERT. Due to the fact that the use of fuzzy numbers requires little information and addresses both variability aspect and dependencies within the network, the uncertainty of project activities is handled by fuzzy set theory instead of probability, which proved to be more useful [10,11].

Successful completion of a construction project means that it is completed on time, within budget and to the required quality. In order for the project to be completed on time, it is necessary to organize the activity relations correctly and to design the project schedule as close as possible to the reality, taking into account all the criteria and risks of the activity periods. The uncertainties involved in construction projects such as weather changes, site conditions, material supply and management quality have a significant impact on estimating the duration of project activities and duration calculations [7, 12]. It is more realistic to analyze these uncertainties in construction projects with fuzzy set theory, which adopts a membership function to represent uncertainty, rather than probability distributions that numerically represent the degree of belonging of an element to a particular cluster. Moreover, in order to accurately determine the completion time of a project under these uncertainties, it is necessary to examine the risk-related duration of the required activities. In this context, the main purpose of this study is to present a fuzzy set theory-based method for measuring risk-related activity duration under uncertainty and to verify its applicability on a real project.

The method mentioned in this study was applied to a wind power project. Uncertainty factors such as weather conditions, supply problems, material quality, site conditions, ground structure, and existence of groundwater in wind power projects prevent the project from being delivered in the promised time frame. The reasons such as the fact that the activities of the wind power projects are unique, lack of historical data, lack of an experienced production planning team in this field (because companies seem to have less experience in such projects) make the analysis more difficult. Therefore, it is possible for project managers to analyze project scheduling problems effectively - only if they determine the project completion time by considering the risks inherent to the activities. Considering that each activity is affected by different factors, and since any delay in critical activities will affect the duration of the project, the importance of accurately predicting such situations is evident.

In this article, a methodology, which provides solutions under fuzzy set theory by including risk factors in durations, is applied to the wind power project of a Turkish company operating in the international market. The results of the applied methodology were compared with the results of CPM and F-PERT. In this context, the contributions of this article are as follows:

- In determining the activity times and risks of the wind power, opinions of the experts involved in the project and the company's historical data were used in combination by employing fuzzy set theory. Thus, it was ensured that the project duration was analyzed/estimated effectively and accurately with possible delays in the completion of the project – by reflecting the impact of the risks on the activity durations realistically.
- In today's world, where the importance of renewable energy is increasing day by day, a detailed list of positive and negative factors inherent to all activities of a wind power project has been prepared and a roadmap has been developed for similar projects.
- In addition, by interpreting the findings together with suggestions on reducing the risks, it has been tried to provide the decision makers with a customized tool for wind power project management.

The rest of this paper is organized as follows: Firstly, literature about project management in wind energy and the difference of our study from the existing studies in the literature are mentioned. In the following section the methodology used in this study is described. Implementation of the applied model, CPM and F-PERT results are given in the Application section. Conclusions and recommendations are provided in the last section.

2. PROJECT MANAGEMENT IN WIND ENERGY

Wind energy emits less carbon emissions than fossil fuels (coal, oil, natural gas, etc.), which cause global warming and whose consumption is increasing day by day. Therefore, wind energy, which is more sensitive to the environment and a potential in energy technologies, is one of the leading renewable energy sources

with its features (clean, infinite, low cost, etc.) [13-16]. Factors such as shorter run-up times, lower and more efficient operating and maintenance costs, and relatively simpler technology [17-19] highlight wind energy among its alternatives; it is a renewable, clean energy source and it currently meets approximately 2% of the world's electricity needs.

According to the Global Wind Energy Council's (GWEC) Global Wind Report 2022, the effects of the global crisis caused by the COVID-19 have begun to diminish, the wind energy sector has been gathering momentum, and with increasing installations, the installed capacity of wind energy has reached 837.5 gigawatts worldwide by the end of 2021 [20]. These findings reflect the fact that investments in electricity generation from wind energy should increase in order to reduce carbon emissions to zero by 2030 in accordance with the "Green Deal". And this means that more wind farms and turbines will be built. Considering the time, effort and capital from the investment decision to the electricity production in such a facility, it is clear that all project steps should be handled very effectively [21]. In particular, for turbine installation, which on average accounts for about 80% of the costs of wind energy investments, an effective project management (consisting of steps like the determination of the potential of the facility to be installed, allocation of the capacity of the investor, obtaining the necessary permits for each turbine, and engineering studies, etc.) is required [22].

A few of the studies in the existing literature on the effective and realistic management of wind energy investment projects are as follows: In order to determine the critical activities and calculate the total project cost and total duration of a wind power plant construction project in Taiwan, Lee et al. [22] used PERT method under normal conditions, and fuzzy PERT method and fuzzy multi-objective linear programming method under uncertain conditions. In their study, they have developed a systematic method for effective use of resources and cost-effective management. Kang et al. [21] underlined the need for an effective project management model due to cost and time constraints in renewable power plant construction and developed a PERT-based fuzzy multi-objective linear programming model. Then they applied the fuzzy multiple weighted-objective linear programming model (FMWOLP) by considering the importance of multiple goals. Applying their model to a wind power project in Taiwan, the authors have aimed to guide management about the slack times of activities, total project time and total project cost. Taghipour et al. [23], on the other hand, evaluated the project planning and control systems by taking into account resource constraints under the fuzzy data approach for the wind tunnel project. Thus, they developed a method for the effective management of time, cost and quality resources in a project -in a way in which the risk of failure to perform the activities that need to be done later, due to the project manager's misestimating of activity durations, is taken into account.

Mohammed et al. [24] used Monte Carlo and CPM methods in their studies, in which they examined the correlation between the cost and planning effects of risk factors for the risk assessment approach for wind farm construction—due to the limited use of quantitative risk assessment models in the construction industry. In order to take advantage of wind energy, one of the rapidly growing renewable energy sources in Canada, they have used these methods together in a wind farm construction project. They examined the effects of risks that may cause unforeseen consequences on the duration and cost of the project while the construction project is being implemented. Thus, they aimed to effectively estimate the time and cost possibilities within the scope of project management in the wind energy sector.

Upon literature survey, a satisfactory number of studies related to the evaluation of investment projects for wind energy were not found. The fact that the criteria, that may affect the duration of the project activities, are not taken into account in the current studies may cause problems in calculating the actual completion time of the project. In order to examine the effects of risks on the completion time and cost of the project, it has been observed that CPM and simulation approach are generally used together. The difference of this study from other wind power project management methods is that; it aims to obtain a more realistic project completion time by examining each factor that may affect the duration of activity one by one and analyzing them under fuzzy set theory.

3. METHODOLOGY

In the present study, the completion time of a wind power project is calculated with CPM, F-PERT and a methodology that allows the durations to be obtained under fuzzy set theory by considering the effects of risk factors [12] and the results are compared with the actual project duration. In the applied methodology, as seen in Equation (1) the activity durations (AD) are obtained by adding the risk-associated activity durations (RD) to the normal activity durations (ND), which is the duration under normal conditions [25]

$$AD = ND + RD. \quad (1)$$

In Equation (1), NDs are crisp numbers obtained under normal conditions, while RDs represent activity durations added or subtracted as a result of uncertainties in project conditions. In order to reflect these uncertainties, RDs are expressed with fuzzy numbers. The most important reason for this is that; it allows experts to represent their judgments simply and robustly [3]. A fuzzy set is formed mathematically by assigning a value to each individual in the universe that represents the degree of membership of the individual in the set [26]. Membership degrees of individuals to clusters are expressed with real numbers ranging from 0 to 1, and the magnitude of these values indicate the degree of belonging of individuals to the fuzzy cluster [27].

To obtain more realistic results, trapezoidal intervals were used to represent risk-associated activity durations (RD), as they allow for the inclusion of both adverse and favorable risks that respectively widen or narrow the range. This approach enables the integration of both expert judgments and historical project data into the analysis, allowing for the estimation of the most likely and largest likely interval for uncertainties in construction activities. In the concept of trapezoidal intervals, developed by [28] to model fuzzy activity durations, the uncertainty caused by risk is represented by two intervals; the most likely interval and the largest likely interval [12]. These two intervals can be determined on the basis of historical and published data and experts' judgments and can be used to construct the membership function of the risk-associated consequence, as shown in Figure 1 [29]. In Figure 1, if Z is accepted as a risk-associated consequence of an activity, $\mu(Z)$ denotes the membership function of Z and Z_h the interval of the consequence at the membership degree h .

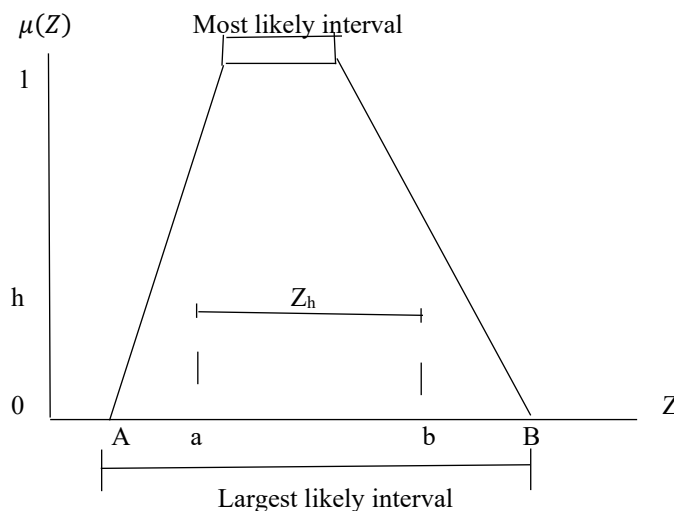


Figure 1. Intervals of Fuzzy membership function

By reducing this trapezoid shape to a vertical line, the risk-associated activity duration can be converted into a deterministic number. For this purpose, the total net Schedule loss/delay (T_h), which will be used in the calculation of RDs, is created as a fuzzy number with membership degree h . In this article, unlike [12], T values are obtained as the difference between the increase in time (L) caused by factors that negatively

affect each activity and the decrease in time (G) caused by factors that affect positively. T values as fuzzy numbers are calculated with the membership functions given in Equation (2) [12, 30]

$$\begin{aligned}\mu_{(T)} &= 1, \quad a < T < b \\ \mu_{(T)} &= \frac{(T-A)}{(a-A)}, \quad A \leq T \leq a \\ \mu_{(T)} &= \frac{(T-B)}{(b-B)}, \quad B \leq T \leq b \\ \mu_{(T)} &= 0, \quad \text{otherwise} .\end{aligned}\quad (2)$$

In Equation (2), A and B are the lower and upper bound values of $T_{h=0}$, respectively; and a and b are the lower and upper bound values of $T_{h=1}$, respectively. The fuzzy mean method given in Equation (3) is used to obtain the RD s by converting the fuzzy T values to crisp numbers [12]

$$RD = \frac{\int T \cdot \mu(T) dT}{\mu(T) dT} \quad (3)$$

where RD is the fuzzy value of the total risk-associated schedule delay and T is the total net schedule loss/delay. While $\mu(T)dT$ given in Equation (4) is equal to the area of the $\mu_{(T)}$ membership function, the numerator of the fraction is calculated as given in Equation (4)

$$\int T \cdot \mu(T) dT = \frac{\int T \cdot (T-A) dT}{(a-A)} + \int T dT + \frac{\int T \cdot (T-B) dT}{(b-B)} . \quad (4)$$

The flow chart summarizing the application steps of the proposed methodology is given in Figure 2.

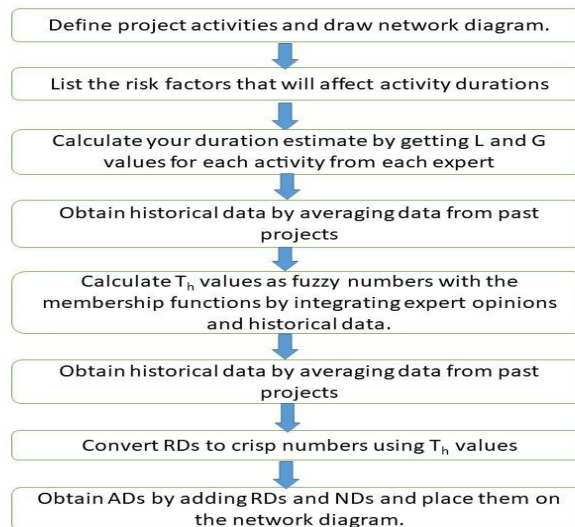


Figure 2. Flow chart of methodology

4. APPLICATION

In this study, an application has been made to the wind power project of a construction company operating on an international scale. The whole process has been shaped by interviews with the company's production planning team. The company carries out many large, medium and small-scale wind power projects. In order for the method used with the provided information in this study to be applicable to wind power projects of all sizes, project planning was reduced to a single grandstand and carried out under various acceptances.

The assumptions agreed with the production planning team are as follows:

- The project includes the excavation, construction and installation works of a single turbine.
- Switchyard and control building construction and their equipments' installation were not included in the project.

- It is assumed that there are 8400 m³ of excavation on the roads, and 4 excavators were used. An excavator is assumed to excavate an average of 350 m³ in a day.
- Excavation capacity of the platform is assumed to be 8400 m³. 4 excavators start together for the 4200 m³ part, and after the completion of this part, 1 excavator excavates the turbine foundation of 1400 m³. The other 3 excavators excavate the remaining 4200 m³ of the platform.
- 2 excavators are planned to work at cable channel excavation and backfilling works.
- It is assumed that the road length is 1500 m and 500 m of crushed stone is assumed to be laid per day.
- It is assumed that totally 3000 m², daily 1500 m² of crushed stone is laid on the platform.
- It is assumed that the required concrete strength is provided in the 7-day concrete test reports.
- It is assumed that the 3-day grout test reports provide the required strength.

Definition of the project activities is given in Table 1 and the network diagram is given in Figure 3.

Table 1. Definition of project activities

Activity	Definition	Duration (day)	Predecessor
A	Mobilization (setting container)	3	-
B	Road- excavation and fill	6	A
C	Road-crushed stone paving	3	B
D	Platform- excavation and fill(beginning)	3	B
E	Platform- excavation and fill (remainder)	4	D
F	Turbine foundation- excavation	4	D
G	Turbine foundation- piping	1	F
H	Turbine foundation- lean concrete	1	G
I	Cable channels- excavation and fill	3	G
J	Turbine foundation- anchor assembly	1	H
K	Turbine foundation- stainless steel	5	J
L	Turbine foundation- formwork	1	K
M	Turbine foundation- concrete	1	L
N	Turbine foundation- 7-day concrete test	7	M
O	Turbine foundation- 28-day concrete test	28	M
P	Turbine foundation- backfill	1	N
R	Turbine foundation- grout	1	E,P
S	Platform- crushed stone paving	2	E,P
T	Grout- test report	3	R
U	Turbine assembly	7	C,I,O,S,T

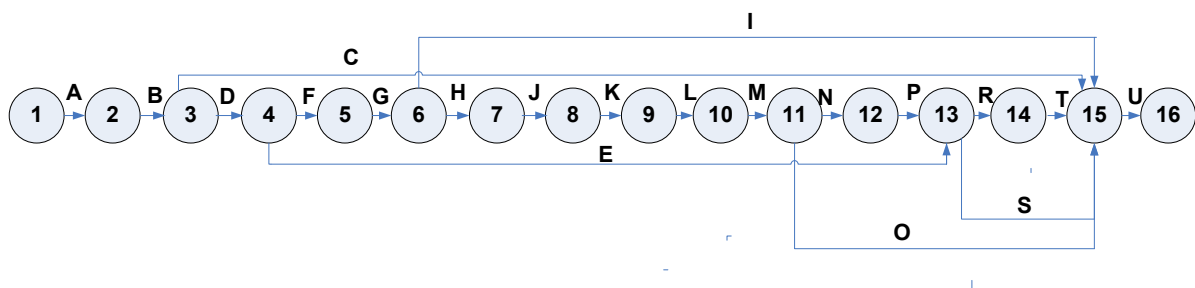


Figure 3. Network of the project

All the factors that have positive and/or negative impact(s) on the activity duration have been determined by meetings with the company's production planning team and are described below in detail.

Mobilization (setting container) / Turbine foundation-formwork/ Turbine foundation-7-day and 28-day concrete tests / Grout-test reports: Experts have stated that the durations of these activities are unaffected by positive or negative impacts.

Road-excavation and fill / Platform-excavation and fill: It has been determined that 3 factors affect the duration of these activities. These factors are as follows:

- *Malfunction of machinery:* The machine is waited to be repaired. Total amounts of daily excavating and filling decrease until the machine is ready to be used.
- *Geological structure of the ground:* An excavator is assumed to excavate approximately 350 m³ per day. Since the presence of firm ground requires the excavator to excavate with a crusher, the excavating speed is assumed to decrease to an average of 200-250 m³ per day. On the other hand, if the ground is soft, this speed is assumed to increase to an average of 400-450 m³ per day.
- *Weather conditions:* Excessive precipitation decelerates the operation.

Road-crushed stone paving: It has been determined that 3 factors affect the duration of these activities. These factors are as follows:

- *Additional material requirement due to the structure of the ground:* If the ground is too soft, more material may be required. In this case, it takes time to apply the new arrival material.
- *Muddy ground:* Since it won't be possible to pave the muddy ground, it will be waited until it gets dry.
- *Failure to provide adequate paving material:* In cases where wrong size or wet paving material is sent by the provider it will take time to get the proper material since the improper party will get rejected.

Turbine foundation-excavation: It has been determined that 3 factors affect the duration of these activities. These factors are as follows:

- *Geological structure of the ground:* An excavator is assumed to excavate approximately 350 m³ per day. Since the presence of firm ground requires the excavator to excavate with a crusher, the excavating speed is assumed to decrease to an average of 200-250 m³ per day. On the other hand, if the ground is soft, this speed is assumed to increase to an average of 400-450 m³ per day.
- *The presence of underground waters during excavation and the structure of the ground:* If underground water is met with during excavation or if it is seen that the ground is loose after geological surveys, ground improvement and drainage activities will be performed.
- *Weather conditions:* Excessive precipitation decelerates the operation

Turbine foundation-piping: There may be difficulties in the supply of materials.

Turbine foundation-lean concrete/ concrete/ backfill /grout: In case of rain, concrete is not poured. In case of excessive rain, there may be a slight delay.

Cable channels-excavation and back filling: It has been determined that 2 factors affect the duration of these activities. These factors are as follows:

- *Structure of the ground:* An excavator is assumed to excavate 250 m of the channel per day. if the ground is firm, this average is assumed to drop to 150 m.
- *Weather conditions:* In case of excessive rain, the ground is waited to get dry.

Turbine foundation-anchor assembly: In case of sending incorrect material by the supplier, a new set is waited to arrive.

Turbine foundation-stainless steel: The experience of the blacksmith team can affect the duration positively or negatively.

Platform-crushed stone paving: It has been determined that 2 factors affect the duration of these activities. These factors are as follows:

- *Muddy ground:* Since it won't be possible to pave the muddy ground, it will be waited until it gets dry.
- *Failure to provide adequate paving material:* In cases where wrong size or wet paving material is sent by the provider it will take time to get the proper material since the improper party will get rejected.

Turbine assembly: Operation is interrupted by extreme foggy and windy weathers.

Considering the above factors affecting each activity positively/negatively, three experts in the production planning team were asked to determine the L and G values. T-values for these data have been calculated. In addition to these, trapezoidal fuzzy numbers were created with the values obtained by taking the historical data averages of similar projects completed by the company. The RD and AD values calculated using the formulas in (1) to (4) are presented in Table 2.

Table 2. Activity durations of the applied methodology

Activity	ND	E1	E2	E3	H	ML	LL	RD	AD
A	3	NA	NA	NA	NA	NA	NA	NA	3
B	6	2.8	3.4	4	3.67	3.4-3.67	2.8-4	3.45	9.45
C	3	1.5	2.2	1.7	2	1.7- 2	1.5-2.2	1.85	4.85
D	3	2.03	1.4	1.78	1.53	1.53-1.78	1.4-2.03	1.69	4.69
E	4	1.7	2.2	2.5	2	2-2.2	1.7-2.5	2.1	6.1
F	4	9.2	8.36	10	9.71	9.2-9.71	8.36-10	9.29	13.29
G	1	1	0.5	1	2	1	0.5-2	1.17	2.17
H	1	1	1.5	0.5	1	1	0.5-1.5	1.00	2.00
I	3	4	4.5	4.2	5	4.2-4.5	4-5	4.44	7.44
J	1	2	3	5	7	3-5	2-7	4.29	5.29
K	5	1	2	1.5	2.5	1.5-2	1-2.5	1.75	6.75
L	1	NA	NA	NA	NA	NA	NA	NA	1.00
M	1	0	0.5	2	1	0.5-1	0-2	0.90	1.90
N	7	NA	NA	NA	NA	NA	NA	NA	7
O	28	NA	NA	NA	NA	NA	NA	NA	28
P	1	0	0.5	1	0.6	0.5-0.6	0-1	0.52	1.52
R	1	0	0.5	1	0.6	0.5-0.6	0-1	0.52	1.52
S	2	1.5	1.3	0.5	1	1-1.3	0.5-1.5	1.06	3.06
T	3	NA	NA	NA	NA	NA	NA	NA	3
U	7	0.5	1	2	1	1	0.5-2	1.17	8.17

ND: Normal Activity Duration; E1, E2, E3: Data from experts, H: Historical data on similar projects, ML: Most Likely Interval; LL: Largest Likely Interval; RD: Risk-associated Activity Duration; AD: Activity Duration

Looking at the applied methodology solutions given in detail in Table 3, it is seen that the duration time of the project is calculated as 85.71 days. The critical path of the project is the path created by activities with a slack value of “0” and is A-B-D-F-G-H-J-K-L-M-O-U.

Table 3. Results of the applied methodology

	ES	EF	LS	LF	Slack
A	0	3	0	3	0
B	3	12.45	3.45	12.45	0
C	12.45	17.3	72.69	77.54	60.2
D	12.45	17.14	12.45	17.14	0
E	17.14	23.24	66.92	73.02	49.8
F	17.14	30.43	17.14	30.43	0
G	30.43	32.6	30.43	32.6	0
H	32.6	34.6	32.6	34.6	0
I	32.6	40.04	70.1	77.54	37.5
J	34.6	39.89	34.6	39.89	0
K	39.89	46.64	39.89	46.64	0
L	46.64	47.64	46.64	47.64	0
M	47.64	49.54	47.64	49.54	0
N	49.54	56.54	64.5	71.5	15
O	49.54	77.54	49.54	77.54	0
P	56.54	58.06	71.5	73.02	15

R	58.06	59.58	73.02	74.54	15
S	56.54	59.6	74.48	77.54	17.9
T	59.58	62.58	74.54	77.54	15
U	77.54	85.71	77.54	85.71	0
Project duration (Days)					85.71
Critical path					A-B-D-F-G-H-J-K-L-M-O-U
*ES: early start; EF: early finish; LS: last start; LF: last finish					

Then, the results obtained from the applied model were compared with the results of F-PERT and CPM. For F-PERT, the experts were asked to determine the three periods of each activity (optimistic-most likely-pessimistic), and triangular fuzzy numbers (TFNs) were obtained by taking the averages. Li and Lee [31]'s comparison method was used in the F-PERT, and McCahon and Lee's [32]'s method was used in the calculation of criticality degrees (Cp), and the obtained values are given in Table 4. The duration of the project was calculated as 71.96 days using the F-PERT method.

Table 4. Fuzzy parameters of the project's paths

Path	Fuzzy path length			Defuzzified path length*	Defuzzified path ratio	Intersection ratio (IRiP)	Critical degree
	a	b	c				
A-B-C-U	17.67	20.00	26.34	21.34	0.30	0.00	0.00
A-B-D-E-R-T-U	24.17	28.34	37.67	30.06	0.42	0.00	0.00
A-B-D-E-S-U	22.17	26.34	35.18	27.90	0.39	0.00	0.00
A-B-D-F-G-H-J-K-L-M-N-P-R-T-U	42.34	49.55	77.65	56.51	0.79	0.56	0.44
A-B-D-F-G-H-J-K-L-M-N-P-S-U	40.34	47.55	75.16	54.35	0.76	0.49	0.37
A-B-D-F-G-H-J-K-L-M-O-U	58.34	64.87	92.66	71.96	1	1.00	1.00*
A-B-D-F-G-I-U	24.34	29.87	45.84	33.35	0.46	0.00	0.00
Project Duration	58.34	64.87	92.66	71.96	-	-	

* Ammar and Abd-Elkhalek [7]'s method was used to calculate the defuzzified project duration (DPD).

The results of the CPM, F-PERT and the applied methodology, which is the subject of the study, as well as the actual completion time of the wind power project, are shown in Figure 4. It has been observed that the value closest to the realized one is obtained by the applied method, which is included in the durations by taking into account all the positive/negative factors related to the activities in a fuzzy environment.

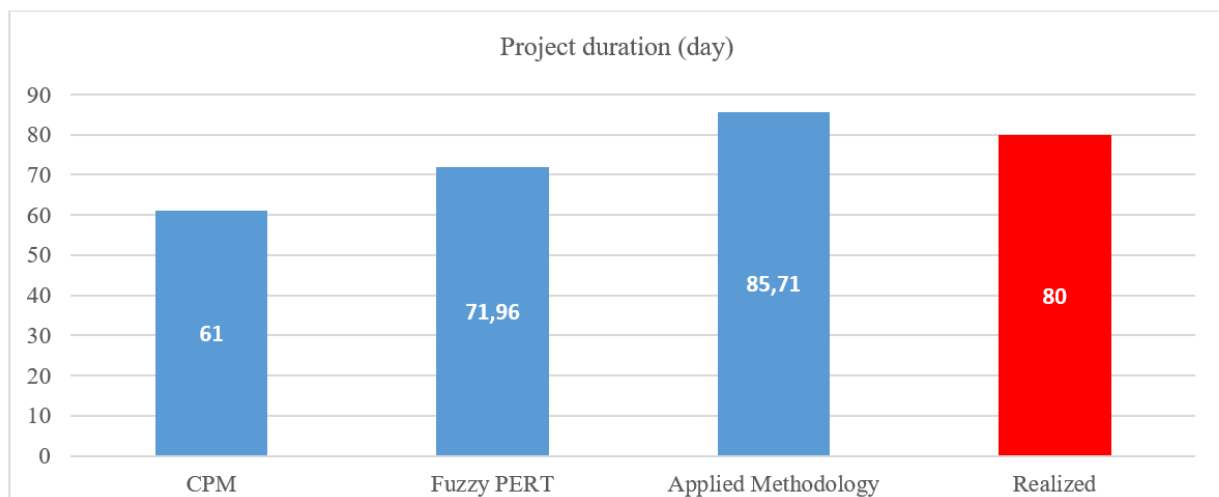


Figure 4. The comparison of the results of project management techniques

5. CONCLUSIONS AND RECOMMENDATIONS

All over the world, the tendency towards the use of renewable energy sources, and the move away from fossil fuels - in order to reach sustainable development - has led to a rapid increase in investments in wind energy. Moreover, wind energy, as an affordable and environmentally friendly source of power, plays a vital role in promoting sustainable development and is gaining increasing significance [33]. The most important aspect of this large-scale wind power investments, a sector in which there is intense competition, is that the construction schedule can be made to meet the promised date within budget and to the required quality. However, uncertainty factors such as weather conditions, supply problems, material quality, site conditions, ground structure, and presence of groundwater in wind power projects delay the project completion time. When the reasons such as the lack of historical data and lack of an experienced production planning team (because companies seem to have less experience in such projects) also add up to these, it becomes difficult for project managers to present, foresee and measure project scheduling problems effectively. In this article, in order to enable effective and realistic analysis of wind turbine projects, a method has been applied that provides solutions under fuzzy set theory by including risk factors in the durations. This method was applied to an international company operating in Türkiye and Europe. In order to evaluate the strength of the model, the same project was also examined with CPM and F-PERT methods and the results of the 3 models were compared with the actual duration of the project.

In the method applied, the factors that positively or negatively affect the operation times of the wind power were determined with the experts involved in the project. The risk-associated activity durations obtained were analyzed under fuzzy set theory and the project completion time was calculated as 85.71 days. Although the project completion time was calculated as 61 days with CPM, and 71.96 days with F-PERT; the project was actually completed in 80 days. As a result of the study, it has been seen that a more realistic time can be estimated for the completion of the project with this method, which includes all the factors affecting the duration of the activities and uses both expert opinion and historical data. Thus, with this study, a customized tool has been presented, in which a risk map for all activities for wind power project management has been created.

Although it is important to estimate the project completion time in wind power projects, it is also important to take measures to reduce this period. Considering that adverse weather conditions usually tend to pose as a negative factor in almost all activities, the first issue to be considered is choosing the right dates for the project. It is important that the construction phase of the project is timed to coincide with the summer months, which will reduce the impacts of possible rains. Similarly, since turbine assembly cannot be done in case of high wind speeds, the activity times in the project should be arranged according to historical meteorological data. Similarly, it will be important to plan to eliminate the risk of machine failures that would consequently delay many activities, especially excavation and filling activities. If a subcontractor declares to employ more than “the required number of machines in order to finish the work” to meet the schedule in the agreement, it will reduce/eliminate the loss of work caused by possible machine failures. Some of the other time delaying situations are; the occurrence of underground water during excavation, or presence of very soft or very firm ground structures. If the geological characteristics of the land vary too much in the EIA (environmental impact assessment) reports, pre-determining the physical properties by making more geological land surveys than usual and drilling at more points, will ensure preparedness. Thus, it will be possible to take the relevant measures in advance. Again, as a recommendation to shorten the time, use of explosives on extremely rocky ground is recommended. In addition to these, choosing an experienced blacksmith team and working with subcontractors that deliver reliable and high-quality work are also recommended.

This study may serve as a guide for all the project decision makers, on realistic estimation of project completion times -regardless of industry. And for future studies, it is recommended to combine this method with others, and make detailed analyses to provide solutions for many real-world problems.

CONFLICTS OF INTEREST

No conflict of interest was declared by the author.

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