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PROJECT MANAGEMENT IN HEALTHCARE: A CASE STUDY FOR PATIENT FLOW EVALUATION IN AN EMERGENCY ROOM USING FUZZY CPM AND FUZZY PERT

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ABSTRACT

An ideal healthcare system is considered as a system that provides the most quality service level, lower costs and unlimited access. Any delay in patient flow may result in undesired consequences and losses in healthcare facilities such as hospitals and their sub units. Project management is defined as application of techniques to project activities to meet the project requirements. It has techniques that can help healthcare facilities and units standardize care and quality, reduce costs, improve effectiveness and decrease prolonged waits. The current study is carried out in an emergency department of a university hospital to understand the patient flow of the department with respect to the Fuzzy Critical Path Method (FCPM) and Fuzzy Program Evaluation Review Technique (FPERT). The reason for incorporating fuzzy sets is stemmed from that fuzzy numbers are more effective for high uncertainty processes as in emergency departments. Activities affecting patient flow through the ED are identified and project network is drawn. 1500 patients' data about the times of each activities are obtained from the observed ED. Findings through application of FCPM and FPERT, the expected time for completion of the project, the critical path and slack times are determined.

Keywords: Healthcare, emergency department, patient flow, fuzzy critical path method, fuzzy program evaluation review technique.

SAĞLIK SEKTÖRÜNDE PROJE YÖNETİMİ: BULANIK KRİTİK YOL VE BULANIK PROGRAM DEĞERLENDİRME VE İNCELEME METOTLARI KULLANILARAK BİR ACİL SERVİSTEKİ HASTA AKIŞININ DEĞERLENDİRİLMESİNE YÖNELİK VAKA ÇALIŞMASI

ÖZ

İdeal bir sağlık sistemi en iyi kalite seviyesinde, en düşük maliyette ve sınırsız erişimle hizmet sağlayan bir sistem olarak değerlendirilmektedir. Hasta akışındaki herhangi bir gecikme hastaneler ve onların alt birimleri gibi sağlık tesislerinde istenmeyen sonuçlara ve kayıplara neden olabilmektedir. Proje yönetimi, proje gerekliliklerini karşılamak için faaliyetlerin projelendirilmesini sağlayan tekniklerin uygulanması olarak tanımlanmaktadır. Proje yönetimi, sağlık tesislerinin hizmet ve kalitelerini standardize etmesi, maliyetlerini düşürmesi, etkinliklerini artırması ve uzun bekleme sürelerini azaltmasını sağlayacak tekniklere sahiptir. Mevcut çalışmada, Bulanık Kritik Yol Metodu (FCPM) ve Bulanık Program Değerlendirme ve İnceleme Metodu (FPERT) kullanılarak bir üniversite hastanesi acil servisindeki hasta akışı değerlendirilmiştir. Bulanık kümelerin bu metotlarla birlikte kullanılmasının sebebi acil servislerdeki yüksek belirsizlik içeren süreçlerin bulanık sayılarla daha etkin ifade edilmesinden kaynaklanmaktadır. Acil servisteki hasta akışını etkileyen faaliyetler tanımlanmış ve proje ağı çizilmiştir. Her bir faaliyete ait süreler için acil servisten 1500 hasta verisi toplanmıştır. FCPM ve FPERT uygulanması sonucunda projenin muhtemel tamamlanma zamanı, kritik yol ve gevşeklik değerleri elde edilmiştir.

Anahtar Sözcükler: Sağlık sektörü, acil servis, hasta akışı, bulanık kritik yol metodu, bulanık PERT.

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1. INTRODUCTION

A project is a series of work tasks that have a certain beginning and an end and leads to an outcome [1]. A project's life cycle typically consist of four stages: (1) formulation and analysis, (2) planning, (3) implementation, and (4) termination [2]. Projects include several activities that must be carefully planned and coordinated to attain the desired level, and may take a long time to complete. Project management deals with the coordination of all initiating, planning, decision, execution, monitoring, control, and closing processes in the course of a project. It includes balancing the competing demands for time, quality, scope, and cost [3]. In a healthcare system, there are three main dimensions including quality, cost and access. From the viewpoint of the patients, an ideal healthcare system is considered as a system that provides the most quality service level, the lower costs and unlimited access. Quality, one of the most important of all, is directly related to the performance and efficiency of sub-systems of healthcare. Hospitals considered as the most important pillar of the healthcare trivet have sub units like emergency departments (ED) which are key access points and provide initial treatment for a broad spectrum of illnesses and injuries, some of which may be life-threatening and require immediate attention [4]. An important factor that affects the performance of healthcare delivery processes in a hospital ED system is the flow of patients [5]. It is indicated that patient flow processes in the EDs are as the following order: triage, registration, placement in an ED bed, clinical assessment, treatment, and/or diagnostics/laboratories followed by disposition [6]. The complexity and uncertainty of these processes bring about different issues such as prolonged waiting times, inefficient use of ED resources, and unbalanced staff scheduling. Prolonged waiting times are constituted by the long waits in triage, delays in testing or obtaining test results, waiting for the physician, and shortage of nursing staff [6,7,17]. Therefore, an alternative for improving the performance of an ED is making changes in the patient flow. These changes may include eliminating unnecessary activities and identifying alternative process flows. By doing this, some operations research methods like CPM, PERT or Gantt chart can help ED executive.

This study is conducted in a university hospital ED to understand the patient flow of the department with respect to the FCPM and FPERT. The reason for incorporating fuzzy sets is stemmed from that fuzzy numbers are more effective for high uncertainty processes as in EDs. Activities affecting patient flow through the ED are identified and project network is drawn. 1500 patients' data about the times of each activities are obtained from the observed ED. Findings through application of these methods, the expected time for completion of the project, the critical path and slack times are determined.

The rest of the study is organized as follows: Section 2 presents related literature on project management applications in healthcare. Section 3 presents an overview of CPM and PERT techniques, and their fuzzy versions. Section 4 deals with our application case in an emergency department of a university hospital to evaluate the patient flow. Finally, our conclusions and limitation of the study are presented in Section 5, as well as some suggestions for future works.

2. LITERATURE REVIEW

Hospitals and healthcare systems have been faced with challenges to deliver desired quality care with limited resources. Therefore, they require procedures to improve patient flow, to provide timely treatment and maximum utilization of available resources [8]. Project management techniques like CPM and PERT are applied in healthcare systems in order to improve patient flow processes. These techniques assist the executives in planning, scheduling and controlling the different activities of healthcare systems and make heavy use of networks to plan and display the flow [4]. Krishna Reddy and Acharyulu [9] apply PERT to identify the process flows in the ED and patient discharge of a corporate hospital. Luttman et al. [10] present a methodology for incorporating PERT and CPM techniques into the design and management of clinical processes.

Lee et al. [11] use PERT and CPM tools on pulmonary lobectomy patients' processes and provide to standardize care, reduce the length of stay and apply quality control processes to improve patients care. Girija and Bhat [4] apply PERT to understand the different process flows of an ED of a tertiary care teaching hospital. They collect a sample of 100 patients' data randomly selected from a population of 460 and research to find critical path, expected completion time, variance of the path and different slack timings associated with the emergency care provided in the ED. Teichgräber et al. [12] use CPM to design and improve work flow in computed tomography (CT).

From this brief literature review, we conclude that project management techniques especially CPM and PERT can be used to help improve patient flow problems of various healthcare systems such as EDs, CT units and outpatient clinics. Unlike the existing literature, this study makes some contributions in some aspects. These include: (1) it uses the fuzzy versions of CPM and PERT since fuzzy based versions are more effective for high uncertainty processes as in EDs and (2) it uses a real data of a leading university hospital ED in Turkey and the application performed in this ED is the first attempt in order to evaluate patient flow.

3. METHODS

In this section we give an overview of CPM and PERT techniques, and their fuzzy versions.

3.1. CPM and PERT Methods

CPM and PERT are tools for planning and coordinating projects. PERT considers the probabilistic nature of completion times. CPM is used mostly for problems with deterministic activity times [2]. Both methods use the precedence information to represent a network chart of activities. A network is a chart of project activities and their precedence relationships with arrows and nodes. An activity represented by an arrow is called activity on arc (AOA). An activity represented by a node is called an activity on node (AON). The activities in the AOA show the consumption of resources and time. Nodes in the AOA represent the beginnings and completions of activities, which are called events; since events are points in time, they do not consume resources or time. However, when the events are represented by nodes in the AON, they represent resource and time consumption.

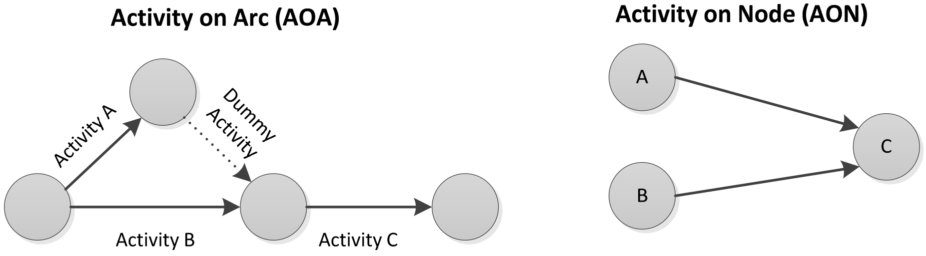

Figure 1. Network representations [2]

The critical path is the longest of the network chart which determines the total duration of the project. All activities on the critical path are considered as critical activities. By calculating the ES (the earliest time an activity can start, if all preceding activities started as early as possible), LS (the latest time the activity can start and not delay the project), EF (the earliest time the activity can finish), and LF (the latest time the activity can finish and not delay the project), the expected project duration, critical path activities, and slack time can be determined [2,4].

The EF for any activity is equal to its ES plus its expected duration t. The ES for activities at nodes with one entering arrow is equal to the EF of the entering arrow (the preceding activity). ES for activities leaving nodes with multiple entering arrows is equal to the largest EF of the entering arrow. The LS for each activity is equal to its LF minus its expected duration t. For nodes with one leaving arrow, the LF for arrows entering that node equals the LS of the leaving arrow. For nodes with multiple leaving arrows, LF for arrows entering that node equals the smallest LS of the leaving arrows. The allowable slippage of time for an activity which is also called as slack time is defined as the difference between the LS and the ES or difference between the LF and EF.

On the other hand, when activity times cannot be expressed with certainty, a probabilistic approach PERT, which takes into account three time estimates for each activity duration is applied as follows [4]: (1) Optimistic time (t_o), (2) Pessimistic time (t_p), and (3) Most likely time (t_m). The expected activity time (t_e) of each activity is computed as in (1).

$$t_e = \frac{t_o + 4t_m + t_p}{6} \tag{1}$$

The variance of each activity is calculated as in (2).

$$\sigma^2 = \left(\frac{t_p - t_o}{6} \right)^2 \tag{2}$$

The completion time for any path is computed as sum of all activity time estimates. The standard deviation of the expected time for each path is also computed, by summing the variances of the activities on a path and then taking the square root of that number. Eventually, a health care decision maker can obtain the probability that the project will be completed by a specified time, as well as the probability that it will take longer [2].

3.2. FCPM and FPERT Methods

Before explaining the steps of FCPM and FPERT, it is useful to review the fuzzy sets and numbers [13-15]. In a universe of discourse *X*, a fuzzy subset *A* of *X* is characterized by a membership function $f_A(x)$ which associates with each element *x* in *X* a real number in the interval [0, 1]. The function value of $f_A(x)$ represents the grade of membership of *x* in *A*. A fuzzy number *A* is a trapezoidal fuzzy number if its membership function $f_A(x)$ is as in (3):

$$f_A(x) = \begin{cases} (x-a)/(b-a), & a \le x \le b \\ 1, & b \le x \le c \\ (x-d)/(c-d), & c \le x \le d \\ 0, & otherwise \end{cases} \tag{3}$$

with $-\infty \le a \le b \le c \le d \le +\infty$, the trapezoidal fuzzy number *A* is represented by (a,b,c,d). Using this function, it is possible to assign a membership degree to each of the element in the universe of discourse X. It is important to note the fact that membership grades are not probabilities. A trapezoidal fuzzy number A of the universe of discourse X can be characterized by a trapezoidal membership function parameterized by a quadruple (a, b, c, d) as shown in Figure 2, where a, b, c and d are real values [14].

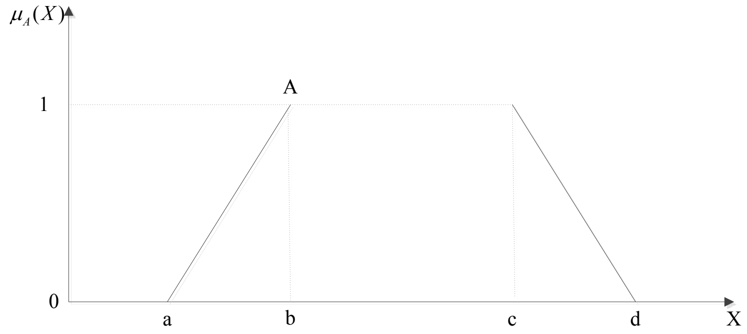

Figure 2. Membership function of trapezoidal fuzzy number A

From Figure 2, we can see that if a=b and c=d, then A is called a crisp interval; if a=b=c=d, then A is a crisp value. In Figure 2, if b=c, then A becomes a triangular fuzzy number as shown in Figure 3, and it can be parameterized by a triplet (a, b, d).

Regarding arithmetic operations of any two trapezoidal fuzzy numbers $A_1 = (a_1, b_1, c_1, d_1)$ and $A_2 = (a_2, b_2, c_2, d_2)$, addition $(\oplus)$ and subtraction (Θ) can be expressed as in (4) and (5).

$$\begin{aligned} A_1 \oplus A_2 &= (a_1, b_1, c_1, d_1) \oplus (a_2, b_2, c_2, d_2) \\ &= (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2) \end{aligned} \tag{4}$$

$$\begin{aligned} A_1 \Theta A_2 &= (a_1, b_1, c_1, d_1) \Theta (a_2, b_2, c_2, d_2) \\ &= (a_1 - d_2, b_1 - d_2, c_1 - b_2, d_1 - a_2) \end{aligned} \tag{5}$$

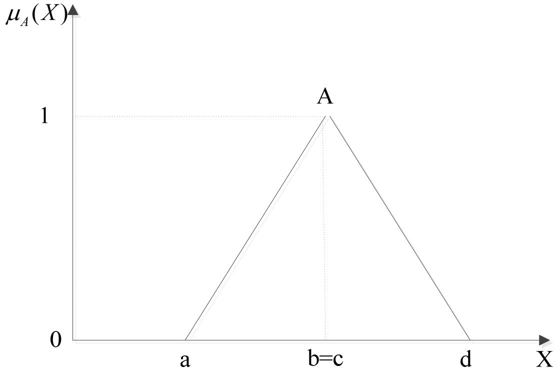

Figure 3. Membership function of triangular fuzzy number A

The notation and process steps of FCPM are given in the following [13-16,18]:

Notation:

N: All nodes in a project network,
A_{ij}: The activity between two nodes (from i to j)
FAT_{ij}: Fuzzy activity time of A_{ij}
EFT: Earliest fuzzy time
LFT: Latest fuzzy time

SFT_{ij}: Total slack fuzzy time of A_{ij}
FCPM (P_n): Fuzzy completion time of n*th* path
t: Number of activities in a project network
S(j): The set of all successor activities of node j.
NS(j): The set of all nodes connected to all successor activities of node j, i.e., $NS(j)=\left\{k \middle| A_{jk} \in S(j), k \in N\right\}$
F(j): The set of all predecessor activities of node j.
NP(j): The set of all nodes connected to all predecessor activities of node j, i.e., $NP(j)=\left\{i \middle| A_{ij} \in F(j), i \in N\right\}$

Steps of FCPM:

Step 1: Accept EFT_1 equals to (0,0,0,0).

Step 2: Calculate β that means risk factor for each A_{ij} with (6). Note that if $\beta<0.5$, it's fewer risky situation. If it is equal to 0.5, it's neutral situation. If $\beta>0.5$, it's risky situation.

$$\beta=\sum_i\sum_j\left(\frac{(b_{ij}-a_{ij})}{(b_{ij}-a_{ij})+(d_{ij}-c_{ij})}\right)/t \tag{6}$$

Step 3: Calculate *EFT* for each node with (7).

$$EFT_j = EFT_i \oplus FAT_{ij} \tag{7}$$

Step 4: Compare EFT_js where intersection nodes and accept maximum number for EFT_j for each node.

$$EFT_j = \max\left\{EFT_i \oplus FAT_{ij}\right\} \tag{8}$$

$$EFT_j = \max\left\{(a_x,b_x,c_x,d_x),(a_y,b_y,c_y,d_y)\right\}$$

Step 4.1: Find x_1 and x_2 values with these equations:

$$x_1=\min\left\{a_x,b_x,c_x,d_x,a_y,b_y,c_y,d_y\right\},\ x_2=\max\left\{a_x,b_x,c_x,d_x,a_y,b_y,c_y,d_y\right\}$$

Step 4.2: Calculate the values of $R((a_x,b_x,c_x,d_x))$ and $R((a_y,b_y,c_y,d_y))$ with these equations:

$$R((a_i,b_i,c_i,d_i))=\beta[(d_i-x_1)/(x_2-x_1-c_i+d_i)]+(1-\beta)[1-(x_2-a_i)/(x_2-x_1+b_i-a_i)]$$

Step 4.3: Compare results of $R((a_i,b_i,c_i,d_i))$ and accept as EFT_j which one is greater.

Step 5: Calculate *LFT* for each node with (9).

$$LFT_j = EFT_k \Theta FAT_{jk} \tag{9}$$

Step 6: Compare LFT_js where intersection nodes and accept minimum number as LFT_j for each node.

$$LFT_j = \min\left\{EFT_k \Theta FAT_{jk}\right\} \tag{10}$$

$$LFT_j = \min\left\{(a_x,b_x,c_x,d_x),(a_y,b_y,c_y,d_y)\right\}$$

The sub steps of *Step 6* are the same with *Step 4*.

Step 7: Calculate *SFT* for each activity as in (11).

$$SFT_{ij} = LFT_j \Theta (EFT_i \oplus FAT_{ij}) \tag{11}$$

Step 8: Find all possible paths and calculate *FCPM* for each one. *FCPM* can be calculated with sum of activities between possible path nodes as in (12).

$$FCPM(P_n) = \sum SFT_{ij} \tag{12}$$

Step 9: Compare *FCPM*s and accept minimum number as *FCPM* just like *Step 6* calculation.

$$FCPM(P_n) = \min\left\{FCPM(P_i) \middle| i = 1,2,3,...,n\right\} \tag{13}$$

Step 10: Which *FCPM* of path is fewer, accept the path as critical path.

Regarding the FPERT calculations, it is required to find a generalized mean value and deviation for the trapezoidal fuzzy numbers. The calculations are given in (14) and (15).

$$G(a_1,b_1,c_1,d_1) = \frac{a_1+b_1+c_1+d_1}{4} \tag{14}$$

$$S(a_1,b_1,c_1,d_1) = \frac{[3(a_1^2+b_1^2+c_1^2+d_1^2)-2(a_1b_1+a_1c_1+a_1d_1+b_1c_1+b_1d_1+c_1d_1)]}{36} \tag{15}$$

Probabilistic estimates in network charts are based on the assumption that the duration time of a path is normally distributed around the expected path time. That brings that activity times are being summed and that sums of random variables tend to be normally distributed when the number of project activities is large, as is frequently the case with PERT projects. To find probability of the project completed time, central limit theorem is used. It is accepted to approximate normal distribution. Normal distribution has two variables which are mean and standard deviation. After the probability calculation results, health care decision makers can obtain the probability that the project will be completed by a specified time, as well as the probability that it will take longer using (16).

$$Z = \frac{X-\mu}{\sigma} \tag{16}$$

4. APPLICATION CASE

The application is performed in a university hospital ED. A sample of 1500 patients' data is used. The data is gathered through the hospital information management system and direct observation method. The patient flow of the ED is as follows: The patient arrives at the ED by ambulance or a private vehicle and is registered before being examined by a doctor. If patient arrives by ambulance, he/she passes recording operation, so proceeds to the doctor. After the examination of doctor, patient is transferred to an available unit depending on patient's severity. A sample is taken from the patient regarding performing lab tests if needed. At the same time, the patient is under control by a nurse and the doctor. The patient can exit with three different ways depending on the results of patient's lab tests and doctor's recommendation as follows: (1) leaving from hospital, (2) being transferred to another hospital, and (3) being shifted to an appropriate department.

The activities of the ED patient flow are identified as shown in Table 1. The fuzzy activity times of the project and the project network chart are shown in Table 2 and Figure 4, respectively. In this paper, the fuzzy activity time is represented by trapezoidal fuzzy numbers [16], where a_{ij}, d_{ij} are minimum and maximum values of assessing activity time for A_{ij}, whereas b_{ij} and c_{ij} are the first quartile and third quartile of activity time for A_{ij}. If there is only one set of four historical data, then a_{ij},b_{ij},c_{ij} and d_{ij} can be sorted from minimum to maximum. Conversely, if one has no further information with respect to activity A_{ij}, the fuzzy activity time $FAT_{ij}=(a_{ij},b_{ij},c_{ij},d_{ij})$ can be evaluated subjectively by the ED decision maker based on his/her experience and subjective judgment.

Table 1. Activities of the ED

Symbol	*Activity*
A	Shifting of the patient from ambulance to the ED
B	Shifting of the patient from private vehicle to the ED
C	Recording of the patient
D	Examining of the patient by doctor
E	Sending of the patient to available area of the ED
F	Checking of the patient by doctor and nurse
G	Performing lab tests
H	Shifting of the patient to appropriate department of the hospital depends on patient's severity
I	Registration
J	Shifting of the patient to ambulance for transferring another hospital
K	Billing

Table 2. FATs for each activity of the ED

Activity	Predecessor	FATs (in minutes)			
A	-	0.5	1.2	1.5	4
B	-	1	1.8	2.1	4
C	B	0.7	1	1	2.5
D	A,C	2.5	5	7	9
E	D	0.4	0.5	0.8	1.4
F	E	8	15	28	134
G	E	1	10	10	125
H	G,F	5	6	8	9
I	G,F	5	8	8	14
J	I	1	2.1	2.5	5
K	I	5	6	6	8

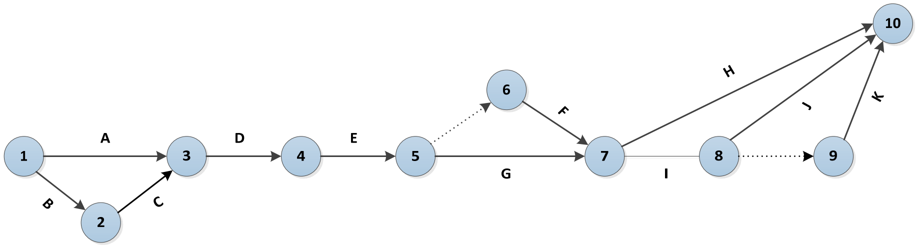

Figure 4. Project network chart of the ED

By using the equations in the related section above, EFT and LFT values of each node are determined as shown in Table III.

Table 3. EFTs and LFTs of each node

Node	EFT values				LFT values			
1	0	0	0	0	-150.3	-15.6	15.6	150.3
2	1	1.8	2.1	4	-146.3	-13.5	17.4	151.3
3	1.7	2.8	3.1	6.5	-143.8	-12.5	18.4	152
4	4.2	7.8	10.1	15.5	-134.8	-5.5	23.4	154.5
5	4.6	8.3	10.9	16.9	-133.4	-4.7	23.9	154.9
6	4.6	8.3	10.9	16.9	-133.4	-4.7	23.9	154.9
7	12.6	23.3	38.9	150.9	0.6	23.3	38.9	162.9
8	17.6	31.3	46.9	164.9	14.6	31.3	46.9	167.9
9	17.6	31.3	46.9	164.9	14.6	31.3	46.9	167.9
10	22.6	37.3	52.9	172.9	22.6	37.3	52.9	172.9

Then total SFTs are calculated for each activity with (7). All possible paths are found and *FCPM*s for each one are calculated with (8). They are compared and *FCPM* (P_i) is obtained. *FCPM* and *R(FCPM* (P_i)*)* values of each possible path are shown in Table IV.

Table 4. FCPM and R(FCPM (P_i)) values of each possible path

#	Possible paths	FCPM (P_i)				R
1	(1–3–4–5–6–7–8–10)	-1046.6	-104.1	114.7	1057.3	0.4288
2	(1–3–4–5–6–7–10)	-886.3	-86	103.2	908	0.4382
3	(1–3–4–5–6–7–8–9–10)	-1202.9	-123.2	126.4	1206.6	0.4203
4	(1–3–4–5–7–10)	-727	-52.4	92.6	764.7	0.4506
5	(1–3–4–5–7–8–10)	-887.3	-70.5	104.1	914	0.4404
6	(1–3–4–5–7–8–9–10)	-1043.6	-89.6	115.8	1063.3	0.4311
7	(1–2–3–4–5–6–7–8–10)	-1199.4	-121.3	128.7	1206.4	0.4209
8	(1–2–3–4–5–6–7–10)	-1039.1	-103.2	117.2	1057.1	0.4296
9	(1–2–3–4–5–6–7–8–9–10)	-1355.7	-140.4	140.4	1355.7	0.413
10	(1–2–3–4–5–7–10)	-879.8	-69.6	106.6	913.8	0.4412
11	(1–2–3–4–5–7–8–10)	-1040.1	-87.7	118.1	1063.1	0.4317
12	(1–2–3–4–5–7–8–9–10)	-1196.4	-106.8	129.8	1212.4	0.4232

As a result, *R(FCPM*(P_9)*)* has minimum value among all possible paths' *FCPM*s. So, the critical path is 1–2–3–4–5–6–7–8–9–10 in this case. Length of treatment period is approximately between 37.3 and 52.9 minutes i.e. (22.6, 37.3, 52.9, 172.9).

The activities on the critical path are: B (shifting of the patient from private vehicle to the ED), C (recording of the patient), D (examining of the patient by doctor), E (sending of the patient to available area of the ED), F (checking of the patient by doctor and nurse), I (registration) and K (billing). As critical activities do not permit any flexibility in scheduling, any delay in any of the critical activities B, C, D, E, F, I or K, will delay the whole emergency patient flow process.

Regarding FPERT, a generalized mean value and deviation are calculated with (14) and (15). Standard deviation and mean values of the project which is computed according to the total σ

and μ values of the activities on the critical path are determined as $\sigma = 34.24,\ \mu = 71.425$. Using (16) some probability calculation results are determined as given in Table V.

Table 5. Probabilities of the project completed time

X	<80	<100	<120	<140	<160
Z value	-0.814	-0.4	0.013	0.426	0.84
Probability	0.209	0.345	0.504	0.663	0.8
X	<180	<200	<220	<240	<280
Z value	1.253	1.666	2.08	2.493	3.319
Probability	0.894	0.953	0.981	0.994	1

5. CONCLUSION

The need to consider economic policies has become inevitable in healthcare sector. In order to reduce the unnecessary waiting, eliminate unnecessary activities and identify alternative process flows in EDs which are considered as heart of hospitals, operations research methods like CPM and PERT play a critical mission. Since deterministic approaches can't afford to complex projects, fuzzy versions of CPM and PERT are applied in this study. A case study is carried out in a university hospital ED to understand the patient flow of the department. Activities affecting patient flow through the ED are identified and project network is drawn. 1500 patients' data about the times of each activities are used in the analysis. Findings through application case, the expected time for completion of the project, the critical path and slack times are determined.

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