A Fuzzy Dynamic Risk-based Approach for Prioritization of Surgical Patients

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***Abstract* – The risk or chance of undesirable outcomes during the procedure is widely used in different areas in health care. However, its' application in prioritization of patients is not currently reported in the literature or practice. This paper focuses on the significance of risk in prioritization of patients, and proposes an innovative framework for prioritization of patients considering uncertainties, group decision making, and associated risk that may threaten patients' health during waiting time. An illustrative example shows that using the proposed framework, decision makers can easily classify patients for surgery according to their criticality. In the lights of the proposed framework, decision makers can; i) manage waiting lists properly, ii) consider several medical professionals' opinions iii) handle uncertainty, iv) increase quality of care, equity and patients' safety, and v) diminish rate of injuries and mortality due to long waiting times. Moreover, this framework can be adopted in other departments in hospitals such as emergency departments, or even other healthcare organizations such as rehabilitation centers, medical clinics and etc.**

***Keywords* –Risk Analysis; Prioritization; Surgical waiting list; Uncertainty; Group Decision Making.**

1 INTRODUCTION

Limited and delayed access to care for patients is a multifaceted and universal problem in public health. Long waiting lists are one of main complaints of surgical patients (Abbasgholizadeh Rahimi, Jamshidi, Ruiz, & Ait-Kadi, 2014). After patients are referred for surgery, their situations are examined if they have non-life threatening condition they will be admitted on a first-come, first serve basis. But, if their conditions are potentially life-threatening, they will be entered into a priority waiting list (Randolph, 2013). Higher priority-patients will be selected for service ahead of those with a lower priority, regardless of when they are placed on the list. And, the same priority patients are ranked in the arrival order (Randolph, 2013). Prioritization of patients on waiting lists and their access to treatment based on various factors is one of the major issues within healthcare organizations. According to US National Library of Medicine, (Medicine, n.d.) access to treatment is defined as "the degree to which individuals are inhibited or facilitated in their ability to gain entry to, and to receive care and services from the health care system". Fraser Institute (Barua & Esmail, 2013) reported that the total waiting time in Canada in 2013 was 95 % longer than in 1993. And also Russell et al. (Russell, Roberts, Williamson, Jolly, & McNeill, 2003) in their recent study indicated an increasing imbalance between the demand for, and availability of access to elective surgery for lower urgency elective procedures. This imbalance causes long waiting time and consequently, waiting of some patients longer than clinically recommended waiting times (Russell, Roberts, Williamson, Jolly, & McNeill, 2003).

In many medical procedures, these long waiting times affect directly on patients' health and quality of care. Reports regarding the harms related to long wait times are increasing; these harms include poorer medical results from care and an increased risk of adverse events (Barua & Esmail, 2013). Fraser Institute estimated, 44273 Canadian women have lost their lives between 1993 and 2009 as a result of lengthy delays in receiving care (Esmail, 2013). Day (Day, 2013) also indicated that "for some diseases delayed treatment can cause reduction in effectiveness of treatment, and often transforms an acute and potentially reversible illness or harm into a chronic, irreversible condition that involves permanent disability".

Prioritization is a complex decision making process, and as a result scoring systems (*i.e.* explicit criteria and weights), have been designed as a decision making tool to guide the surgeons and clinicians to a decision. A scoring system or points system consists of criteria for deciding patients' relative priorities for treatment. Each patient is "scored" on the criteria and their corresponding point values summed to get a "total score", by which patients are ranked relative to each other. An example of a scoring system for prioritizing patients for coronary artery bypass graft (CABG) surgery is illustrated in (Figure 1) (Hansen, Hendry, Naden, Ombler, & Stewart, 2012). Scoring systems were

introduced in 1990s, but afterwards, these initial scoring systems were criticized for being largely arbitrary and resulting in significant numbers of patients being mistakenly denied treatment (sometimes with fatal consequences) besides, "a diverse mix of patient cases – placed and kept on the list for a number of different reasons, and with no agreed criteria for admission to the list." (Fraser, Alley, & Morris, 1993). Subsequently, other scoring systems have been created in New Zealand, United Kingdom and Canada. In New Zealand scoring systems have been produced for hip and knee replacements, varicose veins surgery, cataract surgery, and gynecology, plastic surgery, otorhinolaryngology, and heart valve surgery respectively. In Canada, (2003) in the "Western Canada Waiting List" (WCWL) project (Noseworthy, McGurran, & Hadorn, 2003) scoring tools for priority setting in five clinical areas (cataract surgery; general surgery procedures; hip and knee replacement; magnetic resonance imaging (MRI) scanning, and children's mental health) were developed, and since then it has been used.
On the other hand, some prioritization formulae were developed with the aim of reducing waiting times and prioritizing patients fairly (Mullen, 2003), (Fordyce & Phillips, 1970), (Culyer & Cullis J, 1976), (Langham & Thorogood, 1996), (Hadorn & Holmes, 1997), (Seddon, et al., 1999), (Lack, Edwards, & Boland, 2000). Most of the reviewed works use the same idea of assigning a priority score to each patient based on different criteria, and the resulting priority score was used to specify the patient's order of admission (Mullen, 2003). Naylor et al (Naylor, et al., 1993) aimed at prioritizing patients by describing a different approach on patients' prioritization in the case of coronary revascularisation, in which each patient receives (at the time of referral) a priority code based on an Urgency Rating Scale (URS). Prioritization based on other considerations has also been proposed for situations where the risk of death is low (Hadorn D. , 2000). However, Testi et al. (Testi, Tanfani, Valente, Ansaldo, & Torre, 2008) in their study indicated that, "waiting list prioritization should not be limited to classifying patients into urgency related groups (URGs), but to using a scoring system as well, in order to schedule patient admissions in an explicit and transparent way". And recently, Domènech et al. (Domènech, Adam, Tebé, & Espallargues, 2013) produced a point-count linear scale based tool for elective surgery. Considering all of these, there are main shortcomings in current prioritization systems (Peacock, Mitton, Bate, McCoy, & Donaldson, 2009), (Domènech, Adam, Tebé, & Espallargues, 2013), (Abbasgholizadeh Rahimi, Jamshidi, Ruiz, & Ait-Kadi, 2014), (Mullen, 2003), (Russell, Roberts, Williamson, Jolly, & McNeill, 2003).

2 RISK ANALYSIS

The quality of healthcare processes is a key determinant of the quality of care and related risks (Kenett, 2012). The important term "risk" or "chance of undesirable outcomes during the procedure" is widely used in different areas in health care. Risk ratios are used in medical literature to represent the likelihood of a disease or event occurring relative to an exposure. Risk management is an inherent part of hospitals and health care organizations, although traditionally its focus has been on protecting organizations from financial loss (Bryant & Hagg-Rickert, 2001), (Vincent, 2001). However, with a few notable exceptions, the concept of risk and risk-based metrics as understood by human factors engineers and safety scientists remains relatively unexplored in the specific context of patient safety (Karsh, Holden, Alper, & et al. , 2006) , (Cook, Woods D, & Miller, 1988).
The growing interest in risk management is driven partly by regulations related to corporate governance in the private and public sector. However, much of risk management is still based on informal scoring using subjective judgment (Kenett, 2012). Modern risk management systems incorporate several activities. These activates are summarized in the (Figure 2) (Kenett, 2012).

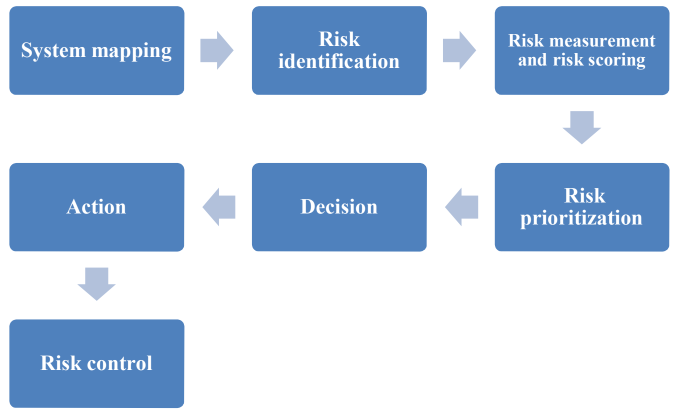

Figure 2. Risk management systems' activities

Although not typically viewed from this perspective, health care situations readily lend themselves to a risk identification and control approach. Prior publications have focused on the need to leverage these concepts of hazard and risk to achieve sustainable safety improvements (Karsh, Holden, Alper, & et al. , 2006), (Battles & Lilford , 2003). However its' application in prioritization is not currently reported in the literature or practice. In the next section, an innovative framework for prioritization of patients considering associated risk is proposed.

3 PROPOSED FRAMEWORK

This part of paper focuses on classification of patients considering risks that threaten patients' health during waiting time. In this section the proposed framework is explained in several steps. It is able to prioritize patients in complex situations, taking into account the different dimensions by considering risks, uncertainty and group of decision makers' opinions. Figure 3 shows the proposed framework.

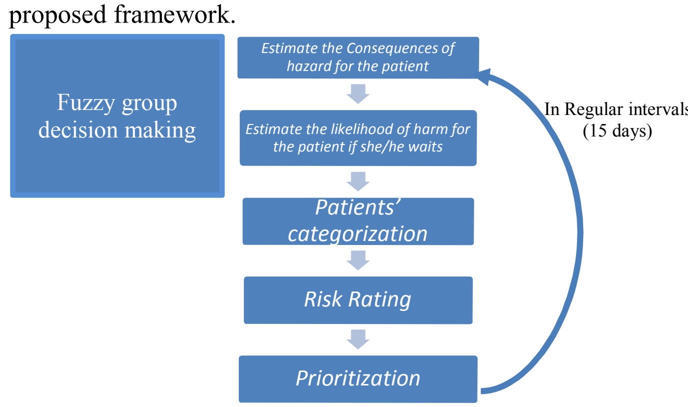

Figure 3. Proposed Risk-based structure of the framework

3.1 Fuzzy group decision making

3.1.1 Considering uncertainty in prioritization

Medical knowledge and clinical practice are always associated with considerable amounts of uncertainty and about everything in medicine is inevitably vague (Sadegh-Zadeh, 2012). Since uncertainty is inherent in fields such as medicine, and fuzzy logic takes into account such uncertainty, fuzzy set theory can be considered as a suitable formalism to deal with the imprecision intrinsic to surgical patients' prioritization problems. Usually the easiest and more preferable way for medical staff and patients to rate the alternatives with respect to different criteria is to use the linguistic variable. Currently used scoring systems have only crisp values for the ratings of criteria considering each case (patient). In order to illustrate the idea of fuzzy MCDM, we deliberately transform the existing crisp values for impact on patient and likelihood of harm to five level linguistic variables. These fuzzy linguistic variables are defined in Table 1 and Table 2. The purpose of the using fuzzy process in our model is two folded: i) to consider associated vagueness and uncertainty in risk based prioritization process ii) to make the rating process easier and less time consuming for medical staffs. Due to simplicity in modeling easy interpretations, among the commonly used fuzzy numbers, triangular fuzzy numbers are likely to be the adoptive one. In order to adequately represent the five-level fuzzy linguistic variables, triangular fuzzy number is used for the analysis hereafter. The Membership function and Triangular Fuzzy reciprocal Scale related to Impact on patient and likelihood of harm can be found in Table 1 and Table 2, respectively. The fuzzy ratings in these tables are defined in accordance with the experience of the authors. For example, the fuzzy variable, "Catastrophic" in impact on patient has its associated triangular fuzzy number with the minimum of 7/2, mode of 4, and maximum of 9/2. The similar definition is then used to other Fuzzy variables.

3.1.2 Group decision making in prioritization

Lack of group decision making is another shortcoming of current prioritization tools which may cause inaccurate prioritization of patients. Traditionally, the prioritization rule was "first in, first come" but since 1990s doctors' point of view are more and more considered. However, there is still a conflict among surgeons and other medical staffs over the prioritization of patients for surgery. Each of them has their own list of priorities for surgical patients based on their knowledge and experience, but finally, surgeons prioritize patients based only on their own opinions. Although in identification of prioritization criteria for developing scoring systems, several medical staffs' ideas have been considered but, rating of patients and mainly prioritization procedure have been suffering from lack of group decision making. This may cause medical staffs' dissatisfaction and inaccurate prioritization. To benefit from all surgery team members' knowledge and experience in prioritization procedure, all of their assessments should be considered. Then in this study, we explained how the proposed framework could consider several decision makers' opinions.

3.2 Estimation of the impact on patient for the patient:

In this step medical professionals (surgeons), estimate the impact on patient (or impact of waiting on patient). This estimation will be based on linguistic variables and the related rank, impact and membership function are shown in the following table.

Table 1. Impact on patient fuzzy scale.

Rank	Impact on patient	Membership function
Catastrophic	Fatality	(7/2,4,9/2)
Very serious	Major harm resulting spread of disease and/or impact on other organs	(5/2,3,7/2)
Medium	Major harm resulting in permanent harm	(3/2,2,5/2)
Small	Harm	(2/3,1,3/2)
Insignificant	Minor harm/ No harm	(1,1,1)

3.3 Estimation of likelihood of harm:

In this step medical professionals (surgeons), estimate the likelihood of harm (that may threaten patients' health on waiting). This estimation will be based on introduced linguistic variables and membership function that are shown in the Table 2.

Table 2. Likelihood of harm fuzzy scale.

Likelihood of harm	Membership function
Almost certain	(7/2,4,9/2)
Probable	(5/2,3,7/2)
Possible	(3/2,2,5/2)
Possible (under unfortunate condition)	(2/3,1,3/2)
Rare	(1,1,1)

3.4 Patients' categorization

In this step a risk matrix is proposed for rating of risk. The proposed matrix can be used to identify the level of risk and help to prioritize patients with critical situations. Figure 4 illustrates the profile matrix and shows how patients would be grouped and classified on the basis of their location. Numbers on x and y axis, are the levels for "impact on patient" and "likelihood of harm". Plotting y-axis against x-axis allows the decision makers to see how each patient falls into a quadrant system as illustrated in Figure 4. Each patient's y-coordinate and x-coordinate for "Likelihood of harm" and "Impact on patient" could be derived using Table 2 and Table 1 consequently.

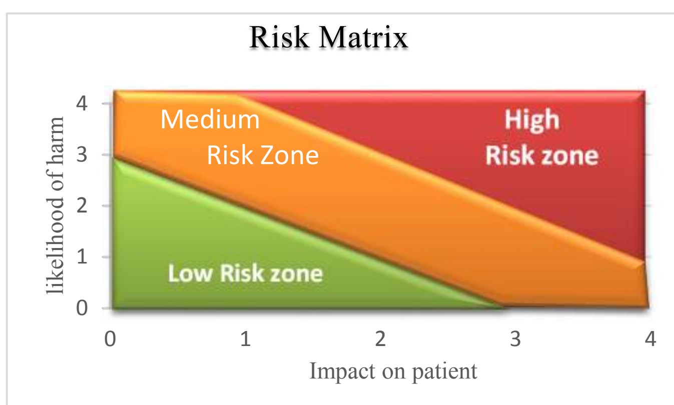

Figure 4. Proposed Risk matrix.

Using proposed risk matrix, decision maker can easily categorize patients into three different types. The risk zones in this matrix provides information about patient's priority and urgency, these zones are explained in the below.

High risk zone; High Risk patients should be treated as immediately as possible.
Medium risk zone; Medium Risk patients can wait for the short-term. These types of patients should be dynamically monitored and reprioritized in order to timely recognize any changes in their situation and risk level.
Low risk zone; Low Risk patients can wait for the longer-term than other patients, since they don't have life threatening situation. However, these patients' health situation should be monitored dynamically during their waiting time.

After plotting, patients that fall into the upper part (High risk zone) can be identified as the most preferable candidates for surgery for further analysis.

3.5 Surgical patients' Prioritization:

In hospitals and specially surgery wards, there is insufficient capacity to be able to operate all surgical patients. Then, patients must be prioritized for access to surgery. The incorporation of associated risks with prioritization and categorization of patients led to proactive identification of high risk patients, and elimination of injuries and preventing future harms of patients. In this part we aim to prioritize patients considering uncertainties, associated risks that threaten patients' health and several medical professionals' opinions.

In the first step, all medical professionals determine each impact of waiting on each patient and likelihood of harm using defined linguistic variables. Then, these linguistic terms should be transformed to triangular fuzzy numbers using Table1 and Table2. Afterwards, the average of all opinions should be calculated and defuzzifed. It is required to reduce a given fuzzy number into a single crisp representative value. This is called defuzzification operation. The defuzzification method of a triangular fuzzy number is shown in Figure 5.The defuzzification value t of a triangular fuzzy number (l, m, u) is equal to (Maji, Biswas, & Roy, 2003):

$$t = \frac{l + m + m + u}{4} \tag{1}$$

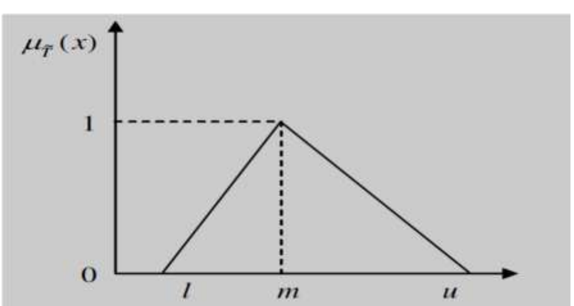

Figure 5. The TFN membership function (Afshari, Yusuf, & Derayatifar, 2013)

After defuzzification of fuzzy numbers using Eq.1, Risk score is calculated by multiplying the "Impact on patient" against the "likelihood of harm", as shown by Eq.2. So in order to estimate the risk level of a particular scenario we need to estimate the consequences of that scenario and the likelihood of that particular consequence occurring.

Risk score *of patient = Impact on patient* × *likelihood of harm* (2)

After obtaining risk score of each patient, decision makers can prioritize patients by considering associated risks that threaten patients' health.

3.6 Dynamic Prioritization:

Surgical waiting list is an environment that changes over time. Patients are dynamic, they are added to the system, their situation changes while they are in the system or they removed from the system because of various reasons. These changes in the patients' situation could be due to surgeons' previous decisions (related to prioritization of patients) or due to events that are outside of their control. Then, dynamic decision making should be carried out and patients be prioritized in a temporal order. Solving this dynamic decision-making problem in patients' prioritization, could improve control of this complex system and also lead to better decisions over time. More importantly, it may prevent worsening of situation of patients on surgery waiting lists accordingly, the mortality and harm rate will be decreased. But prioritization of patients on waiting lists in a temporal order has been overlooked in both research and practice. One of our major contributions in this study is to prioritize patients on waiting lists, considering dynamic situations to prevent worsening of patients' situation on surgery waiting lists. To the best of our knowledge, no study has considered the dynamic issue in prioritization of surgical patients and this is the first study which introduce this issue in surgical patients' prioritization by considering the risks and delay in treatment. As shown in (Figure 3), in this study the new risk based framework is proposed which should be updated in regular intervals. In order to consider the dynamic situation of surgery waiting list and prevent worsening of situation of patients on surgery waiting lists, we suggest to verify the situations of patients (who are in low and medium risk zone of proposed risk matrix) in regular intervals such as, 15 days in order to do the proper actions.

4 ILLUSTRATIVE EXAMPLE

In this section, a hypothetical example is used to illustrate the proposed framework for surgical patients' prioritization. The example concerns four patients (Adams V., Becker L., Peter P., John N.) waiting for surgery on surgical waiting lists with different profiles and situations. There are three medical professionals. And, the main objective is categorization and prioritization of these four surgical patients considering associated risks. Based on patients' medical record and three medical professionals' opinions, impact scale of waiting and likelihood of harm for these four patients are shown in Table 3, 4 and 5.

Table 3. Impact on patient and likelihood of harm rank based on first medical professional's opinion.

Medical Professional 1	Adams V.	Becker L.	Peter P.	John N.
Impact on patient	Small	Catastrophic	Medium	Small
Likelihood of harm	Probable	Possible	Almost certain	Rare

Table 4. Impact on patient and likelihood of harm rank based on second medical professional's opinion.

Medical Professional 2	Adams V.	Becker L.	Peter P.	John N.
Impact on patient	Small	Very serious	Medium	Small
Likelihood of harm	Possible	Possible(under unfortunate condition)	Probable	Rare

Table 5. Impact on patient and likelihood of harm rank based on third medical professional's opinion.

Medical Professional 3	Adams V.	Becker L.	Peter P.	John N.
Impact on patient	Small	Very serious	Small	Small
Likelihood of harm	Probable	Possible	Probable	Possible (under unfortunate condition)

Using Table 1 and Table 2, assigned linguistic terms are transformed to triangular fuzzy numbers and average of these three medical professionals' opinions are calculated. These average numbers are shown in Table 6.

Table 6. Average rank of Impact on patient and likelihood of harm of patients.

	Adams V.	Becker L.	Peter P.	John N.
Impact on patient	(0.6,1,1.5)	(2.83,3.3,3.83)	(0.94,1.3,1.83)	(0.6,1,1.5)
Likelihood of harm	(1.83,2.3,2.83)	(1.2,1.6,2.16)	(2.83,3.3,3.83)	(0.8,1,1.16)

Then, using Eq.1, the fuzzy numbers are defuzzified and transformed to crisp numbers. The defuzzified numbers are shown in Table 7.

Table 7. Defuzzified numbers of Impact on patient and likelihood of harm of patients.

Deffuzified	Adams V.	Becker L.	Peter P.	John N.
Impact on patient	1.04	3.33	1.36	1.041
Likelihood of harm	2.33	1.68	3.33	1.014

Using Figure 4 we can define the patients' categorization.
Figure 6 illustrates the patients' categorization. Figure 6 illustrates categorization of patients for illustrative example, which shows how patients would be grouped and classified on the basis of their risk level.

After categorization of all surgical patients, we see that one of the patients (Becker L.) falls into the High Risk zone, this patient can be identified as the most preferable candidates for surgery and further analysis should be done because he have a high risk score. Besides, we see that two of the patients (Peter P. and Adams V.) falls into the Medium Risk zone, these patients can be identified as the most preferable candidates for surgery after "Becker L." and further analysis should be done.

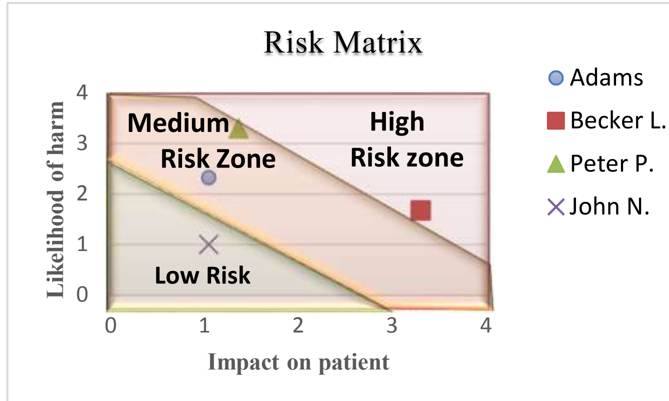

Figure 6. Categorization of patients (illustrative example).

Using Eq. (2), risk score for these patients are calculated and are shown in the second column of the Table 8.

Table 8. Surgical patients' categorization and prioritization.

Patients	Risk Score	Category	Priority
Adams V.	2.431	Medium risk zone	3
Becker L.	5.602	High risk zone	1
Peter P.	4.537	Medium risk zone	2
John N.	1.056	Low risk zone	4

Finally, the priority order of surgical patients would be; "Becker L." > "Peter P." > "Adams V." > "John N.". It can be easily seen that by considering risk score, "Becker L." should be selected as the first priority for surgery and then "Peter P". As mentioned in previous parts, patients are dynamic, they are added to the system and their situation changes while they are in the system or they removed from the system because of various reasons. Then, in order to prevent worsening of situation of these patients on surgery waiting lists, it is recommended to reassess surgical patients' situation on waiting list after two weeks, and reprioritize these four patients.

5 Conclusion and Future Works

Prioritization of surgical patients on waiting lists and their access to treatment based on different perspectives and factors, is one of the major issues within healthcare organizations. Current prioritization systems (i.e. Scoring system) suffer from several shortcomings and weaknesses in assessing the relative priority of patients, which lead to increasing of waiting time, mortality rate and harm rate (Esmail, 2013), (Day, 2013). For instance, associated risk, uncertainties and group decision making in surgical patients' prioritization have been overlooked.

This study firstly focuses on current surgical patients' prioritization tools, and points out their weaknesses. Then a novel risk-based framework is proposed. The two main contributions of this study are: (i) development of a risk-based framework for surgical patients' prioritization, which is not currently reported in the literature or practice, and (ii) proposing a dynamic prioritization framework, to assess the changes in the prioritization of patients in regular intervals before their surgery date. The proposed framework prioritizes a diverse mix of patients in surgical waiting lists into an order of importance considering the following strengths and main features:

1) Associated uncertainties are handled using fuzzy approach, 2) Group decision making between surgery team has been considered in rating procedure, 3) Risk that threaten patients' safety has been considered as an important and distinguished factor, 4) Dynamic situation of surgery waiting lists is handled effectively, and 5) Easy and usable graphic solution (Figure 4) has been proposed for classification of surgical patients.

This is an innovative framework and the above features, distinguish it from currently used methods. This framework produces precise and reliable prioritization results for surgical patients and not only a simple ordering. In addition, it is able to select the best candidate (patient) for surgery based on her/his criticality and risk, in regular intervals. In future works, this framework will be extended and a user friendly software will be developed in order to facilitate implementation of the proposed framework in critical wards like surgery wards in hospitals.

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Coronary anatomy (where LAD = left anterior descending artery)		Score
1 vessel ≥ 50%	0	
2 vessels ≥ 50%, or proximal LAD ≥ 50%	1	
3 vessels ≥ 50%, or proximal LAD ≥ 70%	7	
2 or 3 vessels ≥ 50%, including proximal LAD ≥ 70%	11	
Left main stem ≥ 50-69%	22	
Left main stem ≥ 70%	74	
Troponin (where STEMI = ST elevation myocardial infarction)		
Troponin negative, or STEMI	0	
Non-STEMI Troponin positive	52	
Recent Acute Coronary Syndrome (ACS) during last 2 weeks		
No ACS	0	
ACS: STEMI or No ST depression (≥ 1 mm)	20	
ACS: ST depression (> 1 mm < 2 mm)	42	
ACS: ST depression (≥ 2 mm), or transient ST elevation	73	
ACS: Haemodynamic instability, or serious arrhythmia due to ischaemia	115	
Severity of angina/anginal equivalent		
No angina/Class I	0	
Class II	11	
Class III	22	
Class IV	53	
Treadmill exercise/Perfusion imaging/Territory at Risk		
Negative/mildly positive, or small territory at risk/akinetic	0	
Positive, or moderate territory at risk	20	
Very positive, or large territory at risk	28	
Markedly positive (not scored for territory at risk)	42	
Left ventricular ejection fraction (EF)		
EF < 30%, no/mild reversible ischaemia or viability	0	
EF > 50%	4	
EF = 30-50%	27	
EF < 30% with reversible ischaemia/viability	35	
Predicted benefit to quality of life after surgery		
No/Small benefit	0	
Moderate benefit	27	
Large benefit	35	
Left ventricular failure (LVF) due to ischaemia		
No	0	
Yes	22	
	Total Score:	

Figure 1. Scoring system for prioritising patients for CABG surgery (Hansen, Hendry, Naden, Ombler, & Stewart, 2012).