ANALYSIS OF DECISION MAKING PROCESS FOR A SYSTEMATIC ENGINEERING DESIGN

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ABSTRACT

The decision making process is an important stage of the design process (Roozenburg and Eekels 1995; Spitas 2011). A decision in the design process may lead to extension of concept path or acquiring further knowledge as is described in the C-K Theory of design presented by (Hatchuel 1996). In this paper, we introduce a visual method for making decisions. This novel tool can be used in either C-space or K-space. Furthermore, our recommended technique measures the model uncertainty which is necessary for a robust design (Arvidsson and Gremyr 2008).

Keywords: Design, Decision, tool.

INTRODUCTION

The C-K theory (Hatchuel 1996) explicitly defines two different spaces, the C- and K-space to structure the design process. It distinguishes the C-space and the K-space, where C stands for ‘concept’ and K stands for ‘knowledge’. Design evolves through an interaction between the spaces, which is subject to choices (Roozenburg and Eekels 1995; Spitas 2011). It is directly concluded from this theory that the elements of decisions are present in the whole design process. In other words, one can decide at each stage of the design process if further exploration of C-space is required or if the acquired knowledge from the K-space is sufficient.

The central idea behind the C-K theory is to define a design situation. This approach integrates different aspects of design and can model the whole design process to a considerable extent. Accordingly, irrelevant concepts and so-called ‘far-fetched’ ideas extend the concept path in the design process that may lead to acquiring further knowledge. This again highlights the role of decisions in the design process. In fact, decisions influence the cost and even the characteristics of the end product. Therefore, a systematic decision making approach can lead to a systematic design process.

The focus of this paper is on the decision making process. First, we briefly review the major steps in the design process. Then, we highlight the role of decisions in the design, and present some facts that change decisions. We refer to the tools can be utilized in the design process. These tools can be used for making decisions in either of the C- and K-space or concerning the transit between them.

Then, we suggest a visual method for making decisions in both of the C-space and K-space. This method helps designers to formulate their uncertainties (Rajabalinejad and Mahdi 2010) and use it in the decision making process. This novel methodology is able to conclude if the acquired knowledge, modeled in the K-space, is enough or further exploration of the C-space is required.

As a result, a more robust design can be obtained. Numerical examples are presented for clarification. This method was applied to the ‘Cold Facts’ project (TUDelft 2011) and the results are presented.

STEPS IN THE DESIGN PROCESS

For professional use in the design projects, a systematic approach and open-mindedness allows alternative concepts to be considered. In transition from the abstract level of wishes to the detailed design **(Roozenburg and Eekels 1995; Spitas 2011)**, the following steps can normally be identified:

1) Understand the design's requirements and setting
2) Analyze knowledge (analysis) at the given point in design, update/ elaborate (1) as necessary
3) Find design concepts (with the aim to meet (1) in light of (2)) (heuresis)
4) Analyze concepts with regard to (1) (analysis)
5) Compare and select concepts (evaluation, choice)
6) Further development (repeat from (2))

DECISIONS IN THE DESIGN PROCESS

Decisions in the design process should follow a logical or chronological order. That is a demand of our society for well-developed products, and decisions through the design process plays a key role in forming the end product. In general, good decisions depend on the quality of available information. In the other hand, many decisions are influenced by intuition and personal preferences than by facts and analysis (Mintzberg 1994; Henden 2004). It is, therefore, necessary for designers to support and integrate their intuition with knowledge and insight, obtaining which requires research, practice and ultimately experience (Fischbein 1987).

In the other hand, the complexity of available data can raise the difficulty of analyzing and comprehending it. This type of complexity tends to drive decisions toward the final stages of the design. However, overall understanding of the design problem is very important to identify a strategy. Given these limitations and willingness to make rational decisions, it is essential to provide the best information as a basis for the decisions.

WHY SYSTEMATIC DECISION MAKING?

It is a necessity to structure the decisions in the design process. This becomes evident when the product risk is high. Risk is directly related to cost and consequences. In this section, we present some facts showing that the human decision behavior can be influenced by other parameters.

COMPLEXITY OF DECISION MAKING IN LARGE DESIGNS

There are different sources of uncertainty and complexity that can make the design process complex. These are more probable in large design projects.

From the decision making perspective, there are three main reasons that make a decision process complex.

1) The 'push of the envelope' in a situation that goes beyond the current practice of societal or technical arrangements (uncertainty to predict).
2) Unclear requirement(s) by one or more stakeholders (uncertainty as to what is required).
3) The dynamic of environment where the product is designed for (system variability with respect to both (1) and (2)).

DECISIONS IN THE FRONT-END

Decisions in the front-end of the design process usually influence the whole design. At this stage, concepts must be defined that are technically coherent, fulfill the program of requirements and socially acceptable. They must meet the need of stakeholders and users.

INSUFFICIENCY OF INFORMATION

Insufficiency or absence of factual information usually is used as an excuse for not seeking information upfront. Judgmental information should not be underestimated by the designer. For example, expert judgment has proved to produce surprisingly accurate forecasts (White, Valley et al. 1994).

DECISION BEHAVIOR

People's judgments are not perfect, and even experts make mistakes. Decisions can involve uncertainty with respect to outcome. This uncertainty can lead to risk or opportunities.

HEURISTIC AND INTUITION IN THE DESIGN PROCESS

It is easy to overestimate how much work has been done personally. It is also easy to underestimate how much of the design brief has been addressed or how much of the user's expectation. I.e. the study on the prevalence of breast cancer for women over the age of 40 by (David Eddy,1982) proves how heuristic can go wrong in the process of information and making decisions: In his study on the mammography test, he shows that doctors intuitively assign a 70% to 80% chance of breast cancer to a patient with a positive result of this test, while the real chance is less than 8%.

REVIEW OF THE DECISION TOOLS

TOOLS FOR THE CONCEPT SPACE (C-SPACE)

In this section, we refer to some of the usual methods for making decisions in the design process.

SWOT analysis

SWOT is a simple strategic analysis technique. Its name is an acronym representing four analysis perspectives addressed by: Strengths, weaknesses, opportunities and threats. The purpose is to create awareness of the forces that will impact the design process.

The SWOT analysis can be done in the early stages of the design process in order to obtain a general understanding of the forces influencing design. SWOT is meaningful mainly for analyzing the overall design. In this respect, a more meaningful analysis can be obtained by identifying strength, weakness, and threats for each alternative concept. This will allow the design team to realize certain threats facing various concepts. Similarly, certain strength that contribute to a concept.

Uncertainty analysis

Uncertainty analysis is used to consciously monitor the risks and opportunities for a design. This analysis is justified especially in the early phases of the design by simply considering the likelihood of the possible events and their consequences. Multiplication of the likelihood of an event occurring by the consequences of its occurrence is a valid metric for risk/ opportunity (Henley and Kumamoto 1981). It is important to develop strategies for avoiding occurrence of negative elements (risk) and increasing the likelihood of positive elements (opportunities).

This analysis therefore furnishes the findings of SWOT analysis. The uncertainty analysis can be used to improve the understanding of the uncertainties in each concept in the design.

Sensitivity analysis

Sensitivity analysis is a tool for showing that how sensitive different estimates are regarding the changes of their premise. Therefore, this tool is closely related to uncertainty analysis.

TOOLS FOR THE KNOWLEDGE SPACE (K-SPACE)

To compare and select among alternative design concepts, numerical methods are used or it can be shown numerically. We present some of the comparing tools here.

Spider chart

Comparing this info in the tables or matrixes is useful. But a more convenient method is using the spider chart. A spider chart is used for comparing different concepts.

Criteria testing

Criteria testing is useful for multiple goal analysis. In this method, we can model the impact of different design alternatives on a set of different objectives.

Paired comparisons

To select one of the alternatives among the others at the same time is can be a difficult task when there are many of design alternatives. By the method of paired comparison we can select the preferred alternative by a pair comparison.

A NEW GRAPHICAL TOOL FOR DECISION MAKING

Some of the important methods that are currently used in in the design process were presented in the previous section. Those tools are used for making decisions with the presence of uncertainties. In this respect, it is important to use a method to implement the information of decision makers more accurately. In the previously mentioned methods, the designer's or expert's opinion provides a basis for decisions. However, their confidence on their opinion has not been explicitly addressed.

For this purpose, we suggest a method to address the confidence or uncertainty of designers in the decision making process.

In the other hand, our suggested method aim to enable to communicate easily and intuitively with different members of the design team/ stakeholders. It happens in the design process that the decision makers are not comfortable to comment on their uncertainties in a formal way like as the variation and coefficient of variation (Jaynes and Bretthorst 2003). Having said this, graphs and drawings can be used for a better communication with different users. More importantly, designers are usually strong in visual communication. Therefore, we decided to communicate visually with designers and ask them to present their uncertainties or confidence visually. A simple table is designed for this purpose which is scaled from 0 to 100% (0 to 1). This is shown in Figure 1. Values of 0 and 100% present two extreme conditions when there is no chance of acceptance and when the criterion has been absolutely satisfied. Figure 1(b), for instance, presents a concept that satisfies a certain criterion between 20% and 80%. Assuming independent variables

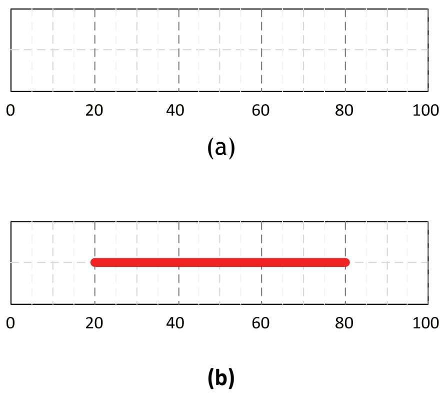

Figure 1. (a) the form that is to be offered to an expert to present his opinion within a confidence interval. (b) The confidence interval presented by the expert. The scale is in percent.

Then, we ask designers to present their feeling about the subject using the graph for their upper and lower confidence interval. It is important to notice that a designer or decision maker can use this approach even for abstracted ideas and concepts. Therefore, this method can be used in either of C- and K-spaces.

INTREPRETATION OF DATA

SIMPLE MEAN VALUE

Given j number of concepts and i number of criteria, we want to make a rational decision to choose among those j concept. We use the following formula to score the most preferred concept (subject).

$$S_j = \sum_{i=1}^{n} \mu_{ij} \tag{1.1}$$

where S_j is the final score of concept (subject) j, and μ_{ij} is the average rank of criterion i of subject j defined as follows.

$$\mu_{ij} = \frac{b_{ij} + a_{ij}}{2} \tag{1.2}$$

where a_{ij} and b_{ij} are respectively the lower and upper limits of the confidence interval for criterion i of concept j. This can also be done visually as shown in Figure 2. The dark area of each figure represents the total score of the related concept. For illustration purpose, we refer to the Cold Facts project explained later in this paper. We want to decide between Concept 1 and Concept 2 given the criteria of Table 1.

Table 1.For making decision, two different concepts of the Cold Facts and three criteria are given.

Criteria	Weight	Concept 1	Concept 2
Light weight	1	Figure 2 (a)	Figure 2 (b)
Aesthetics	1		
Reliable	1		

WEIGHTED MEAN VALUE

Given j number of concepts and i number of criteria for making decision to choose among those j concepts, we can use the following formulation to score the most preferred concept

$$S_j = \sum_{i=1}^{n} \lambda_i \mu_{ij} \tag{1.3}$$

Where $\lambda_j \leq 1$, and S_j is the final score of concept j, and λ_i is the importance factor of criterion i and

μ_{ij} is the average rank of criterion i of subject j.
And

$$\mu_{ij} = \frac{b_{ij} + a_{ij}}{2} \quad (1.4)$$

where a_{ij} and b_{ij} are respectively the lower and upper limits of the confidence interval for criterion i of subject j as shown in Figure 3 using data obtained from Table 2.

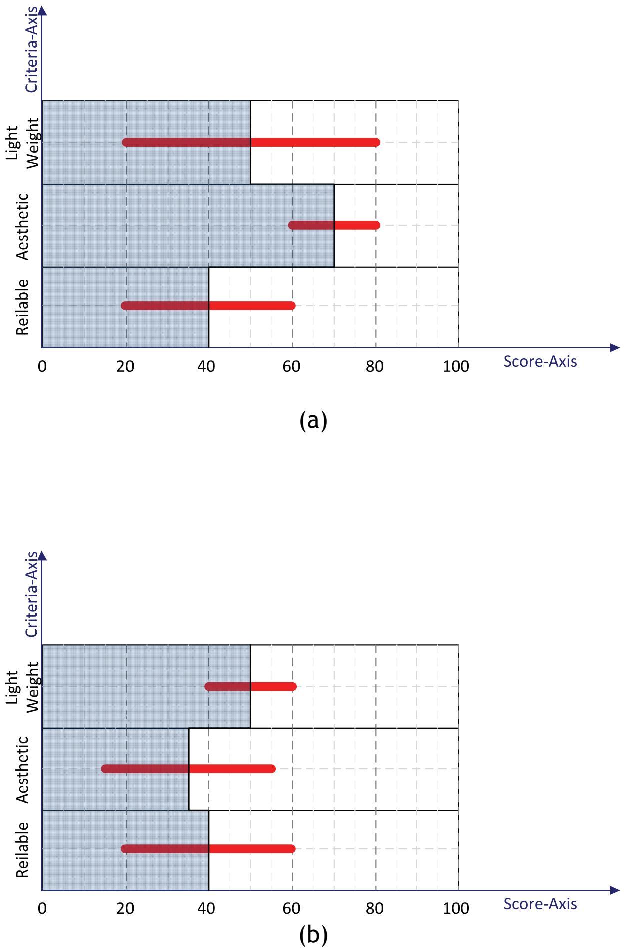

Figure 2. Comparing two different concepts of (a) and (b) based on the mean value method. The total score can be shown as the hatched areas. The horizontal axis is in percent.

Table 2. Different weight factors are given for different design criteria.

Criteria	Weight	Concept 1	Concept 2
Light weight	0.8	Figure 3(a)	Figure 3(b)
Aesthetics	0.3		
Reliable	1.0		

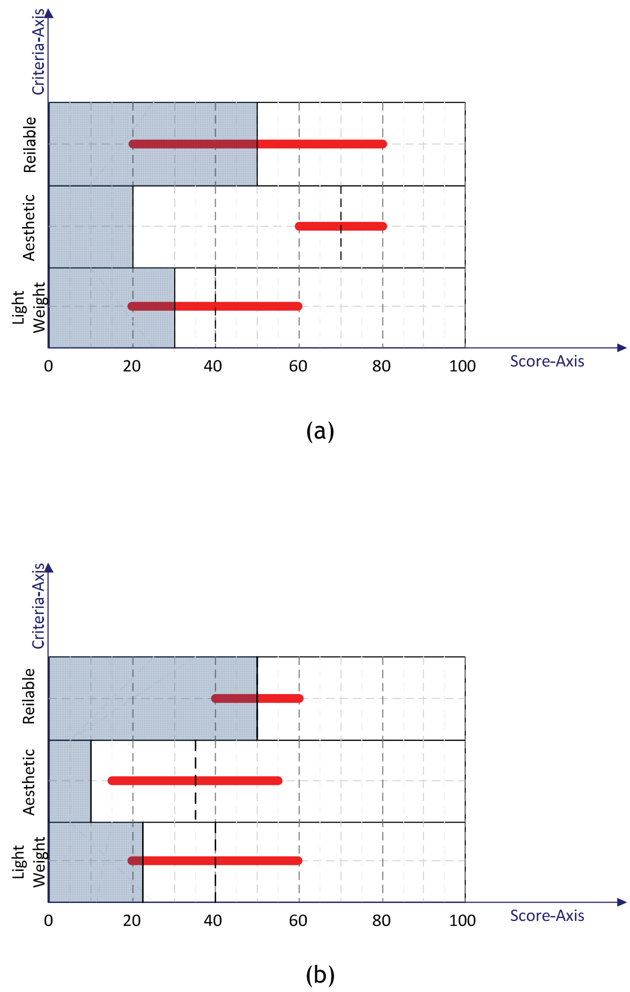

Figure 3. Comparing two different subjects of (a) and (b) based on the weighted mean value method. The total score can be shown as the hatched areas. The horizontal axis is in percent.

TOTAL UNCERTAINTY

The total variation of each design concept can be calculated. The total uncertainty of each subject is proportional to the calculated value by

$$U_j^2 \propto \sum_{i=1}^{n} \left(b_{ij} - a_{ij}\right)^2 \quad (1.5)$$

or

$$U_j \propto \sqrt{\sum_{i=1}^{n}\left(b_{ij}-a_{ij}\right)^2} \quad (1.6)$$

The measured uncertainties are presented in term of variation. Therefore, design subjects with similar scores obtained from Equation (1.3) can be ranked according to their uncertainties. In general, a design with a higher confidence which means a smaller amount of uncertainties are preferred. In fact, the robust design methodology focuses on designs with a smaller amount of uncertainties(Arvidsson and Gremyr 2008).

EXAMPLES

NUMERICAL EXAMPLES

In this section, we implement our method to compare two different concepts presented in Figure 2 and Figure 3. We use the simple mean value method, the weighted mean value method, and calculate the total uncertainty of each method.

Simple mean value method

The simple mean value of concept 1 (Figure 2(a))

$$\begin{aligned} S_1 &= \sum_{i=1}^{3}\mu_{i1} \\ &= \left(\frac{80+20}{2}\right)+\left(\frac{80+60}{2}\right)+\left(\frac{60+20}{2}\right) \\ &= 160 \end{aligned}$$

(1.7)

and the simple mean value of concept 2 (Figure 2Figure 3(b)) is calculated as:

$$S_2 = \sum_{i=1}^{3}\mu_{i2} = 125 \quad (1.8)$$

Weighted mean value method

The weighted mean value is applied to the concepts of Figure 2. The weight factors are given in Table 2. As a result, the total score of Concept 1 (Figure 3(a)) is:

$$\begin{aligned} S_1 &= \sum_{i=1}^{3}\lambda_i\mu_{i1} \\ &= 0.8\times\left(\frac{80+20}{2}\right)+0.3\times\left(\frac{80+60}{2}\right)+1\times\left(\frac{60+20}{2}\right) \\ &= 101 \end{aligned}$$

(1.9)

and the total score of Concept 2 (Figure 3(b)) is calculated as:

$$S_2 = \sum_{i=1}^{3}\lambda_i\mu_{i2} = 90.5 \quad (1.10)$$

TOTAL UNCERTAINTY

The total uncertainty of Concept 1 and 2, given in Figure 2 (a) and Figure 2 (b), is estimated using Equation (1.5) as follows.

$$\begin{aligned} U_1 &\propto \sqrt{\sum_{i=1}^{3}\left(b_{i1}-a_{i1}\right)^2} \\ &\propto \sqrt{(80-20)^2+(80-60)^2+(60-20)^2} \\ &\propto 74.8 \end{aligned}$$

(1.11)

while

$$\begin{aligned} U_2 &\propto \sqrt{\sum_{i=1}^{3}\left(b_{i2}-a_{i2}\right)^2} \quad (1.12) \\ &\propto 60 \end{aligned}$$

COLD FACTS PROJECT

Cold Facts is a program of the Dutch World Wide Fund (WWF Netherlands) on the topic of climate change and the polar regions.

The purpose of this project is to build a reliable and lightweight weather station which is to be deployed at the sea ice surface where it will measure and record data on temperature, barometric pressure and position. The measured data will be added into the database of International Arctic Buoy Program (IABP).

Project specifications

In order to promote scientific data collection in the polar regions, the instrument is to be portable and easily deployable which integrates a weather station and GPS locator. The program of requirements for this projects are that the device should be: lightweight, compact and easy to carry, plug and play, durable in extreme weather conditions, sustainable and satellite uplink.

The developed concepts and design

The design team was a combination of 15 students from different faculties of TUDelft. This interdisciplinary design team was coached by the authors of this paper. There were three different concepts developed by the design team. Making a choice among different concepts was a challenge since some students had more expert knowledge in structural mechanics, some of them in electronics, some of them in creative design methods, etc. To overcome this challenge, we asked all the team members to use our novel decision making method in order to select the most successful concept. We asked them to implement their thoughts into decisions by implementing their uncertainties. This is not possible by the normally used methods in design. As a result, the design team could systematically assess different concepts early, and support its design decisions using the robust design method.

CONCLUSIONS

This paper presents a novel visual method for making decisions, suitable for both the concept and knowledge space and different levels of abstraction. This method enables designers to implement their uncertainties into the design process. For better understanding of the influential parameters on human decisions, a number of examples have been presented based on the 'Cold Facts' project.

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