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EXPLORING THE NEED FOR AN INTERACTIVE SOFTWARE TOOL FOR THE APPROPRIATE SELECTION OF DESIGN METHODS

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Abstract

The incorrect use and selection of design methods by engineers often occurs and leads to disappointing results and general distrust of methods. It constitutes one of the main reasons for lack of use of methods in industry. In this paper an interactive software tool that guides engineers in the appropriate selection of methods is identified as a way to enhance the correct use of methods in industry. The focus of the paper is on presenting the nature of the problem of incorrect use and selection of design methods and the justification for developing such computer-based support.

Keywords: design methods selection, evaluation of design, introduction of methods in industry

1 Design methods in industry and positioning of this paper

Many design methods have been created, e.g., Pugh, Pahl & Beitz, Jones, Cross, but few are consistently used in industry. A survey carried out at Volvo Car Corporation (VCC) shows that the use of methods is not consistent. Some methods are applied on the initiative of engineers themselves. Those methods are used with ad-hoc modifications or for inappropriate situations with some frequency due to possible lack of training, proper descriptions, etc. At other times, methods are used because management provides some training and encourages their use as much as possible. Since all methods suffer deficiencies, i.e., they do not enjoy general validity [1] [2], they will at some stage produce disappointing results thus making engineers reluctant to use them again. By the time it is likely that a new method will have been developed which will be claimed to be the key to company's competitive advantage. The new method will be introduced as a substitute for the failed previous approach. The use of a method comes and goes like fashions in industry. New methods replace previous ones even if they have been conceived to solve different challenges.

In this paper we support a different approach for the implementation of methods in industry. Design methods that have been learned, and used within a company must be kept within the company's knowledge pool when subsequent methods are introduced. The knowledge concerning design methods is a type of resource that a company should retain. New methods must come, but they should not be seen as substitutes for previous ones. Methods are complementary to each other. No one method enjoys general validity. It is important that attempts should not be made to try to find any definitive method since no definitive method exists. Rather, it is better to understand the principles of methods and the circumstances under which they are effective. Therefore, a company can make appropriate and reliable methods selection and undertake staff training and development to fill gaps in company knowledge.

2 State-of-the art in methods selection and contribution of this paper

The factors that prohibit the successful implementation of methods into industry have been reported by several authors, e.g., [3] [4] [5]. As a result of this investigation incorrect selection of methods has been identified as one of the key factors to address. That is to say, an important reason why methods are not successfully implemented in industry is that the frequent inappropriate use of methods leads to disappointing results and mistrust of methods in general. Therefore, selection of methods is an issue that requires attention from academia. The main reasons identified for careful selection of methods are:

- To support the actual needs of a company and avoid absorbing methods because of their popularity [6].
- To manage the revolution-evolution characteristic of a company strategy [2].
- To manage the degree of uncertainty of a product development process and the innovation-adaptation characteristic of the resulting product [2].
- Due to the fact that inappropriate use of methods brings about penalties such as a long development process, biased results, false degree of certainty, non-conformity with user expectations [1] [2] [7].

However, the selection of appropriate methods is a difficult task because:

- Methods are insufficiently and unevenly defined [7] [8]. Examples are not always realistic and descriptions are not always complete. Normally authors insistently explain why their methods produce beneficial results but seldom for which circumstances they are actually useful.
- There is an increasing number of methods available to engineers [9], most of which are claimed to be complete and generally valid [5].
- To learn and understand the inherent characteristics of the methods as they are delivered today, thorough learning and practice are required both of which are time-demanding.

In this context, Ernzer and Birkhofer argue that a three-step approach is convenient for the appropriate selection and implementation of methods [9]. The three steps are: (i) method pool selection, (ii) strategic level selection and (iii) operational level selection. The value of this approach resides not only in structuring the contributions made by academia until present but also in separating three steps of selection that must be done by different "selectors".

The method pool selection is mainly carried out by academia. It aims to standardise the descriptions of methods, evaluate their suitability for application in industry and undertake the education of future users. Within this selection stage the work developed by the German schools is worth mentioning. They have developed an "integrated learning, information, and training environment which utilizes the Internet as the communication platform" [8]. *Thekey*, as it has been called, serves as an interactive database of design methodology knowledge with structuring, researcher-networking and standardising purposes.

Strategic level selection is a company's responsibility. This level of selection is intimately related to methods implementation. The aim is to select methods to be introduced in the company that match its strategic positioning and support the tasks that its employees have to carry out. Work done in the EcoDesign field [6] [9] and design theory and methodology field, e.g., [10], are following this direction. Step-wise processes have been proposed to deal with the implementation of methods, in which selection of methods is one of the steps. Methods to deal with the selection of methods have also been suggested [9] [10] that aim to match the method choice with the needs of the company.

The third level of method selection is the operational level. In this case, the "selectors" are engineers who have to choose a method to solve a specific problem in a project. It is at this level where this paper aims to make its main contribution and where our prior research has been focused. Our assumption is that correct use and selection of methods during the problem solving process will improve confidence in methods and lead to their appropriate use in a systematic way. A model that helps engineers to understand which method to use according to the problem "conditions" was previously developed [2]. In this paper the model is applied to four specific evaluation methods. The task of selecting from the four methods is shown to be complex. Still more difficult is to select one method from the range of methods available in the literature, particularly considering the range of problems faced in industry. This justifies the need for an interactive software tool that guides engineers to select an appropriate design method. The tool, which would beneficially be in software form, should be easy to learn and allow engineers to put into practice the selection model without extensive theoretical knowledge.

3 Research method

The research presented in this paper builds on previous research results that are briefly outlined in this section. For the problem of selection of methods in industry a selection principle was developed to help engineers select them appropriately [2]. The principle contends that convergent methods have different degrees of Innovation-Adaptation (I-A) characteristic. There are methods that are appropriate for the evaluation of precise quantifiable data that have been called *adaptive convergent methods*. There are methods that are appropriate for the evaluation of approximate soft data that have been called *innovative convergent methods*. Most of the methods have an intermediate position between the innovative and adaptive extremes. Guidelines for the identification of the I-A characteristic of convergent methods were explored and can be found in figure 1. They can be used to classify methods according to their I-A characteristic.

INNOVATIVE	CONVERGENT METHODS		ADAPTIVE
	HIGHLY INNOVATIVE:	**HIGHLY ADAPTIVE:**	
	> Require approximate or soft information about concepts	> Require hard and precise information about concepts	
	> Evaluation of a large amount of diverse ideas	> Evaluation of a single concept	
	> Gather together information that helps to take a decision	> Give a numerical solution	

Figure 1. Guidelines for the identification of the I-A characteristic of convergent methods

The guidelines are based on the study of when methods are effective, i.e., when they produce reliable results. The leading factors in the selection of the appropriate method are: the number and diversity of ideas to evaluate, the degree of precision of the inputs required by the evaluation method to operate meaningfully and the desired degree of certainty of the outputs after the method is used. When engineers have to deal with evaluation of early sketchy ideas, the use of adaptive (precise) methods is not the correct choice since they can lead to incorrect decisions being made based on a false sense of certainty or they may become too time-consuming. Also when evaluating concepts of which numerical precise data is available, the use of innovative convergent methods implies accuracy loss that might not be desirable. This selection principle was explained to engineers from diverse companies and gained certain acceptance, but still it does not make the selection of methods simple in practice because it requires from engineers a good understanding of methods. In this paper the principle is applied to four evaluation methods with the aim to explore how it can be used in practise. Selection rules for the four methods are obtained. The methods are: Highlighting technique (HT), Advantages-Limitations-Uniqueness-Opportunities for change (ALUO), Pugh method (Pugh M) and Rating & Weighting method (R&WM). They have been selected as examples because they have some common characteristics, they cover a wide range of the I-A scale of methods and because they are well known so that exhaustive descriptions are not required here. However, the paper does not intend to be an excluding compendium of methods. Our research includes a wide range of methods in order to increase the capacity of decision teams makers to deal with a broad diversity of evaluation challenges.

The reader of this paper should note that the word "selection" is used in two different contexts. On the one hand we are exploring the principles of selection of four different methods, and on the other hand, those four methods are evaluation methods to select the best concept(s). That is to say, the word selection will be used sometimes meaning selection of methods and in other cases for the selection of concepts. The actual meaning is clarified by the context. The exploration of selection principles for the four methods has been structured into three main parts:

1. Common characteristics of methods for the Selection of Discrete, Multi-Criteria (S/D/Mu-C) methods. Here the common characteristics of the four methods are discussed, and principles to select these methods against other existing methods are suggested.
2. Distinctive characteristics of HT, ALUO, Pugh M, R&WM. The characteristics of the four methods are discussed and principles for selection of each individual method as opposed to the other three are suggested.
3. Distinctive characteristics of the elementary methods of Pugh M and R&WM. Two of the methods are composed of elementary methods that perform "elementary tasks". These tasks can be carried out using different methods. Alternative methods are discussed and principles of selection between them are suggested.

4 Common characteristics of S/D/MU-C methods.

HT, ALUO, Pugh M and the R&WM are multi-criteria evaluation methods for the selection of discrete concepts. An explanation of these terms and how they affect the usability of the methods is given in the following section.

4.1 Discrete vs. continuous case selection methods

Sometimes engineers are required to decide which is the best option among several essentially different alternatives, i.e., among discrete concepts. It is, for instance, common that engineers come up with several ideas to solve a problem and they have to decide which one(s) to continue with. The methods presented in this paper are useful for the selection of these kinds of concepts. At other times, engineers have to make decisions concerning continuous concepts, ie, they have to determine the numerical value of a variable or variables that influence attributes of the resulting concept amongst which there may be a trade-off. The determination of the set of values of oil and filler level that optimise a rubber formulation with respect to cost, rebound, tensile and hardness is a continuous case selection challenge (example from [11]) . Methods used to deal with the continuous case can be system dynamics and desirability optimisation [11].

4.2 Multi-criteria vs. mono-criterion selection methods

Mono-criterion selection methods are those methods used to find out which concept out of several, is the one that performs better with respect to a single and specific objective. An example of mono-criterion selection methods is the calculation of a performance in a particular respect. For example, a reliability block diagram can be used to select the most reliable concept. Multi-criteria selection methods are those methods that help decision makers to determine which concept to select according to performance with respect to diverse criteria (objectives). Examples of multi-criteria decision methods are the four methods studied in this paper. There is one factor that differentiates the two types of methods fully. In the mono-criterion selection method, from the beginning the selectors have a clear vision of what makes a concept "perform well". Therefore, the goal is to find out how the different alternatives perform with respect to the "key" criterion and select the best one. In the multi-criteria decision methods the criteria to be used for the selection has to be defined. Moreover different criteria normally belong to different fields of expertise and they do not have the same degree of importance. Multi-criteria decision methods tend to imply the need for multi-disciplinary groups and thus the need for increased time. Multi-criteria selection methods are highly recommended when ensuring that the selected concepts perform at an acceptable level with respect to all criteria. Mono-criterion selection methods should be used complementarily to multi-criteria selection methods.

5 Distinctive characteristics of HT, ALUO, Pugh M, R&WM.

Differences exist between HT, ALUO, Pugh M and R&WM making them suitable for different problem conditions. In **R&WM** (figure 2) the selectors must agree on: the criteria to be able to evaluate the concepts, on the relative importance of each of the criteria and on scores that represent how each concept performs with respect to each criterion. It is the most "fair" of all the four methods but this does not mean that it is always the most appropriate. Since this method requires engineers to score concepts and weight criteria, quantifiable information of the concepts should be available. If it is not, the procedure becomes highly sensitive to the people using it, and even the same set of people can produce varying scores that differ noticeably from one day to next. It also brings about another inconvenience. The method requires a long period of time for completion. This long precise process is only worth undertaking if the results are accurate. Therefore, the use of R&WM is only recommended when there is certain numerical data about how each concept performs and accuracy is desirable.

In **Pugh M** (figure 2) the selectors must also agree on the criteria of the ideal concept and criteria can be weighted for more accuracy. But in contrast to R&WM, selectors do not need to grade with precision on the performance of the concepts, they simply need to evaluate them in terms of whether they are better or worse with respect to a reference concept. Therefore, when numerical data concerning the concepts performance is not available, Pugh M is a better option than R&WM since it is less precise but more reliable. Pugh M could also be used when numerical data is available but selectors prefer to do a rougher and faster evaluation.

Sometimes a concept scores very badly in Pugh but the group does not wish to reject it because of its potential. The problem is not that Pugh M is a poor method, but that other types of methods may be more convenient, such as, **ALUO** (figure 2). The latter is a method for evaluating "tentative" concepts, i.e., concepts that are not very matured and of which essential characteristics can still vary significantly. The strengths, unique characteristics, concerns and ways to overcome such concerns are explored for each of the concepts to evaluate. Selection is based on the statements produced during the analysis process of the concepts. There is a possibility of the concepts that are chosen to continue with may not be any of the concepts evaluated but a possible combination of them.

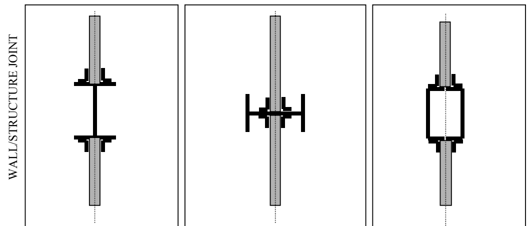
However, in some cases, ALUO may be a too precise method. This happens when the number of ideas is too high and diverse. In such a case there is not enough time to assess every single idea using a method like ALUO. Therefore a method such as **HT** (figure 2) is more appropriate. HT method consists of a group of multi-disciplinary engineers that should hit the most promising, relevant, clear, workable, on target or intriguing ideas, cluster them into groups of common themes and give each group of ideas a name in the form of a statement that synthesises them.

In short, the selection of the correct method from the four explored in this paper should be based on the I-A characteristic of the method. Three parameters are examined to identify the I-A characteristic: (i) the number of ideas and their diversity; (ii) the degree of maturity of the concepts; (iii) and the desired degree of precision of the output of the evaluation. The four methods can be ordered according to their I-A characteristic. The most adaptive one is R&WM, followed by Pugh M, then ALUO and last HT.

Ideas for functional products

Used by various non-qualified users	Medical
• Photo-copy machine by the copy • Washing-machine by the litre of water	• Brain scanning equipment • Dialysis M/Cs • Surgery equipment • X-ray
Transport	**Childcare**
• Engine power by the hour • Flexible personal transport • World-wide travel • Integrated transport Road/Rail/Air	• Educational toys • All baby appliances • Baby-sitter
	Life style
	• Home entertainment • Personal health monitoring & analysis

Highlighting technique (HT)



Advantages	Simple to install High stiffness Economic	Simple to install Good isolation	High stiffness Elegant
Limitations	Bad isolation	Low stiffness Powder accumulation	Expensive Low isolation
Uniqueness	Hide pipes	Hide pipes	
Opportunity for improvement	Isolating panel (easy, expensive)		Isolating blanket (easy, inexpensive)

ALUO

CRITERIA	CONCEPT A	B	C	D
Cost	REFERENCE	-	+	0
Reliability		+	-	+
Development cost		-	-	0
Maintainability		+	+	+
Aesthetics		+	+	-
Ease of manufacture		0	-	-
Commonality		+	-	0
Sum of +'s		4	3	2
Sum of 0's		1	0	3
Sum of -'s		2	4	2
Total Score		2	-1	0
Rank		1	3	2

Pugh method (PM)

CRITERIA	% weight	CONCEPT A (reference) Rating	Weighted Score	B Rating	Weighted Score	C Rating	Weighted Score
Cost	0,23	2	0,46	2	0,46	4	0,92
Reliability	0,14	3	0,42	4	0,56	2	0,28
Development cost	0,23	4	0,92	1	0,23	2	0,46
Maintainability	0,05	3	0,15	4	0,2	5	0,25
Aesthetics	0,09	3	0,27	5	0,45	5	0,45
Ease of manufacture	0,17	3	0,51	3	0,51	2	0,34
Commonality	0,09	4	0,36	5	0,45	2	0,18
Total Score			3,09		2,86		2,88
Rank			1		2		3

Rating and Weighting method (R&WM)

Figure 2. Four multi-criteria evaluation methods for the selection of discrete concepts

6 Distinctive characteristics of the elementary methods of Pugh M and the R&WM.

In order to complete Pugh M and R&WM (figure 2) several "elementary tasks" must be performed. They are: 1. Criteria selection and weighting; 2. Criteria organisation; 3. Concept scoring; 4. Overall performance calculation and selection. Each of these sub-tasks can be done with different elementary methods that affect significantly the result of the evaluation. The principles to select from the alternative elementary methods are briefly discussed in the next sections.

6.1 The elementary methods of R&WM.

1. When weighting the relative importance of criteria various options must be considered:

- Not weighting the criteria if they are believed to be of approximately equal importance.
- Weighting can be made by simple examination. This method is recommended when experts can agree on consistent weighting.
- A prioritisation matrix can be used where the criteria are compared in pairs. It is recommended when a group of engineers needs to thoroughly discuss the relative importance of each criterion in order to reach a common understanding.
- The Analytical hierarchy process. This process is recommended when thorough discussion of the weight of each criterion is required, and additionally there are many criteria at different hierarchical levels. The method ensures consistency in the weights attributed.
- Sensitivity analysis. This can be used in addition to any of the previous techniques mentioned to identify which criteria are more affected by small changes in design.

2. The obtained criteria weights can be used in different ways that affect the way to organise the criteria:

- The weights can be used to multiply the scores of each concept. In this case the criteria are organised as they were in the previous stage.
- The weights of the criteria are not used to multiply the scores, but to classify the criteria in three groups according to their level of importance: (i) essential criteria, which are the criteria with respect to the best concept should perform the best; (ii) complementary criteria, which are important criteria that needs to be considered to be able to form a satisfactory and balanced whole; (iii) and supplementary criteria, which are non-vital but welcomed criteria. This method implies the calculation of the overall performance of the concepts for each of the three different categories of criteria and for the whole. This alternative is convenient when the uncertainty in weighting the importance of the criteria is considered to be relatively high.

3. The aim of scoring the different concepts is to have all the performance criteria expressed in the same unit so that the overall performance can be calculated. There are different methods to connect value scores and attributes magnitudes (or criteria magnitudes) of a product according to the type of relationship between the magnitude and the value score.

- Linear one-limit relationship [12]. This is the simplest case. It is useful when the value score is considered to vary linearly with the attribute magnitude and there is one limit magnitude from which the behaviour is unacceptable that is given 0 as value score and one limit magnitude from which the concept is over-performing that is given 10 as value score. In that case, the experts must only agree on the two limits and interpolate to find out the value score of intermediate attribute magnitudes. Interpolation can be done with the help of formulas, graphical functions or tables.

- Linear two-limits relationship [12]. This case takes place when the attribute magnitude presents two limits of unacceptable behaviour and the relationship between the value score is considered to vary linearly with the attribute magnitude. The experts in this case have to agree on the two magnitude limits of unacceptability, both of which receive a value score of 0. The best performance is the mean of those two magnitudes with a value score of 10. The value score of intermediate magnitudes can be calculated through interpolation with the help of formulas, graphical functions or tables.
- Non-linear relationship [12]. This is the case when experts consider that there is no linear relationship between attribute magnitudes and value scores. Then they are asked to score from one to ten, a range of performances that are expected of a product in some specific conditions and the utility function that best fits the points recorded is drawn.

4. In order to calculate the overall performance, different methods can be used:

- Arithmetical mean. With this method the selectors assume that a good performance of one concept in a criterion compensates for a poor performance in another criterion [1].
- Harmonic mean. It promotes the idea of concepts performing reasonably well in all criteria since it highlights low scores [12]. This is recommended when selectors seek concepts that perform consistently well.

6.2 The elementary methods of Pugh M.

1. Criteria weighting and 2. Criteria organisation have the same alternatives as R&WM.
3. When scoring the different concepts, "better" (+), "equal" (0) and "worse" (-) should be used as compared degrees of behaviour.
4. In order to calculate the overall performance, different methods can be used:

- Sum the number of "+" and subtract the number of "-" and reject the concepts with a negative total score. Using this method the selectors assume that a better performance of one concept than the reference in a criterion compensates for a worse performance in another criterion.
- Separately sum the number of "+", the number of "0" and the number of "-" and using the results gained discuss which of those concepts are better/worse than the reference. This is recommended when selectors seek concepts that perform consistently well.

This procedure does not provide insight into which concept behaves the best, considering interactions between the criteria, it only shows which concepts perform better or worse than the reference concept by comparing criteria in isolation.

7 The complex task of selecting the appropriate method

In figure 3 the decisions that engineers have to make are mapped in order to select one of the four methods according to the principles explained in the previous sections. The number of decisions to make a conscious selection is high: 4 decisions for the highlighting technique and ALUO, 8-9 for Pugh M and W&RM. These decisions are on very different levels but all influence heavily the results obtained. Results are only reliable if the method is consciously selected according to the problem needs. Our experience shows that failed selections occur often.

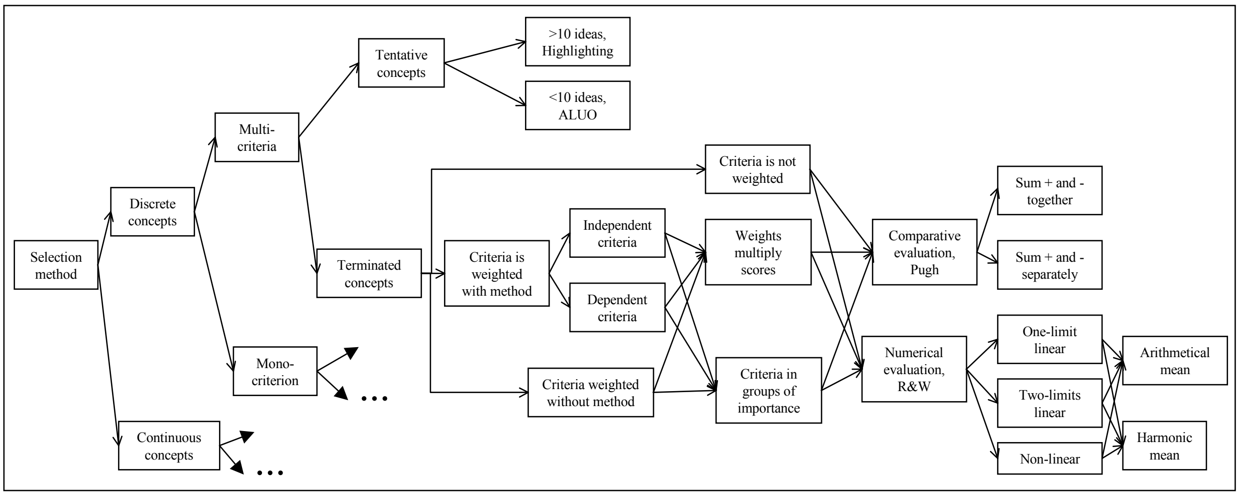


Figure 3. Decisions that have to be taken to make a conscious selection between the Highlighting technique, ALUO, the Pugh method and the Weighting & Rating method.

The way methods are delivered and taught today is not suitable for over-loaded engineers. It is difficult to retain precise knowledge about methods and their selection rules. Engineers need ready-to-use methods that speed up or improve their work performance. The methods, as they are delivered today, with all their influencing selection rules have an opposite effect. Therefore, we believe that a software application that guides engineers in the selection of the correct method and that leads them to the appropriate method software should be created. It should be an interactive tool that poses key questions concerning the problem to be tackled to the engineers and that makes suggestions of method choice according to the responses given.

The software shall not only be useful as a method selection guide, it would also prove its worth as an integrating environment for the methods used in a company. It would present methods in a more appealing format, interactive format, than today and it would allow engineers to learn to use the methods by using them in practice. It would enhance the use of methods in a consistent manner throughout the company and promote the understanding of methods as complementary to each other. The amount of times that the different methods are used, and the problem types they are used on, can be monitored for future reference and for learning exercises. The software could be updated using the knowledge gained about the successful use of methods in the company.

8 Conclusions

It is important to understand the conditions under which methods are effective. A way of achieving this is by comparing methods against each other and defining rules for the selection between them. However, in order that engineers learn and retain a comprehensive set of detailed rules, the choice of method should be presented in a way that supports their needs. An interactive software tool based on the principles explored in this paper will support those needs. The software is being developed within the Polhem laboratory and will be tested in several Swedish industries. Future work is to explore the incorporation of methods for the evaluation of concepts at different maturity levels [13].

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