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# Technical note:

# The improvement of the performance of the emergency department: Application of simulation model and multiple criteria decision method

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**Abstract:** Emergency department has become a useful way to the access to hospital and it is a subject of study for many researchers. The research developed in this paper aims to improve the performance of the emergency department(ED) of Sfax Hospital. Simulation results showed that to manage to increase the number of treated patients and thus to decrease the patient cycle time, it is important to add a specialist physician or a formed general physician. To choose what physician the managers do add, the researchers used the fuzzy PROMETHEE method.

**Keywords:** *Emergency department; Fuzzy; Multi-criteria decision*; *Performance; PROMETHEE*

## 1. Introduction

The word "hospital" comes from the Latin "hospes" which refers to either a visitor or the host who receives the visitor. From "hospes" came the Latin "hospitalia", an apartment for strangers or guests, and the Medieval Latin "hospitale" and the Old French "hospital."

Emergency Department is one of the most section in the hospitals. The Centre for Disease Control defines an “emergency department” as a hospital facility for the provision of unscheduled outpatient services to patients whose conditions require immediate care and is staffed 24 hours a day. Emergency departments become a useful way to access to hospital. The World Health Organisation (WHO) has defined provision of basic life support to all risks situations involving people and goods as main objective of an Emergency Medical Services. Emergency Departments is the place to welcome all patients that present themselves to the hospitals for consultation or hospitalisation and whose stay has not been programmed in charge (Bellou *et al*., 2003). Hos-pital emergency departments (ED) provide the first line of response to life-threatening injuries and illnesses. ED is the first place in the health care delivery system where a person cannot be denied services regardless of insurance coverage or ability to pay. ED also serves as the provider of the last resort for the people who cannot access care elsewhere. “WHO” defines the hospital performance as follows: "that is the best possible result obtained using the same resources". During the last decades, simulation has become a very popular method of analyzing and designing real world systems. Simulation allows an analyst to create a virtual environment of a real or proposed system in order to examine its reactions to various conditions (Carley, 2005). Simulations are favoured over analytical solutions when studying complex, dynamic systems such as an ED. One of the most useful tools to analyze the complexities of an ED environment is simulation.

The ED of hospital is a complex unit where the fight between life and death is always a hair’s breath away, requiring a high degree of coordination and interrelations between human and material elements (Jinn-Yi and Wen-Shan, 2007).

The paper is organized as follows. We start with describing the literature review. In Section 3, the stimulation phase is presented; and in Section 4, we describe simulation model. In Section 5 the PROMETHEE and the fuzzy PROMETHEE method are presented. In Section 6, we illustrate the proposed approach. Finally the last section presents concluding remarks and perspectives for future research.

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## 2. Literature review

The idea of simulation in health service departments is by no means new. Several studies were made by simulation in hospitals in general and Emergency Departments in particular.

In Draeger article (1992), simulation models of Bethesda hospital's three ED were developed, based on the existing processes and empirical data. Model output included patient statistics such as wait and treatment time, staff, and facility utilizations. The graphic animations of the models provided visual, dynamic displays of the activity system. Hospital management used the models to evaluate performance process, and previewed the effects of the nurse staffing and patient flow.

Rossetti *et al.* (1999) discussed the use of computer simulation to test alternative ED attending physician staffing schedules and to analyze the corresponding impacts on patient throughput and resource utilization.

The simulation model can also be used to help identify the process inefficiencies and to evaluate the effects of staffing, layout, resource, and patient flow changes on performance system without disturbing the actual system.

The development of the model was based on the Emergency Department at the University of Virginia Medical Centre in Charlottesville, Virginia.

Jurishica (2005) analyzed each step of a typical ED simulation project, identifying key areas of focus and tips for success. Defining the objective, process map, scenarios, outputs and animation requirements were the first steps. A system for gathering the ED data was discussed, as well as advice for the verification and validation phases. Finally, the findings were analyzed and presented. Jinn's and Wen-Shan's report (2007), showed how the quality of service at a hospital emergency department (ED) can be improved by utilizing simulation and a genetic algorithm (GA) to appropriately adjust the nurses' schedules without hiring additional staff. The simulation model was developed to cover the complete flow of the patient through the ED.

## 3. Phases of simulation

Defining a sound simulation project objective is the first step of the study. Many ED simulation projects have the following common objectives:

- Identify and provide strategy for eliminating the bottlenecks,
- Identify throughput gains from efficient and optimized patient flow,
- Provide the ability to understand the true throughput capacity and the impacts of change on throughput without the investment of additional capital or physical change,
- Analyse nurse, physician and bed utilizations,
- Determine the optimal resource schedule,
- Reduce the patient length of stay (LOS) in the ED,
- Identify strategies for capitalizing on future patient growth (Ferrin *et al.*, 2004).

According to Arvind (2000), Simulation project can be broken down into four major phases:

1. Project Definition
2. Model Building and Testing
3. Experimentation
4. Project Completion

These four major phases can be further broken down into some more stages as shown in Figure 1.

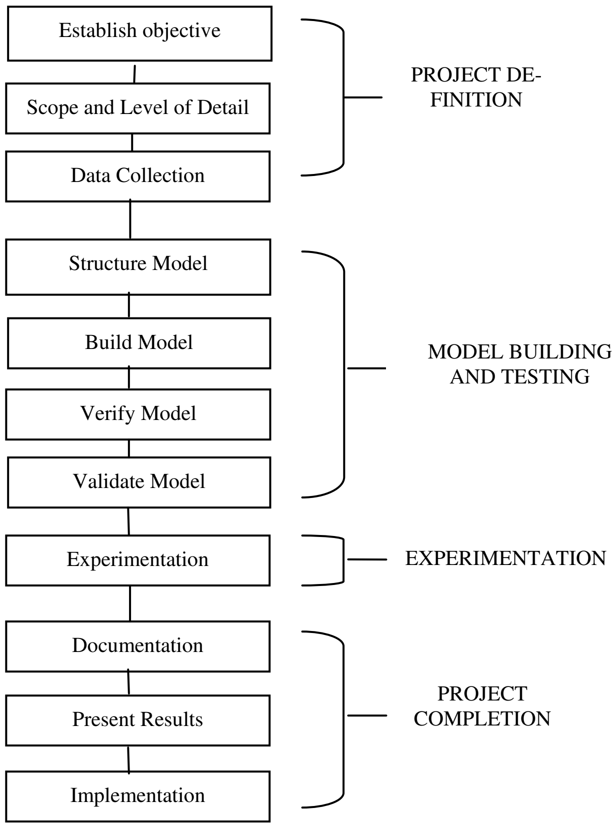


Figure 1: Flowchart showing the basic simulation project methodology.

## 4. Use of the model

### 4.1. Context of the study

Habib Bourguiba hospital is presented as follows:

- Academic Hospital centre since 1985,
- Erected in public establishment of health since 1993.

The missions of the hospital are:

- To lavish current pathology cares and essentially cares of reference,
- To assure the convenient formation of basis and retrain the medical and decorate-medical personnel,
- To develop the activity of research in the medical domain and cares male nurses.

The hospital includes 18 departments; the most important one is the Emergency Department that represents the entrance door of the hospital.

The geographical situation of Sfax City in the centre of the country, point of link between the south and the north of the country makes that the Emergency Department receive an important number of casualties of the public way. As second economic and industrial pole sheltering a lot of companies, the city knows a rather elevated number of work casualties. The department includes:

- 2 rooms of care,
- 1 room of plaster,
- 2 post offices,
- 1 room of general surgery,
- 1 room of orthopedy,
- 1 room for medical visits,
- The average number of patients per day is ± 300,
- The number of personnel is 13.

### 4.2. Witness implementation

This paper describes the simulation model of patient flow in ED Sfax hospital. In the first and the second phases of the simulation model used in the last work (Jlassi *et al*., 2006), the researchers proposed to construct a table summarising the time slots occupied by every patient in the different steps by which he passes. Thereafter, we drew the IDEF3x diagram to identify the process of the patient in the ED. IDEF3X is an extension of the IDEF3 process description capture method. The name IDEF originates from the Air Force program for Integrated Computer- Aided Manufacturing (IC-AM) from which the first ICAM Definition, or IDEF, methods emerged.

IDEF3 was created specifically to capture descriptions of sequences of activities. It can be distinguished from other process modelling methods because it facilitates the capture of the description of what a system actually does.

IDEF3X is a modelling method which combines the ICOM (input, control, output, mechanism) aspect of IDEF0 with the process flow description of IDEF3. The syntactic elements of an IDEF3X model are similar to IDEF3 and include units of behaviour (UOBs), junction boxes, and precedence links. Also, in the other phases, we will transfer the IDEF3x model to the witness model. This choice can be explained by two reasons: first, the WITNESS simulation software provides many advanced tools that facilitate flexible modelling, easy sharing of the simulation efforts, and effective utilization of the work already done in the past (Arvind, 2000). Second, it's the only model provided in the laboratories. In the Witness model the steps are presented as machines and the patient as a piece circulating in the process following predefined way. The stocks represent waiting patients before in a given step. To describe reality in the WITNESS model, the researchers defined the percentage of the patient orientation in the following step from our data in the table.

- Between "Analyses, Radiology and exit of the patient".
- Between the second visit of physician, the patient is examined and the specialist physician"

As far as times associated to each step are concerned two implementations were proposed:

- Static implementation: noted "ST": the period of each step is represented as the average effectuated on the all times associated to patient,
- Dynamic implementation: noted "DY": In this second implementation the duration of each step follows a probable distribution which modelises the waiting and treatment duration of 100 patients.

In this study the second implementation is chosen since it reflects the reality more than the first one.

### 4.3. Use of the model

In this step the researchers use the two precedent WITNESS implementations in two different durations.

To evaluate the performance of our process the following indicators are used:

- Number of coming patient,
- Number of a patient being treated,
- Number of patient treated in the service,
- Number of patient treated in each step,
- The percentage of occupation and disponibility at the level at each step.

In this study the researchers continued to use DY model as it reflects the reality of the patient passage in ED

### 4.4. The process performance evaluation in case of the variation parameters

We will evaluate the performance of the process in case of change in some parameters such as: the number of physicians, number of analysts, the addition of the number of radiology rooms, the number of specialist physicians.

Based on a research and interviews affected with the department staff, the researchers conclude that the principal objective of the ED responsibles is to increase the number of the treated patients, so the time given for the passage of each patient will automatically be reduced.

In Tables 1 to 3, the different results of the variations of several parameters are shown. We may conclude an increase in the number of the treated patient in the department.

This fact appears logical since a second specialist will take in charge of more patients.

Table 4 shows the results of simulation in the case of the addition of a general physician in the first step of patient passage.

We may conclude that the addition of a physician in the first step of a patient passage doesn't a positive result on the process performance. Since the treated patients' number remains unchanged. In contrast, the significant increase of the physicians disponibility in the first step, allows us to propose an intervention at the level of the second passage.

Table 5 shows the results of simulation in the case of the addition of a general physician in the second step of the patient passage. We may conclude a significant increase of the treated patients. This fact reduces the time given to patient passage and improves the disponibility of the physicians in the second passage. Consequently, the number of waiting patients for specialist physicians increases. So the intervention of the experienced physicians during the period of disponibility to treat other patients who need a passage to specialist in a way to reduce the number of waiting patients. Figure 2 shows the simulation results in case of addition of specialist physicians. We may conclude an increase in the number of the treated patient in the department. Figure 3 shows the results of simulation in the case of the addition of a generalist physician in the second step of the patient passage. We may conclude a significant increase of the treated patients. The simulation results showed that to manage to increase the number of treated patients and thus to decrease the cycle time of patient, it is important to add a specialist physician or a formed general physician who has some experience to be able to act in the case of availability on the place of a specialist. To choose what physician to add us is necessary use in the section follow a multi-criteria decision method.

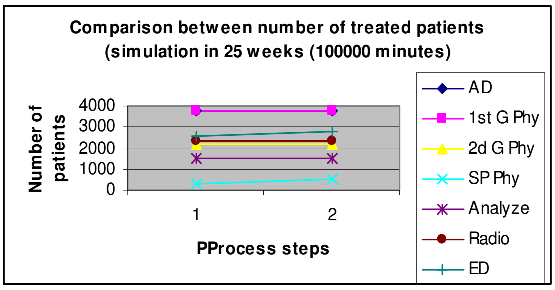


Figure 2: Comparison between the number of treated patients (simulation in 25 weeks, 100000 minutes).

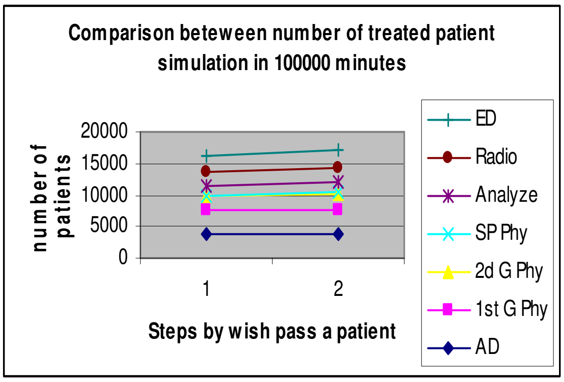


Figure 3: Comparison between the number of treated patients (simulation in 100000 minutes).

Table1: Simulation in 10000 minutes.

| | Patient | | Administrative Procedure | | General Physician | | General physician | | Specialist | | Analyse | | Radiology | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** |
| No. of coming patient | 385 | 384 | | | | | | | | | | | | |
| No. of treated patient | 183 | 247 | 384 | 383 | 383 | 378 | 217 | 223 | 26 | 19 | 147 | 147 | 255 | 239 |
| Being treated | 202 | 137 | | | | | | | | | | | | |
| % Occupation step | | | 100 | 100 | 98.25 | 95.10 | 99.25 | 98.65 | 97.42 | 98.65 | 80.32 | 80.61 | 19.91 | 18.47 |
| % Disponibility step | | | 0 | 0 | 1.71 | 4.90 | 0.75 | 1.35 | 2.52 | 1.35 | 19.67 | 19.38 | 80.08 | 81.55 |

Table2: Simulation in 100000 minutes.

| | Patient | | Administrative Procedure | | General Physician | | General Physician 2eme Passage | | Specialist | | Analyse | | Radiology | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** | **ST** | **DY** |
| No. of coming patients | 3847 | 3746 | | | | | | | | | | | | |
| No. of treated patients | 2409 | 2542 | 3846 | 3745 | 3845 | 3744 | 2187 | 2198 | 269 | 268 | 1531 | 1520 | 2505 | 2307 |
| Being treated | 1438 | 1204 | | | | | | | | | | | | |
| % Occupation | | | 100 | 100 | 98.47 | 96.19 | 99.89 | 99.84 | 99.70 | 99.86 | 82.81 | 82.02 | 19.74 | 18 |
| % Disponibility | | | 0 | 0 | 1.53 | 3.81 | 0.11 | 0.16 | 0.30 | 0.14 | 17.18 | 17.97 | 80.25 | 82 |

This table shows the simulation results in case of addition of specialist physicians.

Table3: Addition of a specialist physician.

| | | Patient | Administrative Procedure | General Physician | General Physician | Specialist | Analyse | Radiology |
|---|---|---|---|---|---|---|---|---|
| No. of coming patients | 1 sem | 384 | | | | | | |
| | 25 sem | 3746 | | | | | | |
| No. of treated patients | 1 sem | 262 | 383 | 378 | 223 | 35 | 148 | 236 |
| | 25 sem | 2821 | 3745 | 3744 | 2198 | 547 | 1520 | 2307 |
| Being treated | 1 sem | 122 | | | | | | |
| | 25 sem | 925 | | | | | | |
| % Occupation | 1 sem | | 100 | 95.10 | 98.40 | 97.45 | 81.21 | 18.32 |
| | 25 sem | | 0 | 96.16 | 99.84 | 99.74 | 82.02 | 18 |
| % Disponibility | 1 sem | | 100 | 4.90 | 1.60 | 2.55 | 18.79 | 81.68 |
| | 25 sem | | 0 | 43.81 | 0.16 | 0.26 | 17.98 | 82 |

Table 4: Addition of a general physician.

| | | Patient | Administrative Procedure | General Physician | General Physician | Specialist | Analyse | Radiology |
|---|---|---|---|---|---|---|---|---|
| Nbre coming patients | 1 sem | 384 | | | | | | |
| | 25 sem | 3746 | | | | | | |
| Nbre treated patients | 1 sem | 256 | 383 | 381 | 223 | 19 | 144 | 232 |
| | 25 sem | 2567 | 3745 | 3744 | 2198 | 268 | 1522 | 2278 |
| Being treated | 1 sem | 128 | | | | | | |
| | 25 sem | 1179 | | | | | | |
| % Occupation | 1 sem | | 100 | 48.47 | 98.15 | 98.65 | 78.53 | 17.72 |
| | 25 sem | | 0 | 48.28 | 99.81 | 99.86 | 82.14 | 17.77 |
| % Disponibility | 1 sem | | 100 | 51.52 | 1.85 | 35 | 21.47 | 82.28 |
| | 25 sem | | 0 | 51.72 | 0.19 | 0.14 | 17.86 | 82.23 |

Table5: Addition of a general physician (the second step).

| | | Patient | Administrative procedure | Generalist physicain | Generalist physician | Spécialist | Analyse | Radiology |
|---|---|---|---|---|---|---|---|---|
| No. of coming patient | 1 sem | 384 | | | | | | |
| | 25 sem | 3747 | | | | | | |
| No. of treated patient | 1 sem | 271 | 384 | 378 | 269 | 19 | 148 | 236 |
| | 25 sem | 2830 | 3745 | 3744 | 2641 | 268 | 1520 | 2307 |
| Being treated | 1 sem | 113 | | | | | | |
| | 25 sem | 916 | | | | | | |
| % Occupation | 1 sem | | 100 | 95.10 | 65.1 | 98.65 | 81.22 | 18.32 |
| | 25 sem | | 100 | 96.19 | 70.15 | 99.86 | 82.02 | 18 |
| % Disponibility | 1 sem | | 0 | 4.90 | 34.9 | 1.35 | 18.78 | 81.68 |
| | 25 sem | | 0 | 3.81 | 39.85 | 0.14 | 17.98 | 820 |

## 5. Multiple criteria decision

Multiple criteria decision making (MCDM) was introduced as a promising and important field of study in the early 1970s. Since then the number of contributions to theories and models, which could be used as a basis for more systematic and rational decision making with multiple criteria, has continued to grow at a steady rate. A number of surveys, e.g. Bana e Costa (1990), show the vita-lity of the field and the multitude of methods which have been developed.

There are many variations on the theme MCDM depending upon the theoretical basis used for the modelling. Zeleny (1982) shows that multiple criteria include both multiple attributes and multiple objectives, and there are two major theoretical approaches built around multiple attribute utility theory (MAUT) and multiple objective linear programming (MOLP), which have served as the basis for a number of theoretical variations.

Bana e Costa and Vincke (1990) argue that with MCDM the first contributions to a truly scientific approach to decision making were made, but find fault with the objectives to carry this all the way as we have to deal with human decision makers who can never reach the degree of consistency needed. They introduce multiple criteria decision aid MCDA as a remedy; this approach can be given the aim "to enhance the degree of conformity and coherence" in the decision processes carried out among (predominantly groups of) decision makers - this is done with a cross-adaptation of the value systems and the objectives of those involved in the process. Even if there are some distinctions between MCDM and MCDA the overall objective is the same: to help decision makers solve complex decision problems in a systematic, consistent and more productive way. There are four major families of methods in MCDM:

- The outranking approach based on the pioneering work by Bernard Roy, and implemented in the Electre and Promethee methods,
- The value and utility theory approaches mainly started by Keeney and Raiffa, and then implemented in a number of methods; a special method in this family is the Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty and then implemented in the Expert Choice software package,
- The largest group is the interactive multiple objective programming approach with pioneering work done by P.L. Yu, Stanley Zionts, Milan Zeleny, Ralph Steuer and a number of others; the MOLP family has been built around utility theory-based trade offs among objectives, with reference point techniques, ideal points, etc. Several methodologies exist for multi-criteria decision aiding (Roy, 1981; Zeleny, 1982).

There are no better or worse techniques, but techniques better suited to particular decision problems than others (Bopoulos *et al.*, 2003).

It is essential to develop in detail all elements related to the situation of MCDA before carrying out the selection of an appropriate MCDA method in order to solve the problem under investigation (Bafardi, 2004). The choice of a certain MCDA method cannot be made at the beginning of the process. This decision should wait until the analyst and the DMs understand the problem, the feasible alternatives, different outcomes, conflicts between the criteria and the level of the data uncertainty (Sulminen *et al.*, 1998).

Perspectives PROMETHEE method belongs to the wider family of the outranking methods. In present work, the most important underlying concepts are presented, while more details are provided by Brans *et al*. (1985).

Moreover in some of the ELECTRE methods the notion of "degree of credibility" is rather difficult for practitioners. In order to avoid these difficulties the researchers propose in this paper a modified approach which is very simple and easily understood by the decision-maker.

It is based on extensions of the notion of criterion. These extended criteria can easily be built by the decision-maker because they represent the natural notion of intensity of preference, and the parameters to be fixed (maximum 2) have a real economic meaning.

A valued outranking graph is then considered by using a preference index. Two possibilities are offered to solve the ranking problem. PROMETHEE I provide a partial preorder and PROMETHEE II a total preorder on the set of possible actions (Brans, 1982).

### 5.1 PROMETHEE method

#### 5.1.1. Principles

The PROMETHEE method (Preference Ranking Organization METhod for Enrichment Evaluation) is a multi-criteria decision-making method developed by Brans *et al.* (1985). It is a quite simple ranking method in conception and application compared with other methods for multi-criteria analysis. It is well adapted to problems where a finite number of alternatives are to be ranked considering several, sometimes conflicting criteria. The evaluation table is the starting point of this method. In this table, the alternatives are evaluated on the different criteria. The implementation of PROMETHEE requires two additional types of information, namely:

- Information on the relative importance (i.e. the weights) of the criteria considered.
- Information on the decision-maker's preference function, which she/he uses when comparing the contribution of the alternatives in terms of each separate criterion.

#### 5.1.2. The weights

The weights can be determined according to various methods (see Nijkamp *et al*.,1990; Eckenrode, 1965) for an overview of these methods). PROMETHEE does not provide specific guidelines for determining these weights, but assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large.

#### 5.1.3. The preference function

The preference function ($P_j$) translates the difference between the evaluations (i.e., scores ) obtained by two alternatives (a and b) in terms of a particular criterion, into a preference degree ranging from 0 to 1 (Figure 4).

The PROMETHEE approach is based on an extension of the criterion notion through the introduction of a function $\theta$, expressing the decision maker's preference for an alternative in relation to another. For a criterion $j$ to be maximized and two alternatives, a and b, the evaluation of the alternative a according to the criterion $j$ can be defined as $C_j(a)$, and the difference of the evaluations as $d_j$ (Pomerol *et al.*, 1980). In other words,

$$d_j = C_j(a) - C_j(b) \quad (1)$$

The evaluation function $\theta$ will vary in the interval [0, 1]. Also, two threshold values, $q$ as the indifference threshold and $p$ as the strict preference one, can be introduced. Thus, $\theta$ can be presented as follows:

$$\theta_j(a,b) = \theta_j(d_j) = \left\{ \begin{matrix} 0 & if\ d_j < q \\ 1 & if\ q \le d_j \le p \\ H_j(d_j) & if\ d_j > p \end{matrix} \right\} \quad (2)$$

where $H_j$ can be one of the six proposed functions. These functions and their detailed definitions can be found. Once the type of $H_j$ criterion function to be used for each criterion is defined, the preference index C(a,b) can be calculated as follows:

$$C(a,b) = \sum_j w_j \theta(a,b)_j \quad (3)$$

where $w_j$ represents the weight of criterion $j$. For a proper application of the PROMETHEE method, weights must be strictly positive and normalized.

The next step is to calculate the flows for an alternative a. There are two types of flows. The leaving flow at a indicates a preference of the alternative a overall other actions. It shows how "good" the alternative a is. The leaving flow is calculated as follows:

$$\varphi^{+}(a) = \sum_{x \in A} C(a,b) \tag{4}$$

The entering flow at a, on the other hand, indicates a preference of all other alternatives, compared to a. It shows how "weak" the alternative a is. The entering flow is calculated as follows:

$$\varphi^{-}(a) = \sum_{x \in A} C(x,a) \tag{5}$$

According to the PROMETHEE I, action a is superior to action b if the leaving flow of a is greater than that of b and the entering flow of a is smaller than that of b. Using our notation, a outranks b if $\varphi^{+}(a) \geq \varphi^{+}(b)$ and $\varphi^{-}(a) \leq \varphi^{-}(b)$. a and b cannot be compared when $\varphi^{+}(a) \geq \varphi^{+}(b)$ and $\varphi^{-}(a) \geq \varphi^{-}(b)$ or $\varphi^{+}(a) \leq \varphi^{+}(b)$ and $\varphi^{-}(a) \leq \varphi^{-}(b)$. To overcome the issue of incomparability and to obtain a complete ranking, the PROMETHEE II method can be applied. The PROMETHEE II takes into consideration the net flows, $\varphi$ the difference of leaving minus entering flows. The alternative with a higher net flow is better than the ones with lower net flows.

Fuzzy numbers and fuzzy set theory provide a strictly mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied (Zimmermann, 1996).

### 5.2. Fuzzy PROMETHEE

Because of the underlying structure for multi-criteria decision problems, the consideration of fuzzy logic within MCDM seems to be almost self-evident. Several surveys compile the fuzzy approaches to MCDM, (Carlson *et al.*, 1996). Most of the outranking methods are per se based on a fuzzy notion through the concepts of `weak preference' and `incomparability' (Chen *et al.*, 1992). For this reason, Ribeiro (1996) might have excluded the outranking approaches from her review on Fuzzy MADM. This kind of fuzziness refers mainly to the objective function and is applied to the comparison of the actions with respect to each criterion. Literature research reveals that several attempts for the integration of fuzzy logic into multi-attribute decision support are also being discussed for the evaluation of fuzzy information. These approaches show that fuzzy logic can be integrated into outranking approaches. However, this particular modelling of imprecision has to be adjusted to the specific decision situation (Zimmermann, 1987).

The fuzzy PROMETHEE method is a combination of the PROMETHEE method and fuzzy numbers. Integration of fuzzy set theory and the

PROMETHEE method was first proposed by Le Téno and Mareschal (1989).

This suggestion was further developed by Geldermann *et al.* (2000) and Goumas and Lygerou (2000). Geldermann *et al.*, (2000) proposed the application of triangular fuzzy numbers for the interpretation of linguistic variables, and Goumas and Lygerou (2000) developed an easy-to-use methodology to apply the fuzzy PROMETHEE to ranking problems.

In this work, the researchers adopt the fuzzy PROMETHEE method as it is described by Goumas and Lygerou (2000). In this case, calculations for evaluation of alternatives, described in the preceding section, will be executed using fuzzy numbers, whereas preferences of the decision maker, that is, the weights, will remain as crisp numbers. Setting alternative evaluations as fuzzy numbers will help to translate qualitative information and vagueness in the decision maker's opinions to a solid mathematical expression.

Preference threshold values $q$ and $p$ will be crisp numbers. If they were taken fuzzy, evaluation might be unclear due to the stretched form of a fuzzy number (Goumas and Lygerou, 2000). Also, criteria weights are not fuzzy; because PROMETHEE requires that the weights sum up to 1, they cannot be specified independently and cannot be specified as fuzzy (Goumas and Lygerou, 2000).

The PROMETHEE method interprets a difference of the evaluations, expressed as $d_j$ , using evaluation functions called $H_j$.

In this case, for certain criteria, we choose a linear preference function with indifference and strict preference threshold values $q$ and $p$, respectively. Thus, the evaluation function $\theta$ , presented in general form in Equation 3, will become:

$$\theta_j(a,b) = \theta_j(d_j) = \left\{ \begin{array}{ll} 0 & if\ d_j < q \\ \dfrac{d_j - q}{p - q} & if\ q \leq d_j \leq p \\ 1 & if\ d_j > p \end{array} \right\} \tag{6}$$

When using the fuzzy PROMETHEE, $d_j$ will be introduced as a fuzzy number (n, c, d) and Equation 7 will be as follows:

$$\theta_j(a,b)=\theta_j(d_j)=\begin{cases}0 & if\ (n-c)<q\\ \dfrac{(n,c,d)-q}{p-q} & if\ q\leq(n-c)\\ & and(n+d)\leq p\\ 1 & if\ (n+d)>p\end{cases} \quad (7)$$

To execute the calculations in Equation 8, one will need basic knowledge of operations with fuzzy numbers. Formulas for basic operations with fuzzy numbers are outlined in Table 6.

At the end of the calculations, fuzzy numbers will be obtained. To derive a solution, these numbers must be ranked, which means that fuzzy numbers have to be compared.

Goumas and Lygerou suggested the use of the index proposed by Yager to overcome this comparison problem. This method corresponds to calculating the weighted average of a given fuzzy number. For instance, the Yager index of the triangular fuzzy number x = (2, 0.5, 0.5) presented in Figure 5 would be the center of the triangle and can be calculated as F(m, a, b) = (3m-a+b)/3 and F (2, 0.5,0.5) = 2. The fuzzy number with the larger Yager index value will be considered bigger than the ones having smaller Yager index values.

## 6. An illustrative application

Assessments were given using linguistic quantifier's. For the number of exploration criteria and for a sample of 100 patients we take the scale following:

(1) Very Weak (15, 15, 0)

(2) Weak (20, 5, 10)

(3) Middle enough (30, 10, 10)

(4) Middle (40, 10, 10)

(5) Elevated enough (50, 10, 10)

(6) Elevated (60, 10, 20)

(7) Very elevated (80, 20, 40)

And the indifference threshold $q$ was considered: $q = 0$, $p = 60$.

For the second criteria, for a sample of 100 patients we take the following scale:

(1) Very Weak (0, 0, 5)

(2) Weak (5, 5, 5)

(3) Middle enough (10, 10, 5)

(4) Middle (15, 5, 10)

(5) Elevated enough (25, 10, 5)

(6) Elevated (30, 5, 5)

(7) Very Elevated (35, 5, 10)

And the indifference threshold $q$ was considered: $q = 0$, $p$ =30. For the criteria cost: is a quasi criteria $q = 200$.

The fuzzy PROMETHEE method has been applied as described in the precedent section, and the evaluation phase outputs are shown in this table. The results show that it is preferable to add a specialist physician in general surgery.

## 7. Conclusion

This paper studied a simulation model which enables us to define indicators to evaluate the performance of the ED of Sfax hospital. The study consists of drawing a passage from a graphic model IDEF3x to a WITNESS model which reflect more the reality in a clearer way. Several numbers of indicators were defined. Different variations of the WITNESS model were proposed, showing the impact of variation in several parameters on the process performance. Simu-lation results showed that to manage to increase the number of treated patients and thus to decrease the cycle time of patient, it is important to add a specialist physician or a formed general physician. To choose what physician the managers do add, the researchers used the fuzzy PROMETHEE method.

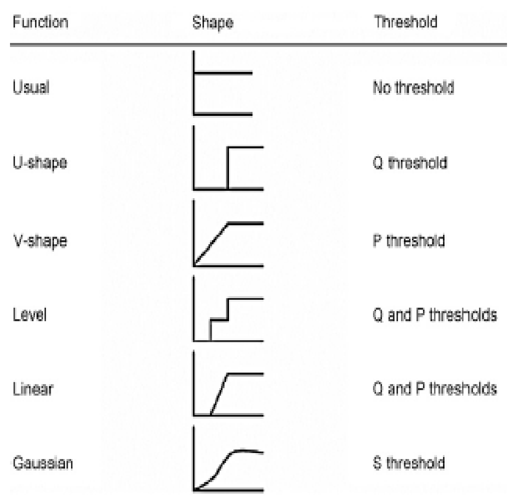


Figure 4: Preference functions of PROMETHEE.

Table 6: Basic fuzzy operations.

| | |
|---|---|
| Addition | $(m,\alpha,\beta)_{LR} \oplus (n,\gamma,\delta)_{LR} = (m+n, \alpha+\gamma, \beta+\delta)_{LR}$ |
| Opposite | $(m,\alpha,\beta)_{LR} = (-m,\beta,\alpha)_{LR}$ |
| Subtraction | $(m,\alpha,\beta)_{LR} - (n,\gamma,\delta)_{LR} = (m-n, \alpha+\delta, \beta+\gamma)_{LR}$ |
| Multiplication by scaler | $(m,\alpha,\beta)_{LR} \otimes (n,0,0) = (mn, \alpha n, \beta n)$ |
| Multiplication par fuzzy: for: $m>0, n>0$ | $(m,\alpha,\beta)_{LR} \otimes (n,\gamma,\delta)_{LR} \approx (mn, m\gamma+n\alpha, m\delta+n\beta)_{LR}$ |
| $m<0, n<0$ | $(m,\alpha,\beta)_{LR} \otimes (n,\gamma,\delta)_{LR} \approx (mn, n\alpha+m\delta, n\beta-m\gamma)_{LR}$ |
| $m<0, n<0$ | $(m,\alpha,\beta)_{LR} \otimes (n,\gamma,\delta)_{LR} \approx (mn, - \beta - m\delta, n\alpha-m\gamma)_{LR}$ |

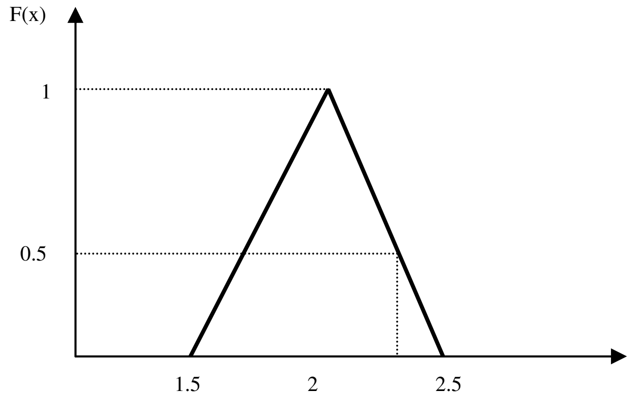


Figure 5: Presentation of fuzzy number x= (2, 0.5, 0.5).

Table 7: Presentation of the problem.

| Actions | Criteria<br>Costs<br>Min | <br>Number of exploration<br>Min | <br>Demand in the opinion of another specialist<br>Min |
|---|---|---|---|
| Doctor of the public health formed (A) | 1200 dinars | (60, 10,20) | (25, 10,5) |
| Assistant : specialist in general surgery (B) | 1600 dinars | (40, 10,10) | (10, 10,5) |
| Assistant : specialist in orthopaedic (C) | 1600 dinars | (50, 10,10) | (15, 5,10) |
| general physician (D) | 1000 dinars | (80, 20,20) | (35, 5,10) |
| Weights | 0.25 | 0.4 | 0.35 |

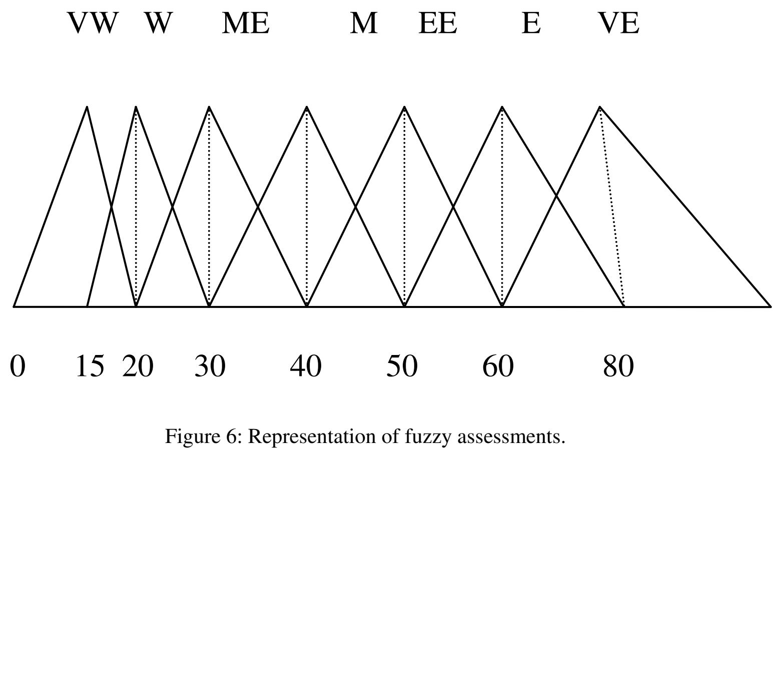


Figure 6: Representation of fuzzy assessments.

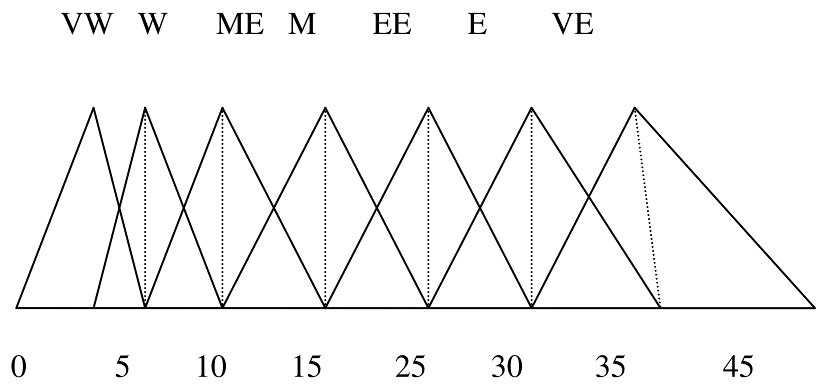


Figure 7: Representation of fuzzy assessments.

Table 8: The obtained results.

| | A | B | C | D | $\phi^+$ | $\phi$ |
|---|---|---|---|---|---|---|
| A | 0 | 0.25 | 0.25 | 0.14 | 0.64 | -0.03 |
| B | 0.67 | 0 | 0 | 0.75 | 1.42 | 0.92 |
| C | 0 | 0 | 0 | 0.95 | 0.95 | 0.45 |
| D | 0 | 0.25 | 0.25 | 0 | 0.5 | -1.34 |
| $\phi-$ | 0.67 | 0.5 | 0.5 | 1.84 | | |

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