NordDesign 2004 – Product Design in Changing Environment
18-20 August 2004, Tampere, Finland

A CONCEPT DEVELOPMENT SUPPORT TOOL FOR MULTIATTRIBUTE DECISION MAKING

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Keywords: design methodology, concept development, concept selection, decision making

Abstract

This paper presents the centric result from a cooperative research project between university and industry partners. The objective of the project was to identify areas in the company's product development process that could benefit from tailored and effective use of existing systematic product development methodologies. Possible areas in the company's product development process were determined by interviewing seven engineers and two industrial designers. Through conducted research and analyses, it was concluded that the concept development phase was a potential area for use of design methodologies and focus was seen to be put on support of the concept development phase as a whole, project input information, and evaluation and decision making in concept development. The aim of this paper is to present the principles of a created support tool for these areas of concept development. The conducted research and the created tool have shown immediate industrial contribution through the good reception of the tool in practice. The academic contribution of the work can be divided into two areas: results that are immediate and results that are later gained through the possibility to evaluate the use of concept development methodology in practice. Immediate academic contributions include the documentation of an approach to justifiably combine three separate design methods. This approach enables the use of new graphical approaches for evaluating concept variants and comparing them against each other. In addition, the use of non-linear preferences in concept selection is discussed.

1 Introduction

The importance of investing resources and effort into the early phases of product development is well known. The bound costs are only a fraction of what they are later in the project [Ward 1995] and the possibility to influence the costs of the to-be product, as well as the ease of making changes to the design [Schuster 1997] are higher than later on. One could say that concept development work is not focused on the design of the actual product, but on making the subsequent design work more productive [Repenning 2001]. It is therefore vital that the best concepts are selected, as they determine the direction of the design embodiment stage [King and Sivaloganathan 1999]. The result of a poor choice is often not known until much later, and if it is then decided to revise the decision, the intervening time and expenditures are mostly unrecoverable [Ullman 2001]. Even though the defining nature of the early design phases on the entire product development process of a company is well founded and likely understood, in practice there exists strong pressure in projects to speed up the concept development phase and produce visible results faster. Time constraints that exist in practice have an effect on the generation and evaluation of concept variants; a satisfactory solution fast may be better than an optimal solution later [Günther and Ehrlenspiel 1999]. In complex and new design problems, design methodology can be usefully employed to assist designers [von der Weth 1999]. It is considered important to apply structured methodological approaches to design projects [National Science Foundation 1996].

Methods that have been presented to support conceptual design include *Quality Function Deployment (QFD)* [e.g. Cohen 1995] for translating customer needs into product design characteristics, various ideation methods for generating concept variants, and structured methods for functional decomposition and the combination of sub-concepts. A well-known method for systematic combination is the *Morphological matrix* [Pahl and Beitz 1984]. Methods that have been presented for evaluating and selecting concepts include *Pugh's evaluation method* [Pugh 1996], *Concept rating methods* [e.g. Pahl and Beitz 1984], the *Analytic hierarchy process (AHP)* [Saaty 1990], and the *Fuzzy set method* [Thurston and Carnahan 1992]. In literature Pugh's evaluation method has also been called *Concept screening* and a method were concepts are rated *Concept scoring* [Ulrich and Eppinger 2000]. The before-mentioned methods for evaluating and selecting concepts have also been criticised. It has been stated that some of the methods are dependent on an arbitrary set of requirement weights and that they do not consider other than linear preferences of the decision maker [See and Lewis 2002]. It has also been stated that none of the above methods are able to consider coupled decisions and that the AHP and Fuzzy set methods are relatively complex [King and Sivaloganathan 1999]. As a result, new methods that claim to better consider these aspects have been presented. These include the *Hypothetical equivalents and inequivalents method* [See and Lewis 2002] and the *Flexible design concept selection method* [King and Sivaloganathan 1999].

Design research is an applied science, which needs to be validated by its effects in industrial application [Andreasen 1996]. Nevertheless, the degree of utilisation of product development tools and methods in industry has been identified relatively low [Wright et al. 1995, Whybrev et al. 2001]. It has been stated that regarding conceptual design, there is a lack of understanding (and perhaps training) that impedes the use of tools in practice [National Science Foundation 1996]. Thus, there is a gap between research and practice; effective methods need to be developed for transferring research results into practice [National Science Foundation 1996] and results from theory and practice need to be combined [Hansen and Andreasen 2004].

In this paper, a *Concept specification and selection tool* that was created in a cooperative research project between university and industry partners is described. The objective of the project was to identify areas in the company's product development process that could benefit from tailored and effective use of existing product development tools and methods. The project can thus be described as one individual effort into reducing the stated "gap" between research and practice.

2 Research approach

In this chapter an overview of the research approach used in creation of the *Concept specification and selection tool* is given. As mentioned, the tool is the result of a cooperative research project between university and industry partners. The objective of the project was to identify areas in the company's product development process that could benefit from tailored and effective use of existing product development tools and methods. The first step of research was therefore to identify if such areas in the company's product development process existed, and to gain information for determining the demand and focus for further work. An evaluation of the company's product development process was completed by interviewing seven engineers and two industrial designers from the company. The interviews were based on a structured questionnaire, which included a list of design tasks/activities compiled on basis of the company's product development process description. The perceived functionality of the tasks/activities were rated by the interviewees (how well does the completion of each task/activity generally perform) and related comments were noted down by the author (commented problems etc.). The time used for each interview ranged between 1,5 and 2 hours. Conclusions for the functionality of each activity were thereafter made on basis of the activity ratings and the related comments of the interviewees. The functionality of the different phases of product development were concluded from the functionality of the individual activities belonging to the phases. In addition, clusters of individual tasks/activities that could be grouped based on a common basis were analysed. After evaluating the results, it was concluded that the concept development phase was a potential area for use of design methodologies and focus was seen to be put on support of the concept development phase as a whole, project input information, and evaluation and decision making in concept development.

To gain more information on existing practices in the company's concept development phase, a retrospective analysis of one completed product development project was completed. This second step of research was based on archive analysis, similar to that used in [Macmillan et al. 2001], as well as interviews of engineers, designers, and marketing involved in the early phases of the project. This step revealed information on context specific approaches used during conceptual design. For example, a note was made on the unsuitability of a systematic concept combination approach to the concept development practices and process applied in this case.

After the above described two analyses, it was seen that the research had provided sufficient information about the design process and context specific concept development practices of the company. It was now possible to identify suitable design tools and methods to be applied to support the concept development phase. These were sought from academia, one source being a previously carried out literature survey [Salonen and Kauhanen 2002]. The selection of the methods was carried out by the author in close cooperation with engineers from the company. As a result, *Paired comparisons* (used e.g. in *QFD* and *AHP*), *Concept screening*, and *Concept scoring* were selected to form a frame for the support tool. Thereafter, the Microsoft Excel based *Concept specification and selection tool* was developed. It is based on the three above-mentioned methodologies.

3 Concept specification and selection tool

In this chapter an overview of the created *Concept specification and selection tool* is given. The tool consists of eight sections (Figure 1). Each of these sections is an individual worksheet or a set of worksheets in a common Microsoft Excel workbook. Each section of the tool is created for a specific target, identified during the completed research of needs for enhanced concept development practices in the context of the company.

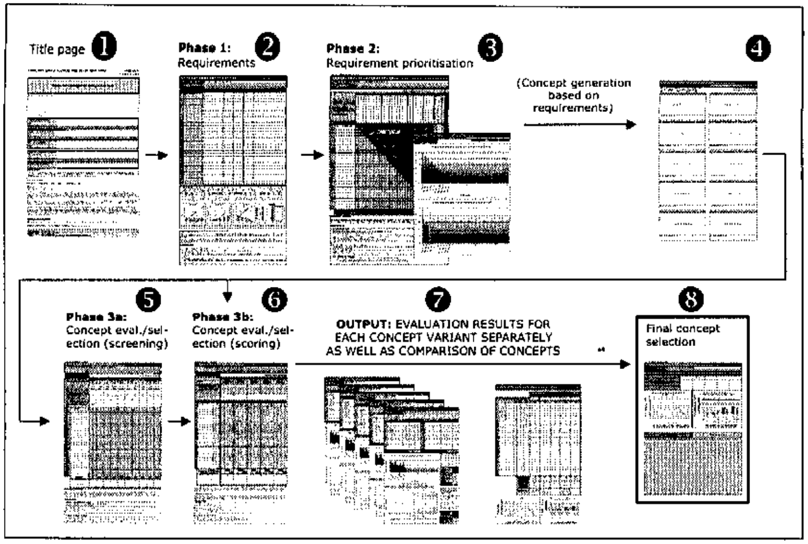


Figure 1. Structure of the concept development support tool

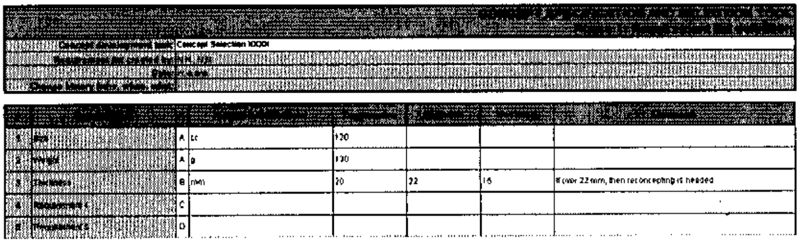
The foundations for each individual section of the tool are presented in the following chapters. The most central methodological principals are also discussed.

3.1 Title page

The first section of the tool (❶ in Figure 1) acts as a title page to the documentation created during the use of the tool. It was noticed during the completed research that compared to the later phases of the development process, the concept development phase was loosely documented. In retrospective, it required efforts to determine what were the requirements for the concept, what specifically were the alternative concepts, and how was the realised concept selected. Therefore, the structure of the tool forms a document, which at the same time that it is used documents central aspects of the concept development phase. The title page states and describes the concept development task as well as describes the contents of the document i.e. the resources, dates and change histories of the later sections. The title page also gives general instructions for use of the tool. The needs for documenting decisions have also been stated elsewhere and it has been identified that in general companies are not documenting the history of decisions and lessons learnt [National Science Foundation 1996].

3.2 Requirements and preferences

It has been stated that one minimum design guideline is that a list of the requirements is made at the start of the process, since this step minimizes the risk of recognizing requirements too late [Günther 1999]. Additionally target values should be set for these requirements [Ullman 2001]. Based on the conducted research, emphasis on a requirement based approach for concept development was also seen to suit the needs in the company context. In addition, with the tool these requirements could be linked with the rest of the development process, thus increasing commitment to them. The second section of the tool (❷ in Figure 1) is thus used for stating the requirements and assigning target, minimum and maximum values to those related specifications, which can be expressed in quantitative values. The requirement list is the foundation for the use of the entire remainder of the tool. The requirements that are stated here are intended to guide the creation of the concepts, and they are used as criteria in later evaluating the concepts. An example of a portion of a requirement list is presented in Figure 2. The upmost portion of the sheet is used for documentation purposes, as described in chapter 3.1.



[illegible]	[illegible]	Concept Selection XXXX					
1	[illegible]	A	cc	120			
2	[illegible]	A	g	130			
3	[illegible]	B	mm	20	22	15	If over 22 mm, then reconcepting is needed
4	[illegible]	C					
5	[illegible]	D					

Figure 2. Requirement list

It has been stated that using a linear preference scale may not truly reflect a decision maker's preferences [See and Lewis 2002]. This was also noticed during the test use of the tool, when *Concept scoring* was applied by a design team to a concept evaluation task. Feedback from the use of the tool stated, that it was not possible to express situations where a requirement e.g. only needs to be fulfilled to an adequate level, but exceeding this level gives no additional value to the concept. This is caused by the fact that concept scoring, as well as other rating methods for concept selection, does not include the option of non-linear preferences. Therefore, the option of three alternative non-linear preferences was added into the tool (Figure 3). A specific preference can be determined with the appropriate column in the requirement list (Figure 2). One of four preferences may be stated by selecting the appropriate preference curve:

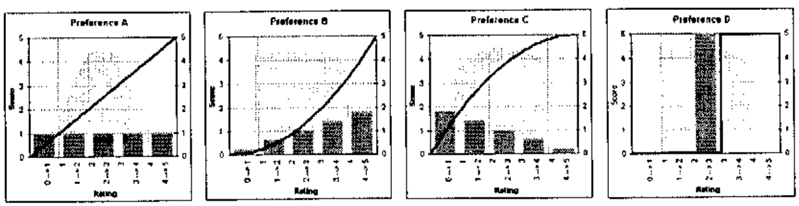


Figure 3. Four alternative requirement preferences (definitions below)

A. *Linear preference curve.* This is the default requirement preference. When used, an improvement in the concept characteristic (rating) in the sixth section of the tool adds the score of the concept linearly: e.g. an improvement in the concept rating from weak to average (2-->3) has an equal effect to that of an improvement from average to good (3-->4).

$$Score = Rating \tag{1}$$

B. *Progressive preference curve.* Proposed for emphasizing the importance of better than average requirement fulfilment. When used, an improvement in the concept characteristic (rating) in the sixth section of the tool adds the score of the concept progressively: e.g. an improvement in the concept rating from average to good (3-->4) has more effect to that of an improvement from weak to average (2-->3).

$$Score = \frac{1}{5} Rating^2 \tag{2}$$

C. *Regressive preference curve.* Proposed to be used when the additional value after average requirement fulfilment is considered low. When used, an improvement in the concept characteristic (rating) in the sixth section of the tool adds the score of the concept regressively: e.g. an improvement in the concept rating from average to good (3-->4) has less effect to that of an improvement from weak to average (2-->3).

$$Score = -\tfrac{1}{5} Rating^2 + 2 \times Rating \qquad (3)$$

D. *Step preference curve.* Proposed to be used for a requirement, which fulfilment is of the type "yes/no". When used, the exact level of requirement fulfilment in the sixth section of the tool has no effect on the value of the concept: only achieving a rating of 3 (average/adequate) is important.

$$Score = 0,\ if\ Rating < 3 \qquad Score = 3,\ if\ Rating \geq 3 \qquad (4)$$

3.3 Requirement prioritisation

Typically, team members do not agree on the importance of requirements [Ullman 2001]. This is far from an ideal situation, but also understandable since depending on personal responsibilities and tasks, designers may perceive the task differently. However, in our research we identified that prioritisation of the requirements is desired to ensure their realism, since not all requirements are as important. If the designers only have a list of requirements without any prioritisation, it is difficult to make trade offs during development. The third section of the tool (❸ in Figure 1) therefore utilises the *Paired comparisons* method to prioritise the requirements (Figure 4). The importances of the requirements are determined by pair wise comparing requirements to each other. After the matrix has been filled, the importance of each requirement is presented in the column right of the matrix. The requirement that is the most times considered more important than the other requirements, receives an importance of 5. The rest of the requirements receive a normalized score on a scale of 0-5. The requirement prioritisation can thereafter be fine-tuned until the team reaches consensus on the most important requirements. Increasing the importance of a requirement however results in the decrease of the relative importance of the other requirements and vice versa.

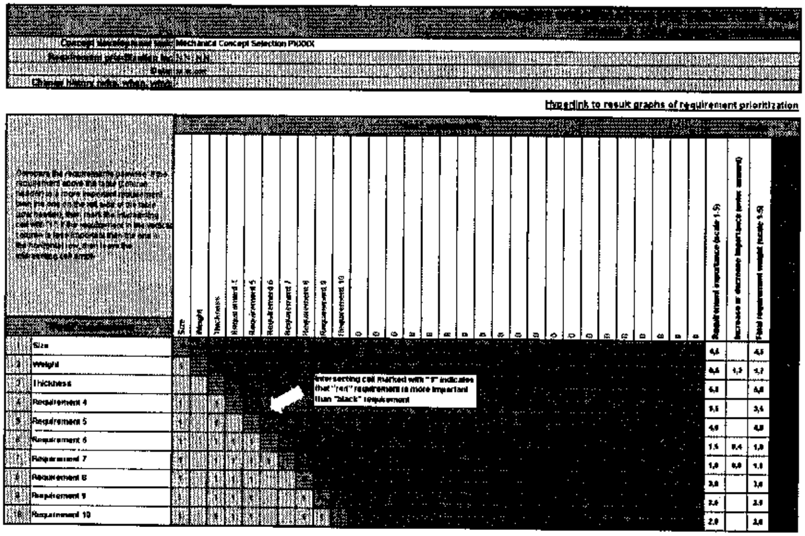


Figure 4. Requirement prioritisation with paired comparisons

3.4 Documentation and description of generated concept variants

Once the requirements and their priorities for the task have been set, potential concepts seeking to fulfil these requirements can be generated. At least for the main principle solutions, two or more variants should be considered [Günther 1999]. However, it has been stated that human problem-solvers tend to develop a potential solution when working to clarify an issue, and this alternative may eventually be the only one generated [Ullman 2001]. Encouragement towards generation of multiple concept variants and the documentation of these generated concept variants were identified as central drivers in creation of the tool. The fourth section of the tool (❹ in Figure 1) is thus constructed for these purposes. It is worth pinpointing that there is no methodology included in the tool to aid in the actual generation of the concept variants.

3.5 Concept evaluation with concept screening

The simplicity of *Pugh's evaluation method* makes it a good screening process against highly unfeasible concepts and can allow the designer to focus on the best concepts using a different concept selection method [King and Sivaloganathan 1999]. Therefore, the fifth section of the tool (❺ in Figure 1) utilises the method to evaluate the generated concept variants based on the input requirements. This section of the tool is especially intended for narrowing down the number of concept variants before e.g. feasibility studies. The methodology will not be discussed in this context, see e.g. [Pugh 1996] or [Ulrich and Eppinger 2000] for more information.

3.6 Concept evaluation with concept scoring

Positive effects of structured decision methods include that they structure decision making, the decision becomes visible and open to deliberation between designers [Hansen and Andreasen 2004]. The conducted research in this project also revealed the need for a systematic concept selection method that is linked to the requirements. For this purpose, the sixth section of the tool (❻ in Figure 1) utilises an enhanced version of the *Concept scoring* method to evaluate the remaining concept variants (Figure 5). In the method, the concepts are rated in relation to each requirement. Here, a scale of 1-5 is used:

1 - poor (concept is expected to have poor characteristics related to the requirement)
2 - weak (concept is expected to have weak characteristics related to the requirement)
3 - average or adequate (concept is expected to have avg. characteristics related to the req.)
4 - good (concept is expected to have good characteristics related to the requirement)
5 - excellent (concept is expected to have excellent characteristics related to the requirement)

Once the concepts have been rated in relation to each requirement, three values for each concept are presented: average rating, weighted average rating, and weighted average score. The average rating presents the average rating given to the concept in all the requirements. The weighted average rating likely better describes the level of the concept, since it also takes into consideration the varying importance of the different requirements. The weighted score further takes into consideration the preferences for the requirement fulfilment (A/B/C/D), determined in the second section of the tool. The weighted average score may thus best rank the concepts, since it does not consider all improvements in the concept ratings linear (having the same additional value). For example, if the preference for the requirement is *regressive* (C), an improvement of the concept rating from 4 to 5 adds the value of the concept very little (e.g. Requirement 4 in Figure 5). The weighted average score may however be misleading in presenting the absolute level of the concept, since the preference curves increase or decrease the absolute values of the concepts, depending on the preference curve. Thus, the weighted average rating is the highlighted value for this purpose.

				Variant 1			Variant 2				Variant 4		
1	Thickness	B	16,7	4	0,67	0,54	5	0,84	0,84	[redacted]	5	0,84	0,84
2	Size	A	15,1	4	0,60	0,60	4	0,60	0,60		2	0,30	0,30
3	Requirement 5	D	13,4	3	0,40	0,67	3	0,40	0,67		5	0,67	0,67
4	Requirement 4	C	11,7	4	0,47	0,56	4	0,47	0,56		5	0,59	0,59
5	Requirement 8	C	10,0	3	0,30	0,42	3	0,30	0,42		3	0,30	0,42
6	Requirement 9	C	8,4	3	0,25	0,35	3	0,25	0,35		2	0,17	0,27
7	Requirement 10	C	6,7	4	0,27	0,32	4	0,27	0,32		3	0,20	0,28
8	Requirement 6	A	6,4	3	0,19	0,19	3	0,19	0,19		4	0,25	0,25
9	Requirement 7	A	6,0	4	0,24	0,24	4	0,24	0,24		3	0,18	0,18
10	Weight	A	5,7	2	0,11	0,11	2	0,11	0,11		2	0,11	0,11
	Average rating (left), weighted avg. rating (middle), and weighted avg. score (right); max 5,00 *			3,40		4,01	3,50		4,31		3,40		3,91
	Rank based on average rating (left), weighted avg. rating (middle), and weighted avg. score (right) *			2	3		1	1			2	2	

Figure 5. Concept evaluation with enhanced concept scoring

It has been stated that the results of numerical concept selection methods are rarely believed at face value [Otto and Wood 1995]. This was also the adopted viewpoint in creation of the tool, even though the *Concept scoring* method has been enhanced with the option of using non-linear preferences to better take into consideration the designers' intentions. There might still be several reasons to select another concept than the highest ranked one. For example poor requirement fulfilment in even one requirement could eventually turn out to be critical. Therefore, in the seventh section of the tool thorough concept evaluation results are presented for each concept variant separately, as well as for comparison of the concepts. The results are produced based on the use of the preceding sections of the tool.

3.7 Concept evaluation results

In [King and Sivaloganathan 1999], graphical concept selection methods are differentiated from non-graphical ones. In the seventh section of the tool (❼ in Figure 1), the used non-graphical concept selection method - *Concept scoring* - is given graphical extensions. Four types of graphical representations to aid concept evaluation and selection are included in the tool: two types of graphs for each concept variant separately, and two types of graphs for comparison of the concepts to each other.

The two types of evaluation graphs that are produced for each concept variant separately aid the design team in noticing detailed characteristics of the concepts, i.e. characteristics that relate to the individual requirements set for the concepts. In the first type of evaluation graph, concept characteristics are compared against an 'average concept' – a hypothetical concept that is formed as the average of all the concepts evaluated in the sixth section of the tool. From this graph, the requirements where the concept under evaluation is stronger or weaker than the other concepts (the 'average concept' representing the other concepts) can be noticed. The other type of evaluation graph that is produced for each concept variant separately is a visual representation of the strengths and weaknesses of the concept (Figure 6). The theoretical 'right on target' line implies that in the most important requirements, good or excellent requirement satisfaction is desirable. In the less important requirements, an average/adequate requirement fulfilment may already be satisfying. In use of the tool so far, this graph type of the concept's characteristics has shown to be especially illustrative.

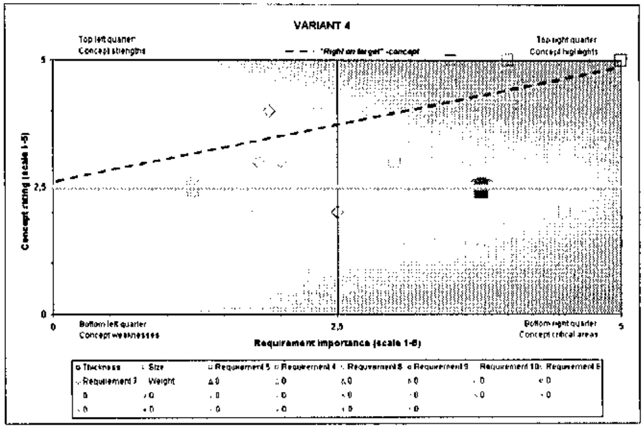


Figure 6. A concept evaluation graph for an individual concept

In addition to the graphs presenting the detailed characteristics of the individual concepts, two graph types are further used to aid the design team to compare the concepts to each other. The first type of comparison graph evaluates the concepts against each other regarding the ratings given to the concepts in the sixth section of the tool. The characteristics of the concepts are plotted into the graph with a trend line (Figure 7). A trend line of a strong concept balances to the right (concept has only few ratings of the value 1 or 2), and a trend line of a weak concept balances to the left (concept has only few ratings of the value 4 or 5). In the second type of comparison graph, the concepts are also compared to each other regarding the ratings given to the concepts, but now together with the importance of the requirements. The concepts are evaluated against each other regarding the distribution of the concept characteristics from the graph type of Figure 6, i.e. the portion of concept characteristics situated in each quarter of the graph. A good concept naturally has a high portion of *concepts highlights* and *concept strengths*, and preferably no *concept critical areas* or *concept weaknesses*.

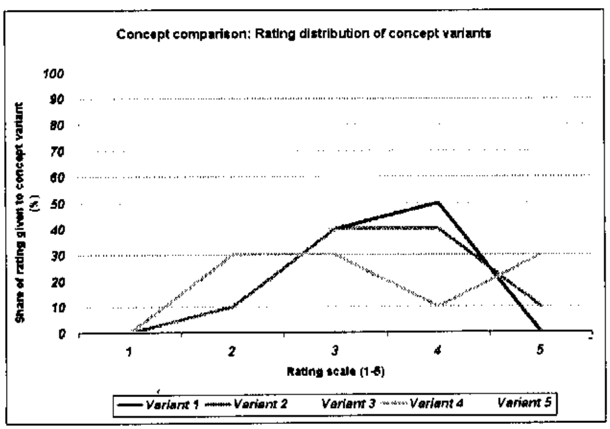


Figure 7. A concept evaluation graph for comparison of concepts

3.8 Final concept selection

It has been stated that designers do not rely solely on the results of decision making methods, but also on the use of relevant design strategies [Ahmed and Hansen 2002]. When the knowledge gained through evaluation is sufficient, a decision using judgement based on this knowledge can be made [Ullman 2001]. Therefore, after evaluating the concepts based on the result graphs, and when the knowledge gained through evaluation is seen sufficient, the final concept selection is documented into the eighth section of the tool (❽ in Figure 1).

4 Discussion

Though the tool has been created to support concept development and concept selection as a whole, it is still worth pinpointing that it does not ensure that the best concepts are generated, and ultimately selected. In Table 1 the author subjectively compares the benefits of using the tool against seven alternative sources of risk for making a poor decision [Ullman 2001]. Correct use of the tool in product development projects likely best reduces the risk of choosing a poor alternative, as well as e.g. improves effectiveness in both making a decision and implementing the decision.

Table 1 Sources of risks for making a poor decision [Ullman 2001] and areas where the concept development support tool is seen to have an impact

Risk type	*Risk resulting from*	*Effect of tool*
Decision-maker risk	Decision-maker ineffectiveness	+
Organizational risk	Ineffective team or organisation	+
Envisioning risk	Solving the wrong problem	
Ideation risk	Not developing good alternatives	+
Evaluation risk	Choosing a poor alternative	++
Strategic risk	Not following a beneficial strategy	
Realization risk	Not being able to implement the decision	+

Key: ' ' use of tool can not be considered to reduce the risk factor, '+' use of tool can reduce the risk factor, '++' use of tool presumed to reduce the risk factor

5 Conclusions

The interest of industry in tools should be seen, as 'need signals' to understand and use for further development by academia. It has been stated that there is a gap between research and practice; effective methods need to be developed for transferring research results into practice and results from theory and practice need to be combined. The *Concept specification and selection tool* presented in this paper is the result from a cooperative research project between university and industry partners. The conducted research and the created tool have shown immediate industrial contribution through the good reception of the tool in practice. The academic contribution of the work can be divided into two areas: results that are immediate and results that are later gained through the possibility to evaluate the actual use of the concept development methods in practice. Immediate academic contributions include the documentation of an approach to justifiably, on basis of an industry 'need signal', combine three separate design methodologies so that they form a combination for support of the concept development phase as a whole – in an industry context. This paper has further introduced new graphical approaches for evaluating concept variants, and for comparing them against each other. Enhancement of concept scoring with three alternative non-linear preferences has also been discussed. The possibility to evaluate the actual use of the concept development methods - and the results achieved with them - is believed to later give valuable insight into the needs for future developments in concept development methodology. According to the conducted work so far, concept development is definitely an area where research of design methodology can contribute.

Acknowledgements

The author would like to give appreciation to all the engineers and designers at the company who participated with valuable insight in the project and gave their contribution to the creation of the tool.

References

Ahmed S., Hansen C.T., 2002, A Decision-making Model for Engineering Designers, Proceedings of Engineering Design Conference 2002, July 9-11, 2002, London, UK

Andreasen M.M., 1996, Challenges in Nordic Design Research, Proceedings of NordDesign'96, August 28-30, 1996, Espoo, Finland

Cohen L., 1995, Quality Function Deployment – How to Make QFD Work For You, Addison-Wesley, p. 348

Günther J., Ehrlenspiel K., 1999, Comparing Designers from Practice and Designers with Systematic Design Education, Design Studies, Vol. 20, pp. 439-451

Hansen C.T., Andreasen M.M., 2004, A Mapping of Design Decision-making, 8th International Design Conference – Design 2004, May 18-21, 2004, Dubrovnik, Croatia

King A.M., Sivaloganathan S., 1999, Development of a Methodology for Concept Selection in Flexible Design Strategies, Journal of Engineering Design, Vol. 10, pp. 329-349

Macmillan S., Steele J., Austin S., Kirby P., Spence R., 2001, Development and Verification of a Generic Framework for Conceptual Design, Design Studies, Vol. 22, pp. 169-191

National Science Foundation, 1996, Research Opportunities in Engineering Design, NSF Strategic Planning Workshop, Final report, April 1996, USA

Otto K.N., Wood K.L., 1995, Estimating Errors in Concept Selection, Proceedings of the ASME Design Theory and Methodology Conference, Boston, USA

Pahl G., Beitz W., 1984, Engineering Design, Springer-Verlag, p. 450

Pugh S., 1996, Creative Innovative Products Using Total Design. Addison-Wesley, p.544

Repenning N.P., 2001, Understanding Fire Fighting in New Product Development, Journal of Product Innovation Management, Vol. 18, pp. 285-300

Saaty T.L., 1990, How to Make a Decision: The Analytic Hierarchy Process, European Journal of Operational Research, Vol. 48, pp. 9-26

Salonen M., Kauhanen P., 2002, Systematic Design Tools for the Concepting Phase of the Product Development Process, Unpublished, Available from the author

See T.-K., Lewis K., 2002, Multiattribute Decision Making Using Hypothetical Equivalents, Proceedings of DETC'02, September 29 – October 2, 2002, Montreal, Canada

Schuster H. R., 1997, A Computer Aid for Specification Development, Conceptual Design and Manufacturing Cost Estimation in Mechanical Design, Ph.D. Thesis, University of Stallenbosch, South Africa, p. 254

Thurston D.L., Carnahan J.V., 1992, Fuzzy Ratings and Utility Analysis in Preliminary Design Evaluation of Multiple Attributes, Journal of Mechanical Design, Vol. 114, pp. 648-658

Ullman D.G., 2001, Robust Decision-making for Engineering Designers, Journal of Engineering Design, Vol. 12, pp. 3-13

Ward S.C., Chapman B.C., 1995, Risk-management Perspective on the Project Lifecycle, International Journal of Project Management, Vol. 13, pp. 145-149

von der Weth, R., 1999, Design Instinct? - the Development of Individual Strategies, Design Studies, Vol. 20, pp. 453-463

Whybrev K., Shaw A., Aitchison D., Raine J., 2001, Use of Design Tools and Methodologies for Rapid Product Development in the New Zealand Manufacturing Industry, Proceedings of ICED'01, August 21-23, 2001, Glasgow, UK

Wright I.C., Chapman A.C. et al., 1995, A Survey of Methods Utilisation During the Product Design Process in UK Industry, Engineering Design Institute, Loughborough University of Technology