Forecasting construction time for road projects and infrastructure using the fuzzy PERT method

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Abstract. It is essential to organize and plan any project at all stages, from start to finish; however, it is also necessary to certify completion by means of correct and effective methods. Scheduling projects using scientific approaches and sophisticated scheduling tools helps guarantee to project completion by the scheduled dates, as well as allowing institutions and municipal departments to make accurate estimations for project execution. The construction of roads includes several activity packages, one of which is the generation of road infrastructure such as that related to the sewer work (such as water and wastewater), the drilling and pouring work, the electrical work, and finally the paving. One of the most difficult jobs facing a manager in terms of such a project is the scheduling of activities over time. In many projects, the scheduling is done compactly, such that each activity that matches one scheduled in previous projects is scheduled but not detailed, with estimates based on previous overall times. In this research, however, each major activity was divided into several sub-activities to allow more accurate calculation of duration based on several criteria that affect the activities’ use of time. Three timings were thus estimated for each activity: a pessimistic time, an optimistic time, and a normal time. The PERT method was improved by using a Fuzzy Delphi technique to estimate the actual time required to implement each activity. The overall scheduling of a project in Karbala city, the rehabilitation of the road connecting the intersection of the Al-Ghadeer district to the intersection of the Al-Mudraa district was done in this manner. The project implementation period was predicted at 301 days, which is very close to the 322-day actual duration in which the work was carried out. The findings confirmed that the improved PERT method using the Fuzzy Delphi technique was the most accurate way to predict execution time.

Keywords: PERT method, Scheduling techniques, Fuzzy Delphi, Road paving.

1. Introduction

Most projects that have been implemented by the municipal departments of the Ministry of Construction, Housing, Municipalities and Public Works have been characterized by their size and complicated nature. Despite this, simple methods have been used across all scheduling for these projects, such as Gantt charts. Many of these projects have thus been delayed due to lack of connection between various project activities and a lack of understanding with regard to the reasons for logical sequences; indeed, there has arguably been insufficient use of logical sequential relations in the process of scheduling these projects in any case.
Decision makers need to turn their energies to creating efficient projects, and many managers are now aware that they can administer the scheduling, planning, and implementation of all projects more precisely. Several unconventional scientific tools and methods have thus emerged, with the most important being the PERT method, which seeks to ensure the implementation of projects with the fewest possible time units. The CPM and Program Evaluation and Review Technique (PERT) method was first used in project scheduling in the 1950s: the PERT method was developed to manage the Polaris missile production cycle. The exploitation of such techniques for specialized scheduling of projects thus reduces time and costs in the process of achieving the objectives of the organization.

Project scheduling is one of the most difficult jobs faced by managers, as all project details must be taken into consideration in order to plan and schedule project activities effectively; a timetable must then be drawn up that reflects reality and project progress monitored against this. Each project must have a start date clearly defined, and dates for all activities that must be done directly to implement project activities. Moreover, the project must have a precise completion date to allow a project work plan to be developed [1]. A project is a temporary activity and must thus have defined start and end dates; it may also need to use specific resources to achieve the desired results [2]. The scheduling process transforms the project work plan into a timing plan that controls and motivates the project as a whole. It can also be used to monitor and organize events and the activities of the project. It must thus apply across the full scope of the project. In [1], the researchers demonstrated that the scheduling can be defined as a model that presents activities, sets dates and milestones for the project, allocates all the resources needed by the project, defines the beginning and end of the project, and determines the sequence and priorities of all project activities and their overlap.

2. Research problem
Most projects are subjected to delays in completion time, particularly where there is confusion in the process of implementation. Municipal Projects in Kerbala are usually scheduled in non-scientific ways, which leads to problems with projects implementation timing that negatively affects the completion time of projects. In this research, a scientific method was thus used to schedule project activities using the Delphi technique to modify a Fuzzy PERT scheduling technique.

3. Research goal
To assess and apply the Fuzzy Delphi method to predicting the actual execution time required for a project.

4. Previous studies
Conventionally, scheduling theory has been concerned with apportionment of resources to tasks or activities [3]. Rapid progress has been made regarding the methods and procedures of scheduling based on two techniques, however. The first involves scheduling project resources in a limited manner that takes into account all restrictions imposed on activities and events in order to reduce the overall project duration; the problem of scheduling project activities based on limited resources is one of the oldest problems faced by project scheduling methods, and there are now a number of methods to solve this problem. The second technique is settlement of a project's resources that takes into account the constraints faced by project activities and the need to complete the project on its specified date, which thus uses settlement methods to distribute resources [4]. Representing times for project activities in the form of fuzzy groups has been found to achieve better success than representing them numerically in many studies, [5] and [6]. More generally, several methods and solutions have been proposed to determine activity times for events, with finding ways to determine fuzzy times for project activities attracting widespread interest [7,8].

Most methods used in scheduling project activities are based on the critical path method, calculating the time from the start to the end of the project and dividing down [9]; actual activity times are replaced with fuzzy activity times in research on fuzzy times, based on the failure of the returns method to calculate exact times. For the same path, this probability method offers a range of different
times according to the importance of the activity. Dubois et al suggested several approaches to calculating different sets of values utilizing a fuzzy PERT method [9], while polynomial algorithms were developed to schedule project start times in a business network with critical paths by Janas and Zelinki, who explained the concept of critical networks and the generalization of natural time. Chen and Huang [10] created a means of dealing with managing project completion time alongside critical activity time for project networks in a new method using a fuzzy triangle with positive values. However, these calculations did not correspond to the reverse pass in terms of calculating the overall time for the project, and the method thus cannot calculate any overrun of the project. Van Drop and Kotoz [11] showed the extent of the benefit of the four variables used in the scheduling methodology of the PERT method and the extent to which the three projected times of a project (optimistic, pessimistic, and natural) may be utilized.

5. Evaluation and follow-up of project programs: Program Evaluation and Review Technique (PERT)

This technique emerged due to the problems faced by the US Navy in the development of the Polaris missile project. The US Navy had developed a new, time-consuming method in which the network connected tasks to each other on a time and precedence basis, producing critical points throughout the project [12]. This was then developed as a risk-taking tool to ensure that estimates were based on the best available information with a "pert chart" developed to show the Project Network [13]. Non-recurrent operations not previously carried out in the same way, including research and development projects, have little reliable prior information available [13,14]. To gain the information needed for PERT is, however, relatively easy, and this allows development of a minimum sequence of all activities, this leads to more precise control of the specifications and requirements of the project as a whole [15]. This technique does require some statistical knowledge in order to understand the process of calculating the times of activities, along with a computer program designed to support peer computing or networking, as distributed application architecture is required to partition tasks or workloads between peers, who are equally privileged, equipotent participants within the application [16]. A PERT network is thus essentially a flowchart that depicts the sequence of activities required to complete the project and the time or costs associated with each activity. Based on the PERT network, the manager must think about what to do and, in particular, identify those events that depend on each other. PERT makes it easy to compare the effects that various procedural choices may have on scheduling and costs, thus permitting managers to monitor project progress, identify potential bottlenecks, and transfer resources as necessary to keep the project on time [17].

The method requires the user to assign three possible periods to frame the practical scope for each activity; it then applies simple statistical formulae to calculate the mean and variance of the time required to complete the series of events leading to significant achievement [18].

6. The Combination of PERT and Fuzzy Delphi Methods

The PERT method can be improved by the application of the Fuzzy Delphi method to calculate the time required for the project. In this section, the relevant characteristics of the two methods are thus examined:

(i) PERT is one of the most widely used and popular business applications, with a range of useful characteristics [19]

1. It forms the basis of project planning and provides administrators with the means to optimize the use of resources available to achieve the objectives of the organization within the required times and costs.

2. It helps the administrators responsible for decision-making to deal with the risk that accompanies various programs by enabling them to answer the following questions:
   a. What delays may affect the completion of some activities prior to completion of the project?
   b. What activities have a certain degree of flexibility?
   c. What are the critical activities and how are they handled?
3. It is an important basis for obtaining facts to support the decision-making process.
4. It is a means of planning and control based on a schedule that determines the beginning and end of activities and thus ensures that stages are accomplish as planned as well as allowing for corrections in the event of any deviations.
5. It provides the basic structure for the supply and transmission of information.

(ii) The Fuzzy Delphi technique is an analytical method, based on the Delphi technique and the Fuzzy Concept. The traditional Delphi technique was developed in the 1950s and 1960s at the RAND Corporation, Santa Monica, CA [20], and it is possibly the most well-known group judgment technique. The Delphi technique is essentially an iterative structured process for the systematic collection and collation of judgments from a group of experts on a particular issue by means of a series of questionnaires, interspersed with controlled opinion feedback.

7. Analysis steps using the Fuzzy Delphi technique
The Fuzzy Delphi method is a simplification of the classical technique for extended range prediction. The essence of the Delphi method is defined as follows:
1. The first step involves asking those with experience in the field, as well as any relevant specialists and qualified people, to express scientific opinions, separately and independently, about the date of the realization of a specific event, whether in science, business, or technology. This may also involve asking them to predict the general state of the economy, the market, or technology at that time.
2. These individual data points are statistically analyzed for the arithmetic mean, and this result is communicated to the experts.
3. The experts review the results and provide new estimates; these are again statistically analyzed and sent back to the experts for evaluation.
4. The process is repeated several times until a reasonable and acceptable solution, as defined from the perspective of the manager or management body, is reached.

Two or three attempts may be sufficient to reach the desired results. However, long-term forecasting problems involve incomplete and imprecise data, and the decisions made by the experts depend on their individual competence and expertise and are thus subjective. This makes it generally more appropriate to present this data in ranges numbers rather than as specific numbers. Trigonometric numbers in particular are suitable for this purpose, as they are easily constructed by specifying three values, the smallest possible, the largest possible, and the most reasonable; rather than an unsubstantiated average, the analysis is thus based on an ambiguous but bounded medium [21].

8. Case Study
In this research, one of the road-establishing projects in the Karbala governorate in Iraq was taken as a case study for the application of the technique. The project involved rehabilitating the road connecting the intersection of the Al-Ghadeer district to the intersection of the Al-Mudraa district, and it was one of the projects established in the governorate by the municipality department of the province. The length of road covered by the project was about 1.5 km, with an area of foundation paving of 15,500 square meters and paving of 20,500 square meters. The duration of the construction work for the project was predicted at about 270 days without any additional project periods; the additional periods for this project added up to about 30 days, giving a total project time of 300 days.

9. Research Method
In this research, a group of engineers working on similar construction projects was chosen to estimate the actual time for each of the project activities. Information about the three times for each section of the project, the pessimistic, the optimistic and the natural, were also collected. The PERT method was improved by applying the use of Fuzzy Delphi to estimate the ratios of the three time estimates, and this was used to calculate the actual time required to complete activities for use in scheduling the
This method thus took the effects of external factors surrounding the project into account, providing a better estimate for project implementation. The project was divided into six main activities, excluding the start and end activities, which were all required to complete the paving of the street. The activities used in scheduling the project were not detailed, however, and several had merging issues. Thus, in this research, the six main activities were divided into sub-groups to better identify any problems that might cause delay in the establishment of the project and to determine the activities required to complete the project. A group of experts and engineers working in the field of constructing and scheduling such activities was chosen to provide details for these six main activities. Subsequently, the actual activities by which the project was established determined, with 37 activities identified for this project. These were divided and detailed as shown in Table 1, which illustrates the six main events and their sub-sections.

### Table 1. Activities coding system.

| Type of Works          | Symbol          |
|------------------------|-----------------|
| Municipal Works        | A1, A2, A3, A4, A5, A6, A7, A8, A9, A10 |
| Sewer works            | B1, B2, B3      |
| Trench works           | C1, C2, C3      |
| Communication Fences    | D1, D2 D3       |
| Optical cable works    | E1, E2, E3, E4, E5, E6, E7 |
| Water works            | F1, F2, F3, F4  |
| Dummy activities       | X1, X2, X3, X4, X5 |

Appendix A offers details of each activity; these may be used in scheduling any street paving project. Finally, with the help of the group of experts and engineers, information was collected about the precedence of each activity and its sequence within the network required to establish a project for street paving.

Table 2. a and b show the sequencing process for each activity and the estimated times for each of the activities. The main difficulty of this method lies in gathering information, which is often why, even as the basis for planning the implementation of any project, it is not supported by specialists in the field of scheduling activities and establish projects; however, this in turn is major reason for delays in project completion due to the resultant poor network planning. Identifying the overlap and the priorities that occur between activities is necessary to obtain the best critical path, and the identified overlaps must reflect the practical reality of events. For example, in this case, one of the communication ferry activities can overlap electrical trench activities and optical cable activities, making interactions between them critical to the project planning and scheduling process.

### Table 2a. Activities’ dependencies and expected times

| Activities | Previous activities | Optimistic time | Normal time | Pessimistic time |
|------------|---------------------|-----------------|-------------|------------------|
| Start      |                     | 0               | 0           | 0                |
| A1         | start               | 18              | 24          | 33               |
| A2         | start               | 18              | 24          | 26               |
| A3         | A1, A2              | 11              | 13          | 18               |
| A4         | A3                  | 22              | 28          | 31               |
| A5         | A4                  | 22              | 28          | 31               |
| B1         | A5                  | 31              | 40          | 55               |
| X1         | A5                  | 18              | 18          | 18               |
| B2         | X1                  | 26              | 33          | 46               |
| X2         | X1                  | 9               | 9           | 9                |
| B3         | X2                  | 4               | 5           | 5                |
| X3         | B1, B2, B3          | 0               | 0           | 0                |
| Activities | Previous activities | Optimistic time | Normal time | Pessimistic time |
|------------|---------------------|-----------------|-------------|-----------------|
| F4         | F3, F2              | 2               | 2           | 2               |
| A6         | X3, C3, D1, E1, F4  | 31              | 40          | 44              |
| D2         | A6                  | 15              | 18          | 20              |
| D3         | A6                  | 15              | 18          | 26              |
| E2         | A6                  | 15              | 18          | 20              |
| E3         | A6                  | 11              | 13          | 18              |
| E4         | E3, E2              | 16              | 20          | 28              |
| E5         | E4                  | 16              | 20          | 22              |
| E6         | E5                  | 2               | 2           | 2               |
| E7         | E6                  | 8               | 9           | 11              |
| X4         | D2, D3, E6          | 0               | 0           | 0               |
| A7         | X4                  | 21              | 26          | 29              |
| X5         | X4                  | 9               | 9           | 9               |
| A8         | X5                  | 26              | 33          | 37              |
| A9         | X4                  | 31              | 40          | 44              |
| A10        | A9                  | 31              | 40          | 44              |
| End        | A7, A8, A10         | 0               | 0           | 0               |

The data in Table 2. a and b was entered into the WINQSB program, which is a simplified program that calculates the total time for the establishment of a project, and which also calculates the longest required path. Using the traditional PERT method, the total time for the project was calculated as 322 days. The longest path is represented by the red line in Figure 1, which is start, A1, A3, A4, A5, X1, B2, X3, A6, E2, E4, E5, E6, X4, A9, A10, end.
10. Estimating activities’ durations using the Fuzzy Delphi method

All long-range predictions involve imprecise and imperfect data; additionally, even decisions made by experts rely on their individual capabilities and are subjective. This makes it more suitable for such data to be presented using fuzzy numbers instead of crisp numbers. Triangular numbers are particularly suitable for this, as they can be constructed easily by specifying three values, the smallest, the largest, and the most plausible. Instead of using a crisp average, analysis can then be based on the fuzzy average.

**Step 1.** A group of experts \( E_i \) where \( i = 1, 2, \ldots, n \) are requested to provide a possible realization date for a certain event (whether in science, engineering or another field) in the form of the earliest predicted date, \( a_{1(i)} \), the most plausible date \( a_{M(i)} \), and their latest predicted date \( a_{2(i)} \). The data given by these experts \( E_i \) can then be presented in the form of triangular numbers

\[
A_i = (a_{1(i)}, a_{M(i)}, a_{2(i)}); i = 1, \ldots, n
\]  

(1)

**Step 2.** The average (mean) \( A_{ave} = (m_1, m_M, m_2) \) of all \( A_i \) is then computed, and for each expert \( E_i \) the deviation between \( A_{ave} \) and \( A_i \) is computed as a triangular number defined by

\[
A_{ave} - A_i = (m_1 - a_{1(i)}, m_M - a_{M(i)}, m_2 - a_{2(i)})
\]

\[
= \frac{1}{n} \sum_{i=1}^{n} a_{1(i)} - a_{1(i)} + \frac{1}{n} \sum_{i=1}^{n} a_{M(i)} - a_{M(i)} + \frac{1}{n} \sum_{i=1}^{n} a_{2(i)} - a_{2(i)}
\]  

(2)

The deviation, \( A_{ave} - A_i \), is sent back to expert \( E_i \) for reexamination.

**Step 3.** Each \( E_i \) presents a new triangular number such that

\[
B_i = (b_{1(i)}, b_{M(i)}, b_{2(i)}); i = 1, \ldots, n
\]  

(3)

This process is iterative between steps 2 and 3, in that the triangular average \( B_m \) is calculated with the substitution of \( b_{1(i)}, b_{M(i)}, b_{2(i)} \) into equation 2, and new triangular numbers \( C_i = (c_{1(i)}, c_{M(i)}, c_{2(i)} \) are produced and their average \( C_m \) calculated. This procedure can be repeated until any two successive means become reasonably close, as shown in Figure 2.
Step 4: At any later time, the forecast may be reexamined using the same process if any important information becomes available due to new discoveries. The Fuzzy Delphi method is a typical multi-expert forecasting procedure for combining views and opinions [21]. These steps were applied to each of the project activities, as shown in Table 2, and a number of iterations were applied to reach converging average values ($A_{avg}$, $B_{avg}$, and $C_{avg}$), as shown in Table 3.

Finally, the three timeframes of the project (Optimistic, Normal, Pessimistic) were obtained by applying the Fuzzy PERT method as shown in Table 4.
These times were entered into the WINQSB program, causing the total project time to become 301 days, as shown in Figure 3. The project was planned to be completed within 270 days; however, in practice, the project faced several issues that prevented it from being completed on time, which added an extra 30 days to the total time of the project. As scheduling with the PERT method gave the total time for the completion of the project as 322 days, while the fuzzy PERT method offered a total time for the project of 301 days, the latter was closer to the actual time for the completion of the project.

![Expected Project Completion Time - 301.81 days](image)

**Figure 3.** Longest path model using fuzzy PERT method in WINQSB program.
11. Conclusions
1- The project in the case study was scheduled for execution within a maximum of 301 days.
2- The use of iteration processes in Delphi method to assigning the three probable times of execution leads to more accurate prediction.
3- Using the fuzzy Delphi method was more accurate than the PERT method alone in determining the execution time of the project.
4- There is an urgent need for experts in road construction to estimate the expected time of each activity when planning projects.

12. Recommendations
1- Training programs featuring methods and techniques for scheduling projects should be set up for engineering managers in municipal departments in order to improve the scheduling of appropriate projects for the future.
2- The process of scheduling projects must be recognized as one of the most important conditions for success by the companies referred to such projects. As such it must be measured alongside conditions of efficiency, experience of similar work, lowest bids, and the availability of capital, ensuring the company's understanding of advanced scientific methods of scheduling techniques to enable project success.

Appendix A

| Symbol | Active Details of Activities |
|--------|------------------------------|
| START  | Dummy activity represents the beginning of events |
| A1     | The preparation and processing of all the mechanisms to break and remove the old tiling and scraping, digging and settling the road with the lowest depth of the threshold falls within the section of the street |
| A2     | Raising the debris resulting from scouring the streets outside the municipal boundaries |
| A3     | Procedures for the examination of natural soil and treatment of rattan areas with rough sand and groundwater withdrawal |
| A4     | Brushes and cleaning of a layer of clean dirt with a thickness of 20 cm with a good reduction of not less than 75% |
| A5     | Preparing the material and preparing for the old side, digging the path, digging the soil, laying a layer of gravel, the type C, casting the base of the side mold, and then constructing the side mold, and dyeing three layers of colors. |
| A6     | Brushes and leveling of two layers of Gravel B Class B thickness of the layer 15 cm with good clays by not less than 95% for each layer successful inspection |
| A7     | 32. Preparing and examining all materials and preparing for quarrying, sidewalks, and burial with clean dirt and soil curbs. Laying down a layer of crushed gravel, class C, with a thickness of 10 cm, with the curbs, and then paving with a Muqarnas Sticker of 6 cm thickness. |
| A8     | Preparation for drilling and burying in clean soil for the path of the sand wall and soil mound with a brush and a layer of gravel type C under the wall thickness of 10 cm and pour the wall with a dimension of 15X30 cm |
| A9     | Preparing and preparing the asphalt layer bedding with a thickness of 10 cm with a minimum of 97% and a successful inspection |
| A10    | Preparation and preparation of the layers of asphalt layer bonding with a thickness of 6 cm with a minimum of 97% mixing and successful inspection |
| B1     | Preparation and inspection of all materials (200 mm pipe, D type gravel, sand, crushed gravel and cement), equipment and tools for crushing tracks and drilling (70-90 cm) deep, Gravel of the type D, thickness 20 cm from all sides and the area of the connection of the pipe and the cement (sand / sand) (3/1) |
| B2     | Drilling and pouring side discharge holes with dimensions 40 x 50 cm and thickness of 20 cm with a depth of 70 - 90 cm and the processing and installation of the aortic clamp (starting 14 days after the start of the event B1) |
B3 Preparing the equipment to raise or reduce the exhausting covers for the manholes and Man sub which is limited by the representative of Karbala municipality
C1 Setting the rates and digging the concrete trench with a distance of 1 m depth x 1.2 m. The width surrounds the cables with the rubble outside the site.
C2 Spraying a layer of gravel with a thickness of 25 cm with a 95% C3 Pour the conveyor stream using the wood-glazed concrete with reinforced concrete with the burial D1 Preparation for the excavation of the place where the hollow and casting concrete with dimensions 160X160X160 cm thickness of walls 20 cm subject to tests and the placement of pipes 20 cm high on the base of the manholes with the cover of the abyss and all required work D2 All material processing and inspection (160 mm plastic pipe, river dust, warning tape, washed sand, crushed gravel, cement, reinforcing steel, medium-sized steel,
D3 Preparation for drilling depth of 110 cm and width of 60 cm and the extension of the pipes with three lines and brushes of two layers of river dirt down and top pipes 10 and 30 cm respectively, and then extending the warning tape width 40 cm and complete the burial
E1 Preparation for digging work for the place and the casting of the concrete with dimensions 160X160X160 cm thickness of walls 20 cm is subject to laboratory tests and the preparation of the cover and put the eyelid dimensions of 60 X90 cm and height of 12 cm and everything that requires work E2 Installation and testing of plastic pipe diameter 160 mm with all accessories of length measuring 6 m E3 Preparation for manual and automatic drilling of 100-120 cm depth and laying of plastic pipes in three lines with two layers of soil dirt down and top pipes 10 and 30 meters high on the lines and then extending the warning tape 40 cm width and completion of the burial E4 Preparation for the work of the holes in the streets with a depth of 80-120 cm with the injection of a plastic tube diameter 160 mm and all that requires work E5 Preparing and carrying out manual hand-held cables for 24-hour armed cable and all work required E6 Supplying a photovoltaic node with all accessories, including a 50-calorie thermometer for the purpose of connecting and protecting the optical cable terminals E7 Conducting the inspection, binding and welding of all parts of the network internal and external optical cables and inserting them into service F1 All materials are processed and tested. A plastic pipe is 225 mm 110 mm. It is designed to do crushing works for floor and drilling thresholds at a depth of 140 cm and width of 50 cm and laying of pipes and burying in river soil under the pipe thickness of 15 cm and above 25 cm thickness and completion of burial F2 Initialization To edit the feed feeder substrate on the asbestos pipe diameter 225 mm F3 Connecting the substations of the 110 mm diameter plastic pipe with the newly launched 225 mm diameter plastic pipe and scraping it from the asbestos pipe diameter 225 mm with the start and end of the plastic pipe diameter 225 mm.
F4 Canceling sources of feed for the old 225 mm diameter asbestos pipe X1 Dummy Activity The purpose of linking between efficacy B1 and activities B2 is due to the activity of B2 beginning 14 days after the start of activity B1 X2 Dummy activity linking efficiency B3 and activity B2 because B3 activity begins 7 days after the start of the activity B2 X3 Dummy Activity X4 Dummy Activity X5 Dummy Activity END Dummy activity represents the ending of events

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