A Framework for Requirement Elicitation, Analysis, Documentation and Prioritisation under Uncertainty

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Abstract— This paper offers a pluralistic framework for coping with requirements in the early phases of design where there is lack of knowledge about a system, its architect and functions. The framework is used to elicit, analyze, document and prioritize the requirements. It embeds probabilistic approach and offers the knowledge based selection of requirements. The inherited probabilistic approach facilitates communication and accommodates tolerance and flexibility in sharing opinions and embraces uncertain information. This framework uses a graphical tool to intuitively collect uncertain information. It uses the probability theory to process that. It also facilitates storage and reuse of the collected information. An example shows the application of this method through the ColdFacts project.

Keywords—requirement; framework; uncertainty; elicitation; analysis

I. NOMENCLATURE

α	relative weight
E	expected value
λ	relative weight of requirements
m	number of stakeholders
n	number of requirements
r_i	a random number representing the importance of the i-th requirement
r_{i_k}	a random number representing the opinion of the k-th stakeholder over the i-th requirement
s_k	a random number representing the importance of the k-th stakeholder
s_{k_j}	a random number representing the opinion of the j-th stakeholder over the k-th stakeholder
σ	standard deviation
Var	variance

II. INTRODUCTION

1.1. Requirements: elicitation and prioritization

Focusing on (critical) requirements is considered a key to success or failure [1, 2]. To emphasize this, design text books often focus on three levels of requirements which are goals, objectives and wishes. Design goals are indeed the conditions that must be met, design objectives are used to evaluate design alternatives and design wishes are preferences for improving design [3]. These three categories of design requirements help to establish strategies for product development and evaluation. However, establishment of clear borders between these categories is not always possible and prioritization of requirements is a necessity for focusing on the most important requirements.

To define system requirements, identification of stakeholders is one of the earliest steps. A review research by Pacheco and Garcia [4] confirms that an incomplete set of stakeholders may lead to incomplete requirements. A system designer has to pay attention to the problems arising from the scope, understanding and validation of requirements [5, 6] in the course of communication with stakeholders.

Not all the stakeholders are known in early project lifecycle and new stakeholders may be realized through communication with the known stakeholders. Salado and Nilchiani [7] suggest a set of questions for discovering new stakeholders in order to identify a complete set of stakeholders. Complex systems often include a relatively high number of stakeholders with different (conflicting) interests [8].

Stakeholders may have different requirements with different levels of importance. For example, if the requirements for a mobile weather station are aesthetic, reliability and light weight, they have not the same importance given the context, e.g. product environment and function.

Ranking of requirements based on their importance is well discussed in decision models. The use of multi criteria decision models typically involves a systematic ranking process as for instance indicated in [9, 10]. The influence of the ranking process on final decisions is for example explained in [11]. A review of subjective ranking methods shows that different methods cannot guarantee accurate results. This inconsistency in judgment explains difficulty of assigning reliable and subjective weights to the requirements. A systematic approach for ranking is described in [12] which is a generalization of Saaty's pairwise structure [13]. Given the presence of subjectivity in the ranking process, sensitivity analysis of the design criteria is used to study the influence of variation and the ranking process on the decisions made [14]. Furthermore, some approaches e.g. the task-oriented weighing approach is effectively used. This approach is meant to limit the subjectivity of criteria weighting [15]. It suggests an algorithm to rank criteria objectively while considering the uncertainty in criteria weight [16]. The approach is based on introducing fuzzy numbers that imposes specified membership functions, which has been also used in [17, 18].

However, there is an obstacle for system designers to communicate the proposed methods with different stakeholders. The stakeholders can be individuals, corporations, organizations and authorities, with different fields/ levels of knowledge and experience [19]. The stakeholders have interest in the project and they desire to express their knowledge and expertise to improve the system. They also have expectations which have to be formulated as requirements and addressed at the end. Besides, designers can rely on stakeholders or experts in order to manage design uncertainties; it is proven that experts provide frameworks for making knowledge based decisions under uncertainty [20, 21]. It, therefore, offers a human solution in terms of preferred alternatives. The uncertainty in importance of design requirements is also of human nature which should be reflected in the weighting process.

2. Uncertain requirements

2.1. Presentation

We aim to present a realistic and intuitive approach that can communicate to people with different fields of knowledge and expertise. The method must be transparent, easy to implement and readily adaptable by different users. For this purpose, graphs are used to effectively communicate with different users. The format presented in Figure 1 is used to identify the importance of a requirement according to a stakeholder's opinion. It shows that linguistic or numerical scale are applicable for communication, and one can assign a range of possible importance to a certain requirement.

A probability distribution function (PDF) is assigned to this recorded data. Symmetric opinions are assumed here in this paper as described in [22, 23] and the collected data is treated as a random variable with a Gaussian distribution aiming to achieve set of a stochastic weight factors.

2.1. Formulation

Having m stakeholders, each stakeholder evaluates the importance of all the stakeholders. This information is presented by stochastic variables $s_{k_1}, s_{k_2}, \ldots, s_{k_{m}}$, where s_{k_j} represents the opinion of j-th stakeholder over the importance of k-th stakeholder, and its expected value and

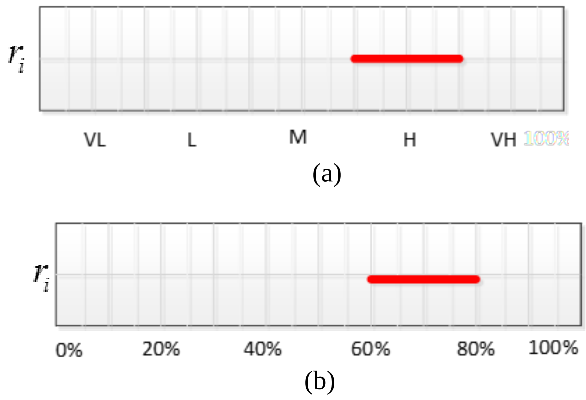

Figure 1. An example of a stakeholder's opinion about the importance of the i-th requirement r_i .

variance are respectively shown by $\mathrm{E}[s_{k_j}]$ and $\mathrm{Var}[s_{k_j}]$. The expected relative weight and variation for the importance of each stakeholder is achieved by the following equations.

$$E[\alpha_k] = \frac{1}{\sum_{k=1}^{m} \mathrm{E}[s_k]} \sum_{j=1}^{m} \mathrm{E}[s_{k_j}] \quad (1)$$

$$\mathrm{Var}[\alpha_k] = \frac{1}{\left(\sum_{k=1}^{m} \mathrm{E}[s_k]\right)^2} \sum_{j=1}^{m} \mathrm{Var}[s_{k_j}] \quad (2)$$

Now m stakeholders assess the importance of the i-th requirement r_i, and this information is represented by stochastic variables $r_{i_1}, r_{i_2}, \ldots, r_{i_m}$, where r_{i_k} presents the k-th stakeholder's opinion over the importance of the i-th requirement. As a result, the overall expected value and variation of the opinions over the importance of the i-th requirement r_{i_k} are calculated by the following equations.

$$\begin{aligned} \mathrm{E}[r_i] &= \sum_{k=1}^{m} \mathrm{E}[\alpha_k r_{i_k}] \\ &= \sum_{k=1}^{m} \frac{\mathrm{E}[\alpha_k]\mathrm{Var}[r_{i_k}] + \mathrm{E}[r_{i_k}]\mathrm{Var}[\alpha_k]}{\mathrm{Var}[\alpha_k] + \mathrm{Var}[r_{i_k}]} \end{aligned} \quad (3)$$

$$\begin{aligned} \mathrm{Var}[r_i] &= \sum_{k=1}^{m} \mathrm{Var}[\alpha_k r_{i_k}] \\ &= \sum_{k=1}^{m} \frac{\mathrm{Var}[r_{i_k}]\mathrm{Var}[\alpha_k]}{\mathrm{Var}[\alpha_k] + \mathrm{Var}[r_{i_k}]} \end{aligned} \quad (4)$$

ISBN: 978-1-61804-340-5

One may ignore the variation for importance of stakeholder (Equation 4) to simplify the calculation. This result in the following equations.

$$\mathrm{E}[r_i] = \sum_{k=1}^{m} \mathrm{E}[\alpha_k r_{i_k}] = \frac{1}{\sum_{k=1}^{m} \mathrm{E}[s_k]} \sum_{k=1}^{m} \mathrm{E}[s_k]\,\mathrm{E}[r_{i_k}] \quad (5)$$

$$\mathrm{Var}[r_i] = \sum_{k=1}^{m} \mathrm{Var}[\alpha_k r_{i_k}] = \frac{\sum_{k=1}^{m} \mathrm{E}[s_k]^2\,\mathrm{Var}[r_{i_k}]}{\left(\sum_{k=1}^{m} \mathrm{E}[s_k]\right)^2} \quad (6)$$

After normalization, the following equations are concluded.

$$\lambda_i = \frac{\mathrm{E}[r_i]}{\sum_{i=1}^{n} \mathrm{E}[r_i]} \quad (7)$$

$$\sigma_{\lambda_i}^2 = \frac{\mathrm{Var}[r_i]}{\sum_{i=1}^{n} \mathrm{Var}[r_i]} \quad (8)$$

where λ_i and σ_{λ_i} are respectively the weight factor and standard deviation for the requirements. λ_i is normally the criteria for ranking parameters for deterministic approaches. In order to take the uncertainty into account, we use the relative standard error (RSE) which is also known as "reliability index" [24] formulated as

$$\beta_i = \frac{\lambda_i}{\sigma_{\lambda_i}} \quad (9)$$

Where β_i is the reliability index for the i-th requirement. The algorithm for applying this method is described next and an example application of it is presented in the next section.

3. Algorithm

The following steps present the ranking process for requirements:

- List m stakeholders.
- Draw tables and list stakeholder $(s_1, s_2, ..., s_m)$ using the numeric or verbal format shown in Figure 1.
- Ask the stakeholders to fill the tables. This step concludes m series of tables. Use s_{k_j} format to label the collected information.
- Use Equation 1-2 and calculate $\mathrm{E}[\alpha_k]$ and $\mathrm{Var}[\alpha_k]$.
- List n requirements.
- Draw tables and list requirements $(r_1, r_2, ..., r_n)$ using the numeric or verbal format shown in Figure 1.
- Ask the stakeholders to fill the tables. This step concludes m series of tables. Use r_{i_k} format to label the collected information.
- Use Equations 3 and 4 (or simplified Equations 5 and 6) to calculate $\mathrm{E}[r_i]$ and $\mathrm{Var}[r_i]$ for each requirement r_i.
- Use Equations 7 and 8 to calculate the normalized weight of each requirement and its variance (or standard deviation).
- If new stakeholders or values are realized, reiterate from the first step. Reuse of the collected information is possible.
- Use Equation 9 to calculate the reliability index for the i-th requirement.

This process integrates the collected information and results an overview to a system designer for sorting the requirements based on the stakeholders' opinion. Next section presents an example application that shows the process and expected outcomes.

4. Example application

To illustrate the application of our proposed method, the ColdFacts projected is presented in this paper. The Cold Facts is a program of the Dutch World Wide Fund (WWF Netherlands) established on the topic of climate change in the Polar Regions. The purpose of this project is to build a weather station to be deployed at the sea ice surface to measure and record temperature, barometric pressure and position data. There are a number of design requirements that the design team need to prioritize to be able to focus on the most important aspects. For illustration, Figure 2 shows the list of some relevant design requirements and an example data from two experts on the importance and relevance of the requirements. Figure 2(a) and (b) the collected data from the first and second experts.

Using the proposed method in this paper, a designer is able to process the collected data. The presented information is limited to two experts for the illustration purpose. Furthermore, the experts are evenly graded and they have the same weight factor. A design team should indeed approach different design stakeholders and conclude a multi-perspective view on the importance of design criteria and the uncertainty around them.

ISBN: 978-1-61804-340-5

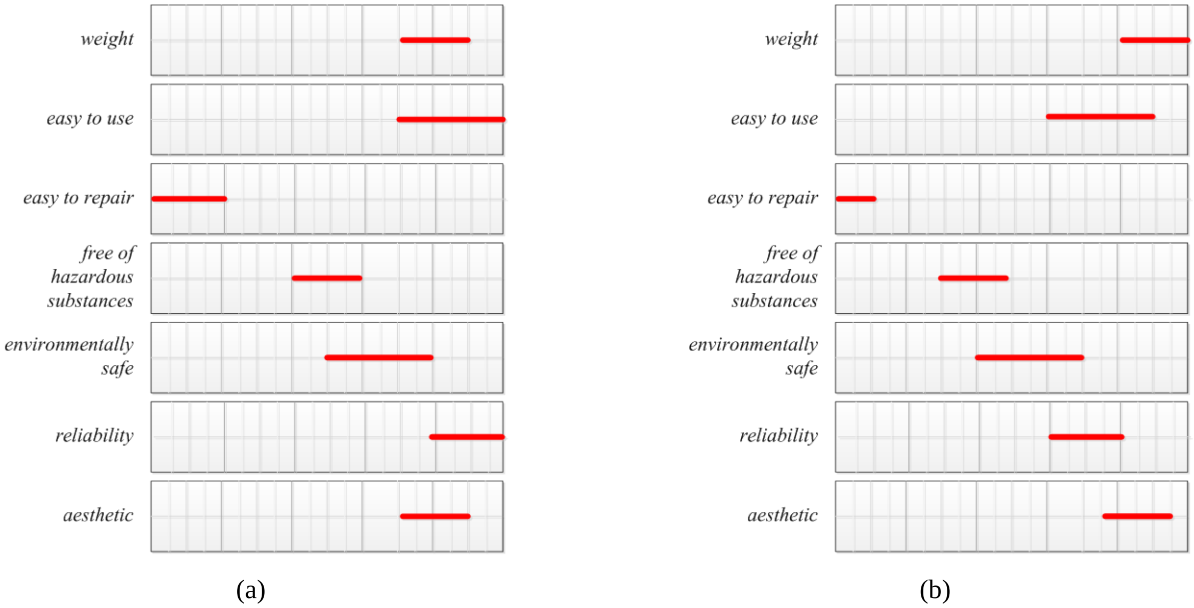

Figure 2. This figure presents the opinion of two experts over the importance of the proposed design requirements.

Table 1 presents the results. The first column of this table shows a list of design requirements which are to be ranked by stakeholders or experts. The second and third columns of this table show the expected values and standard deviations for the importance of the requirements according to the collected expert data. Their normalized values are presented in the next two columns. This concludes the relative importance of four requirements which are: light weight, easy to use, aesthetic and reliability. From these, one observes large uncertainty on the importance of "easy to use" requirements. One, therefore, gives more priority to the other three parameters which are of high importance with a high degree of certainty.

To take into account the uncertainty, the reliability index is an appropriate criteria for ranking the requirements as discussed before. This is shown in the last column of Table 1. The reliability index, therefore, takes into account both the relative weight and uncertainty and provides a criterion for ranking the requirements.

In another perspective, one can see that "easy to repair" has the lowest importance. This is because it has a low grade with a high level of uncertainty.

Table 1. This table presents the requirements and their weight factors, standard deviations, relative weights, uncertainties in relative weight, and the relative uncertainties.

Requirements	Expected value ($\mathbf{E}[r_i]$ %)	Standard deviation ($\sqrt{\mathbf{Var}[r_i]}$ %)	Relative weight (λ_i %)	Uncertainty in weight (σ_{λ_i} %)	Reliability index for requirement (β_i %)
Light weight	85	5	19	1.2	15.8
Easy to use	80	7.5	18	1.7	10.6
Easy to repair	7.5	4	2	0.9	2.2
Free of hazardous substances	45	5	10	1.1	9.1
Environmentally safe	60	7.5	14	1.7	8.2
Aesthetic	80	5	18	1.1	16.4
Reliability	82.5	5	19	1.1	17.3

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5. Conclusions

This study highlights the importance of design requirements in engineering design. The requirements may indeed change in the course of design process, yet radical changes in the requirements often leads to extra design iterations, and raking of the requirements can be a challenging task comparable to making design choices.

This study proposes a framework that enables a system designer to communicate with stakeholders collect their opinions, combine them and rank the requirements. It uses a graphical tool that is intuitively used. The proposed approach promotes the probabilistic thinking and establishes the principals of a method for using uncertain information based on the probability theory. An example application of this method has been shown through the ColdFacts project.

The proposed approach facilitated information collection and integration in the context of ClodFact project. Yet its application in large, complex or high-tech systems [8] requires further research. Furthermore, the proposed framework can be integrated with currently implemented tools in system design, systems engineering or system architect to stimulate probabilistic thinking. This is a subject to further research.

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