Supporting medical technology development with the analytic hierarchy process

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USING THE ANALYTIC HIERARCHY PROCESS TO SUPPORT TEAMS IN DEFINING NEW PRODUCT OBJECTIVES

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Defining new product objectives is a critical problem solving activity to new product success. The analytic hierarchy process appears to be an adequate technique for multi-criteria decision analysis to support the definition of new product objectives. To illustrate this support, we applied this technique to a project focused on the development of a liver perfusion system to preserve donor livers. It quantitatively supported discussions between technological developers and clinical practitioners focused on the product requirements and the pursued performance of the liver perfusion system relative to an envisaged competitor. The discussions significantly reduced disagreements about the new product objectives between the group members. They resulted in a quantitative overview of the importance of the product requirements and the relative performance of the alternatives with regard to these requirements. Furthermore, research activities necessary to fulfil these objectives were discerned. The group members were committed to these outcomes. This application shows the value of introducing the AHP as a means to steer new products to solve problems to a higher extent than competing products do.

5.1 Introduction

The product development process is often divided into two general stages, the planning or predevelopment stage, and the development stage (Souder and Moenaert, 1992). An overarching theme of these stages is the product concept, a statement about how the new product is anticipated to fulfil its objectives relative to other products or problem solutions already available (Crawford, 1991). During the planning stage, information is shared in order to assess a new product idea, to define a valid new product concept, and to determine whether or not the organization will invest resources in the concrete development of this product concept (Cooper and Kleinschmidt, 1986). During the development stage, the accepted product concept is developed towards a product that can be commercially launched in the market place. Particularly the planning stage has found to be critical to new product success (Cooper, 1985). To profoundly perform this stage, an essential balance has to be found between creativity and structure (Kuhrana and Rosenthal, 1997).

Market-led new products aim to solve problems superiorily than competing product do (Cooper, 1985). Looking upon new product development as a problem-solving process, in our view, can be valuable to structure the critical information-sharing processes in new product development. Problem-solving models provide a purposeful context to structure information-sharing processes. However, one need to complement the problem-solving model of product development as applied in current product development studies. According to this model, the first problem-solving activities are to recognise the problem to be solved by a new product and to define the new product objectives. Problem solving continues with the iterative development cycles, including the activities: to design alternative product concepts, build computer models or prototypes of these concepts, run experiments, and to analyse and evaluate the test outcomes (Thomke and Fujimoto, 2000). Studies using this model found that the efficiency of the experimental development activities can be improved by speeding up, reducing the costs of, and overlapping the development cycles (Thomke and Fujimoto, 2000). Nevertheless, their findings do not enhance the planning activities: problem recognition and the definition of the new product objectives.

Despite the importance of defining new product development objectives, this activity often receives too little systematic attention. This is for example shown in Gupta and Wilemon's research findings that an inadequate definition of the new product objectives is the most common reason for product development delays (Gupta and Wilemon, 1990). Such strategic activities are typically ill structured and unprogrammed (Gear *et al*, 1999). Moreover, the relevant technological and user groups are often not involved simultaneously (Mulder, 1992). Consequently, the objectives, which may not have the commitment of all groups involved in new product development, easily ignore relevant performance criteria. Because objectives are attentional controls, they will cause performance on criteria they do not directly address to suffer (Shalley, 1995). In overall, the objectives need to attune to the user needs, technological possibilities, competitive opportunities, and resource availability.

A new problem-solving perspective relevant to new product development must allow creative thinking. Creativity is particularly relevant for contriving alternative design solutions (Sutton and Hargadon, 1996). A strategy that leaves opportunity, as well as provides the essential focus for creative behaviour is to structure the process of defining new product objectives. These objectives provide a common frame of reference for different functional groups, to transfer information, to exchange ideas, to initiate new project activities, to structure tasks, and to keep being oriented towards common task outcomes (Moenaert and Souder, 1990). Moreover, they allow the product concept to be reshaped in the early stages of new product development, which can significantly enhance new product success (Stevens *et al*, 1999).

This study explicitly focuses on the definition of new product objectives. This predevelopment activity is considered to benefit most strongly from systemisation, yet is neglected by other studies that applied a problem-solving perspective. We use insights from the problem-solving and decision-making literature to adequately support this activity. Accordingly, we applied the analytic hierarchy process (AHP), a quantitative technique for multi-criteria decision analysis, to structure the definition of adequate objectives for new products. We illustrate this support by means of an empirical application.

5.2 Tools for multi-criteria decision analysis to support the problem-solving process

New product development can be considered a complex problem-solving process. Information concerning the context that defines the problem the new product needs to solve and the new product solutions is often missing or in contradiction with each other (Clark, 1985), and many actors are involved, each with their own perspectives, goals, and emotions. In the problem-solving process the following task-related stages are generally distinguished: recognising the problem, defining the problem, specifying the objectives to be met, generating alternative solutions, evaluating the solutions, generating courses for implementation, implementing the adopted solution, and monitoring its performance. Analytic support to solving such complex problems focuses explicitly on decision making, which can be defined as the steps from defining the problem up to and including generating courses for implementation (Cooke and Slack, 1984). A comprehensive understanding of the decision-making process is essential to adequately apply the adequate tool to support decision making.

A tacit assumption underlying the early, normative decision-making models is that decisions are, and ought to be, made purely on cognitive grounds (Keren, 1996). However, human decision-making proved to deviate in systematic ways from these models. In general, non-cognitive variables such as emotions, and motivation influence the decision-making process. Decision-making models need to adequately deal with the interplay between the cognitive and non-cognitive variables (Keren, 1996). These variables relate to several interrelated factors that shape the group interaction processes. These factors include the properties of the individual group members, of the group, the group task, and the environment in which the group operates (McGrath, 1984).

The hierarchical model is a comprehensive model that captures this complexity of group decision-making. This model consists of the group boundary and three interrelated dimensions including task-maintenance, explicit-implicit, and normative-localised (Hoffman, 1982). The group boundary defines the membership composition of the group, and the members' degree of commitment to this group. The hierarchical model divides the group decision-making processes into task and maintenance functions. The task functions deal with solving a problem by this group in its organizational context. The maintenance functions aim to facilitate the group cohesion, the members' ability to co-operate, and the members' group and task commitment. The model assumes that when either task or maintenance functions are attended to explicitly, the other is occurring implicitly. Both group norms and individual characteristics, including personality, abilities, role functions or attitudes of the group members, influence the decision-making processes (Nour and Yen, 1992).

In general, the key task during the planning stage of new product development is to reduce uncertainty in order to increase task analysability and to decrease task variability in the development stage (Moenaert *et al*, 1995). The sources of the uncertainty are the user needs, the technological and the competitive environment, the needed resources for the project (Souder and Moenaert, 1992), and work unit interdependency (Tushman and Nadler, 1980). The uncertainty reduction is best achieved by encouraging R&D, marketing (Souder and Moenaert, 1992), users (Gales and Mansour-Cole, 1995) and possibly manufacturing (Liker *et al*, 1999) to share information. However, the more the project involves new technologies, or markets the less uncertainty they will have reduced by the end of the planning stage (Moenaert *et al*, 1995). Accordingly, fresh questions and problems are likely to arise periodically. On a continuing basis, therefore, a problem-solving group needs to be formed that includes representatives from the functional groups with the relevant knowledge and the required commitment to the development and implementation of the project planning.

The essential task-related phases of an analytical decision process are intelligence, design, choice (Simon, 1957), and support for implementation (Lewandowski and Wierzbicki, 1989). During the intelligence phase, the group members define the problem, specify the objectives to be met, and generate alternative solutions. In design, these factors are structured into a decision tree. During choice, the solutions are evaluated, and support for implementation of the best solution is provided through the generation of courses of action. In our case, the problem is the lack of fit between the needs for a product and the properties of existing product solutions. The objectives to be met correspond to the requirements the new product needs to fulfil. The alternative solutions are the product concept to be, and other products or problem solutions already available.

By following this sequence of task activities, the group is involved with maintenance functions as well. Separating the divergent intelligence and the convergent choice phase helps the group to restrict them away from the information-sharing pitfalls: to ignore relevant decision criteria and to prematurely focus on solutions (Stasser *et al*, 1989). Yet a structured agenda alone is not sufficient to support decision-making performance. Decision support is beneficial that exposes the disagreements, ambiguity, uncertainty, contradiction and lack of information. This urges the project members on sharing more information and additional reasoning to better understand their judgements and to expand their view on the new product objectives (Henig and buchanan, 1996). Forming a critical degree of consensus and mutual understanding of the reasons for continuing differences is essential for continuing group and task commitment (Gear *et al*, 1999). In new product development these differences are commonly related to diverging time-senses, motives, goals, loyalty, and senses of responsibility (Souder, 1987).

Due to their diverging perspectives, interests, experiences and knowledge, the group members will posses different information, and will perceive the same information differently. This diversity can only lead to high information-sharing performance when the members understand each other, and combine and build on each other's information or ideas (Maznevski, 1994). However, production blocking, evaluation apprehension, free riding (Diehl and Strohme, 1989) and groupthink (Janis, 1982) impede information sharing. Except for the first impediment, these problems can be lessened by group norms that encourage listening and responding constructively to views expressed by others, providing support and recognizing the interests and achievements of others. Accordingly, the group members need to share unique and relevant information concerning the problem definition, the product requirements and the new products. This information needs to be perceived to be novel and relevant in order to support the conversion of the individual members' judgments into joint group judgements (El-Shinnawy and Vinze, 1998). Conflict resolution techniques need to focus on the confrontation and of task-related disagreements, while avoiding social pressure towards group consensus discussion (Pelled and Adler, 1994; Schweiger *et al*, 1986). This pressure can eliminate critical thinking, diversity in information input and reasoning, creativity, and commitment.

Tools for multi-criteria decision analysis can provide maintenance support by facilitating the exchange of information and consensus formation through structuring the decision-making process and by making explicit the disagreements among group members (Timmermans and Vlek, 1996). More fundamentally, they provide analytic support to the decision-making task to evaluate a finite number of decision alternatives under a finite number of performance criteria. The most commonly used tools for multi-criteria decision analysis are the elimination and choice translating reality (ELECTRE), the simple multi-attribute rating technique (SMART), the analytic hierarchy process (AHP), and the multi-attribute utility theory (MAUT) (Lootsma and Schuijt, 1997). These tools support the decision-makers to analyse the importances of the criteria and the preferences for the alternatives concerning these criteria, in order to generate an overall score for the alternatives. They vary particularly in their approach to model the preferences of the decision-makers for the alternatives (Lootsma, 2000). See appendix A for an overview of the quantitative methodology of the AHP.

Based on the decision-makers' preference or indifference for one alternative in each pair of alternatives concerning the respective criteria, ELECTRE only ranks the alternatives in a complete or incomplete order (Roy, 1991). In the AHP, a nine-point scale ranging from extreme preference to indifference refines the preferences concerning the pairwise comparisons (Saaty and Vargas, 1991). In SMART, concerning each criterion the performance of the alternatives is expressed in grades on a 0 to 100 scale (Von Winterfeldt and Edwards, 1986). MAUT introduces a utility function for assigning a value between zero and one to reflect how well the alternatives satisfy the criteria (Von Winterfeldt and Edwards, 1986). This utility function is derived from the monetary equivalent for a lottery between two alternatives. In contrast with ELECTRE, the AHP, SMART, and MAUT generate cardinal scores for the alternatives.

While ELECTRE, AHP and SMART are more oriented towards a straightforward support of information exchange, MAUT is more focused on deriving a mathematically sophisticated preference model. In defining new product objectives, the essence lies in supporting the information-sharing and implementation processes between the heterogeneous experts. Accordingly, the relatively easy to use ELECTRE, AHP and SMART satisfy this need to a higher extent. In new product objectives, trade-offs between product requirements are legitimate. Accordingly, insight is required in the importance of these weighting factors and the corresponding performance of the new product solutions. Of the four tools, only ELECTRE does not support these essential analyses. Competitive framing is relevant in new product development (Smith, 1995). As SMART keeps a holistic view on the performance of the alternatives, AHP pairwise compares the performance of the alternative new products, thus providing a competitive point of reference (Lootsma and Schuijt, 1997). Moreover, the redundant pairwise comparisons in the AHP allow a check on the inconsistency in judgements, indicating the need for sharing additional information (Henig and Buchanan, 1996). Due to these factors, AHP seems to steer the discussions concerned with the definition of new product objectives towards the reduction of relevant sources of uncertainty. It stimulates the sharing of information in order to make well-deliberated choices concerning the product's design solutions and market position. Accordingly, we consider it to be the most adequate tool for multi-criteria decision analysis to support defining new product objectives. We will illustrate the use of this tool in defining new product objectives by means of an empirical application.

5.3 Using the AHP to define new product objectives; a case study

5.3.1 Pre decision-making stages

Problem recognition

Through informal discussion with liver transplantation surgeons, academic researchers became aware of the urgency to solve the liver transplantation problems caused by the unsatisfactory duration and quality of liver preservation as experienced by these surgeons. The university hospital and university involved initiated a project to develop a new device for liver preservation by continuous perfusion.

Initiation of the decision-making group

The first step is to select the new product to be assessed, which is in our case the new device for liver perfusion, and the appropriate facilitator for this assessment. This facilitator needs to be able to basically apprehend the discussions about the new product, however does not need to be an expert in the new product field. He or she should be competent in encouraging broad-based participation in the discussions, structuring and steering the communication processes, and applying the group decision support system (Clawson *et al*, 1993).

The facilitator invites the panel members in consultation with the core project members. Reasons to include members are to obtain a balanced representation of the relevant expertises involved in the technological development and application of the new product, and of the diverse organizational groups that are charged with the new product activities or whose support for these activities are essential. A cautious selection needs to be made because in larger groups consensus becomes harder to achieve, and commitment to the group declines (DeSanctis and Gallupe, 1987). In our case study, the panel selection was guided by the results of a questionnaire in which the project members rated the most relevant persons in terms of their expertise, and resources (appendix B). Table 1 gives an overview of the expertises and organizational backgrounds of the panel members in our case study.

Table 1. The problem-solving group

NO.	EXPERTISE	ORGANIZATION
T_1	Electronics	University
T_2	Physics	University
U_1	Medical science	University hospital
T_3	Mechanical engineering	University
U_2	transplantation surgery	University hospital
U_3	Animal experiments	University
U_4	Surgery specializatons	University hospital
T_4	Mechanical engineering	University
U_5	Farmacokinetics	University

In order to provide a common ground for the exchange of information between these professionally heterogeneous panel members, the facilitator sent, in consultation with the core project members, information about the field of liver perfusion and the attributes of the existing perfusion systems to the panel members. In addition, the program of the panel session (appendix C) and information about the group decision support system are sent.

5.3.2 Decision-making stages

Introduction

During the panel session, the group members are sitting in a u-shaped setting with the facilitator in front facing the group. The hardware consists of a laptop on which Team Expert Choice is installed, a projection system, a radiofrequency receiver, and individual wireless keypads for the panel members. The facilitator prepares the software by inserting the names of the panel members in the group file of Team Expert Choice. The actual meeting begins with a one-hour introduction. The facilitator informs the panel members about the procedures of Team Expert Choice on the basis of a practical example, and core projects members explain the backgrounds of the new product project.

Intelligence

In the introduction of the problem definition stage the facilitator emphasised group rules for brainstorming that correspond to the appropriate group norms for information sharing in new product development. These rules include to: defer criticism, combine and improve suggested ideas, say all ideas that come to mind, yet stay focused on the topic of concern (Sutton and Hargadon, 1996). The panel members first defined the clinical problem to be solved by the new product. The development of a liver perfusion system aims to increase the duration and the quality of liver preservation. This relates to the clinical needs to lengthen the storage time of donor livers and to accept livers of lesser quality for transplantation. Next, the panel members determined the alternative perfusion system that represents the state-of-the-art standard of liver preservation. Currently, the common standard is to store donor livers in iceboxes. However, the panel members assume that this method will become obsolete with the introduction of liver perfusion systems. Experience with kidney perfusion systems teaches us that they significantly improve the duration and quality of kidney preservation. Since the most widely accepted kidney perfusion system is likely to be adjusted to preserve livers, this adjusted system was defined as the standard for liver perfusion. The facilitator entered a description of the aim of the project and the alternative liver perfusion systems in Team Expert Choice, as projected on the overall screen. Finally, a brainstorming mode followed about product requirements of the liver perfusion system. In order to reduce production blocking, the panel members were awarded 10 minutes of individual time to write down product requirements. Group brainstorming followed in which the panel members mentioned and elucidated product requirements. These requirements were entered by the facilitator in Team Expert Choice and projected on the overall screen.

Design

The next step was to arrange these product requirements in a hierarchic order. Using the drag and drop function of Team Expert Choice, the facilitator clusters similar requirements and names these clusters. The derived structure including main and sub-requirements is discussed in the group to ensure that each level is composed of requirements that are mutual exclusive, clear, comprehensive, and are of importance within the same order of magnitude. It was revised until the group had no further comments to add, modify or delete requirements. Finally, the Team Expert Choice model is composed of the aim of the project, the main requirements, sub-requirements, and the alternative liver perfusion systems (figure 1).

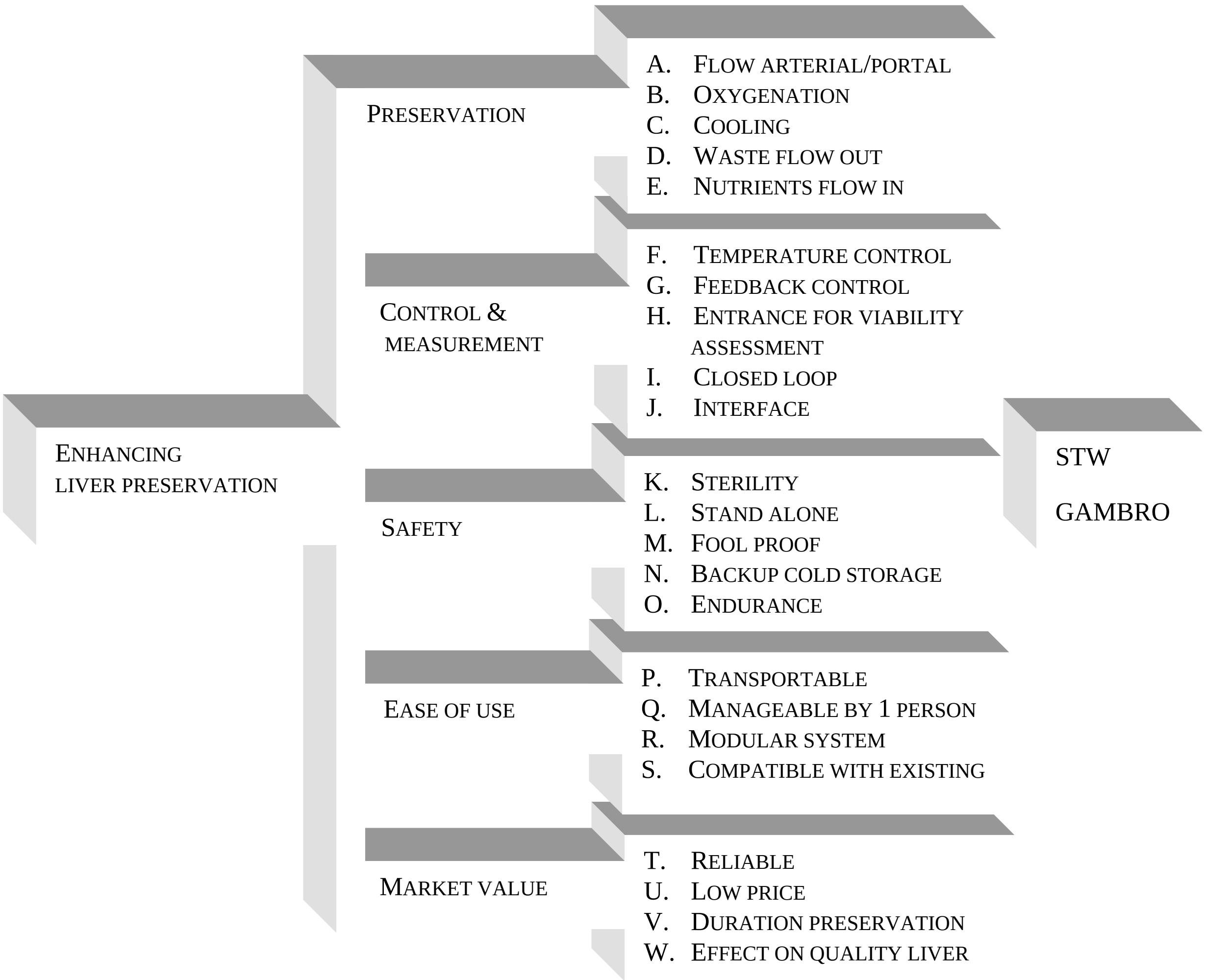

Figure 1. The decision-making structure

Evaluation and choice

Effective support for multi-criteria decision analysis facilitates the individual panel members as well as the group as a whole (Timmermans and Vlek, 1996). Therefore, the panel members were asked to fill in a questionnaire composed of pairwise comparisons to derive the weighting factors for the requirements and alternative perfusion systems (appendix D). First, the relative importance of each pair of two main requirements in fulfilling the goal of the project was compared. Secondly, the relative importance of each pair of sub-requirements was compared with regard to the importance of the corresponding main requirements. Finally, the relative qualities of the alternative liver perfusion systems were compared with regard to each sub-requirement. The most important or most preferred factor of each pair of factors was assigned a score from 1 to 9, of which 1 represents equal importance or quality and 9 extremely higher importance or quality. The next focus was to unite the diverse perspectives of the panel members on the same sets of comparisons. The facilitator reminded the panel members to tap of the information distribution over the members, and the acceptability of diverging judgements. Using their hand-held radiographic keypads, the panel members gave their judgements on each pairwise comparison. Individual judgements were projected on a screen, allowing the members of the panel to discuss the rationales behind their individual scores (figure 2).

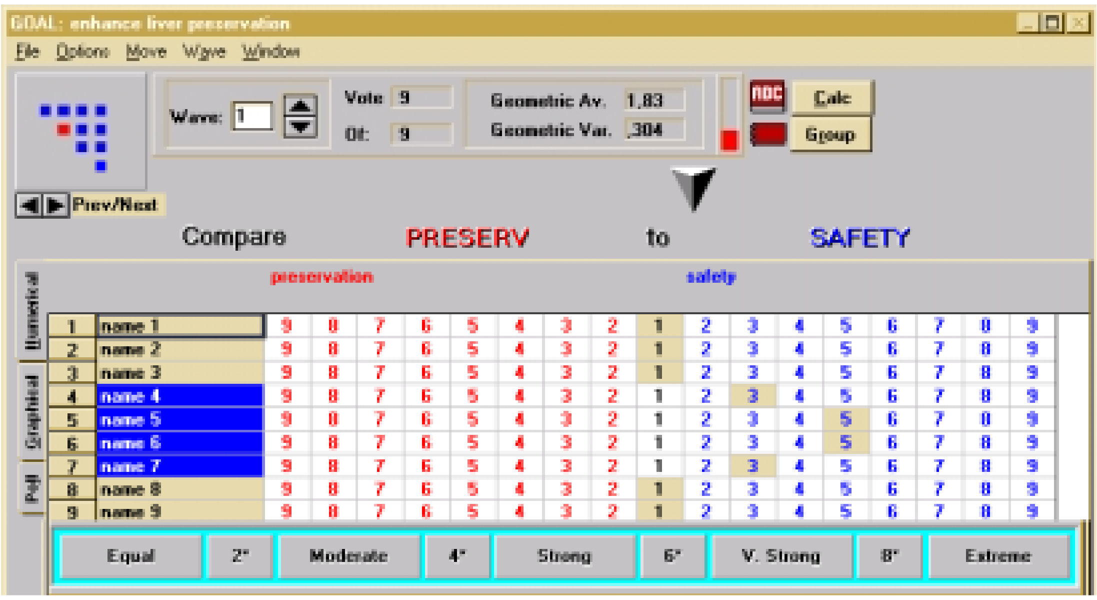

Figure 2. The pairwise comparisons screen

During the discussions, the panel members could alter their judgements. For each pairwise comparison, these final individual judgements are aggregated based on the geometric mean. After each cluster of pairwise comparisons, Team Expert Choice computes an inconsistency ratio that shows how consistent each pairwise comparison is with regard to the remainder of the comparisons. When an inconsistency ratio was higher than 0.10, the panel members were asked to reconsider their judgements. The final weighting factors for the requirements and sub-requirements were derived from these final group judgements. We used the distributive mode, which divides the weights of the sub-requirements among the perfusion systems relative to their quality. Supported by graphics showing the weighting factors related to each cluster of product requirements (figure 3), the validity of these results were discussed and approved of. Table 2 shows an overview of the final weighting factors and priorities.

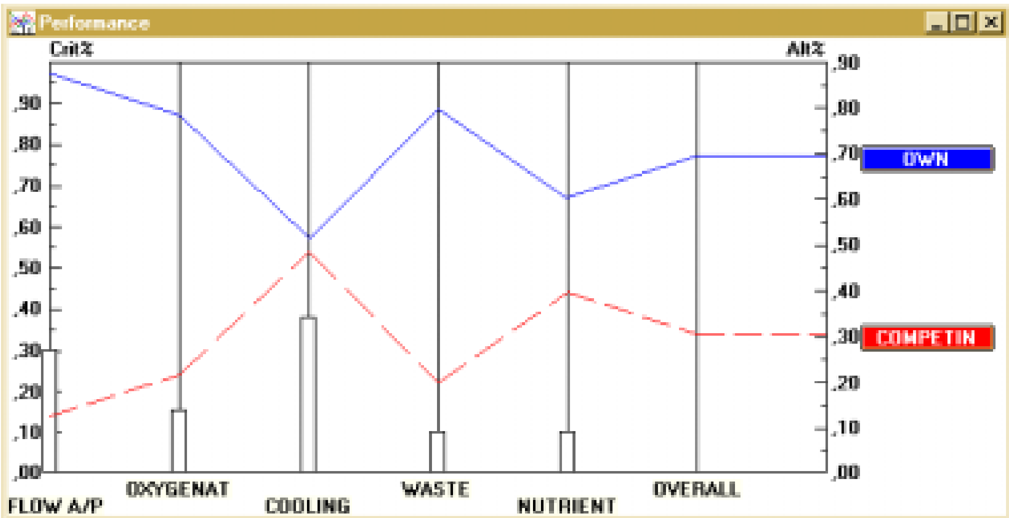

Figure 3. Graphic showing the results on preservation

Table 2. The final weighting factors of the requirements and priorities of the alternatives

REQUIREMENTS	PRESERVATION .25					CONTROL .08					SAFETY .42					EASE OF USE .07				MARKET VALUE .20			
SYSTEMS	A. .29	B. .15	C. .37	D. .09	E. .09	F. .17	G. .29	H. .18	I. .23	J. .13	K. .65	L. .08	M. .06	N. .12	O. .09	P. .51	Q. .09	R. .34	S. .07	T. .23	U. .05	V. .30	W. .42
Competing system .36	.12	.22	.49	.20	.40	.65	.20	.43	.23	.64	.51	.33	.45	.20	.34	.22	.36	.13	.50	.60	.29	.14	.19
Own system .64	.88	.78	.51	.80	.60	.35	.80	.57	.77	.37	.49	.67	.56	.80	.66	.78	.65	.87	.50	.40	.71	.86	.81

Support for implementation

In the second stage, the panel members divided the liver perfusion system into relatively independent technological components. When the panel members agreed on the proper division, the facilitator inserted the names of these components in the direct ratings spreadsheet of Team Expert Choice. This spreadsheet consists of columns with the sub-requirements, rows with the technological components, and cells to indicate the relation between the technological components and the sub-requirements. These relations take into account how well the team aims to fulfil each sub-requirement in comparison with the competing liver perfusion system. A four-point scale was used to describe the relations between the components and sub-requirements, including competitive opportunity (+), be aware of (!), competitive threat (-) and no relation (0). Discussions about these relations were guided by the panel members' projected, iterative judgements (figure 4). The most frequent judgement was entered as the group judgement by the facilitator in the direct ratings spreadsheet. Table 3 shows the final group judgements.

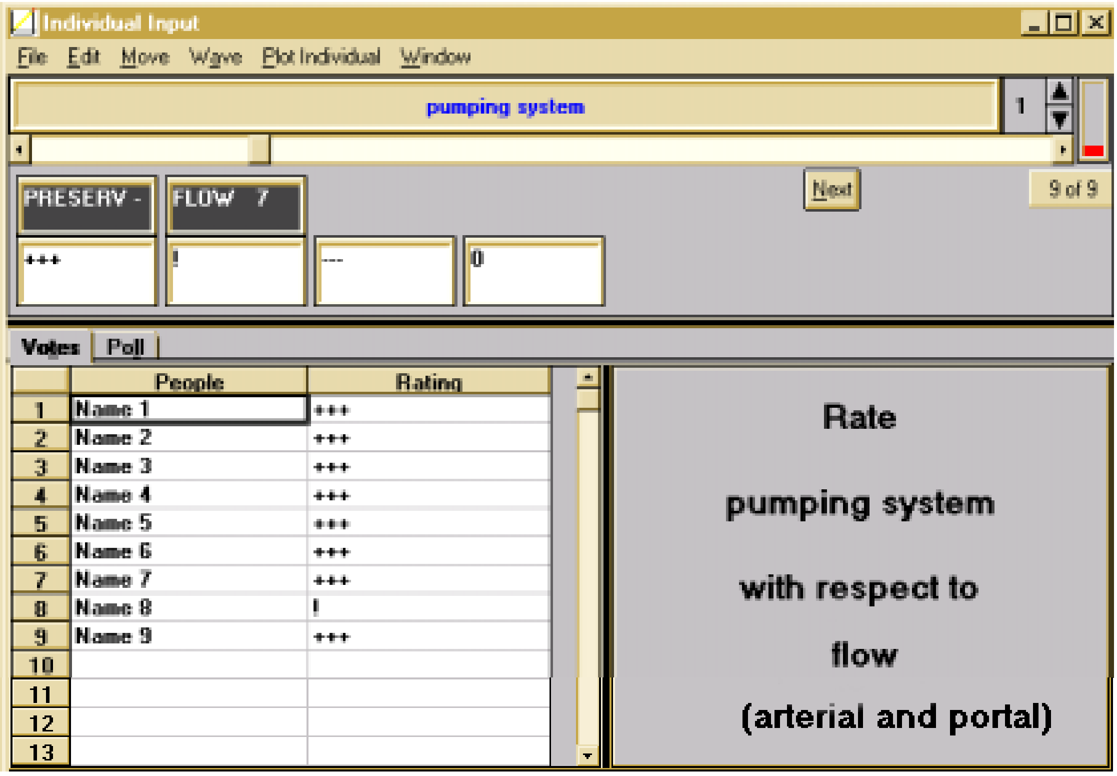

Figure 4. The direct rating screen

Table 3. Relations between technological components and requirements

REQUIREMENTS	PRESERVATION					CONTROL					SAFETY					EASE OF USE				MARKET VALUE			
COMPONENTS	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.	P.	Q.	R.	S.	T.	U.	V.	W.
Pumping system	+			+			+				!	!						+		!	!	+	+
Energy source			!									!				+		+		!	!		
Controler	+		!	!	!	-	+		!	-	!	!	+		+		!	+		!	-	+	+
Cooling system			!			-						!		+		!		+		+	+		
Oxygenator		!																+			!	+	+
Flow circuit	!			+	!				!		-				+		!	+	!				
Packaging				!	!			!		-	-		!	-	-	+	+	+		!	+		

For each technological component, the group brainstormed about the most critical areas of research required to fulfil the product requirements. These areas of research focused on medical application uncertainties as well as technological uncertainties. A short description of the research areas was entered in the spreadsheet by the facilitator. Guided by these research areas, the panel members discussed the necessity of including additional researchers into the team. Regarding their distinct competencies, the core project members decided to invite one of the present panel members as an official member into the project team, and an external researcher as an expert advisor.

5.3.3 Post decision-making stages

Review of the decision-making processes and outcomes of the panel session

With regard to the new product objectives, the panel group's weighting factors before and after the discussions differed on average with 22 per cent, resulting in a significant change of 10 of the 74 weighting factors (independent t-test, two-tailed $p < 0.02$). There were no significant differences between the changes of the medical user subgroup (on average 25 per cent) and the technical development subgroup (on average 26 per cent) (paired-samples t-test, two-tailed $p < 0.02$). On average, the individual panel members reduced the inconsistency in their judgements with merely 1 per cent during the discussions. Nevertheless, the final group judgements, expressed in the geometric mean of the individual judgements, have the acceptable overall inconsistency ratio of 0.04.

Furthermore, the panel group reduced 48 per cent of the prior variance between the individual members' weighting factors. The reduction of the variance within the user and within the technical development subgroup was respectively 61 and 32 per cent. The reduction of the variance between these subgroups was higher: 74 per cent. Nevertheless, no significant differences between the subgroups were found for any of the final weighting factors (independent t-test, two-tailed $p < 0.02$) [1].

The average panel rating on each proposition about the adequacy of the panel session was a 6 on the 7-point Likert scale ranging from strongly disagree to strongly agree. These results entail that the panel members were satisfied with the comprehensiveness of the set of product requirements, the shared definition of the factors relevant to this decision, and the novelty and relevance of the information exchanged. They considered the degree of consensus formed, the quality of the outcomes, the accuracy of the outcomes, and their commitment to the outcomes to be reasonably high. The session was thought as to constitute a satisfactory foundation to the further collaboration in the project.

Implementation of the outcomes

Currently, one year after the panel session, the first research activity as discerned for each of the components of the liver perfusion system has been largely completed. Due to the results of these activities, an additional critical area of research has been added to the planning. The team members still intend to focus subsequently on the remainder half of the activities as agreed on in the planning.

[1] A graphical oversight of the Euclidean distances between the weighting factors of the individual panel members shows in more detail the differences in judgements within the panel before and after the panel discussions (appendix 5.1).

5.4 Conclusions and discussion

In order to define adequate new product objectives, new product development teams have to deal with a high level of uncertainty. Sources of uncertainty are related to the newness and dynamics of the markets, technologies and resources and work unit task interdependency (Tushman and Nadler, 1980). Additional uncertainty results from the limited information available to the group members and their emotional states (Zahedi, 1986). The AHP provides a user-friendly means to deal with this uncertainty. We applied this tool to support the exchange of information about the market, technologies and resources, and consensus formation between the group members involved in the technological development and application of a liver perfusion system. It focused on the comparison between the performance of the pursued new product and a competing product solution regarding a heterogeneous range of product requirements.

Due to their different experiences, organizational roles and levels of expertise the group members were likely to have initially diverging perceptions and information about the new product objectives for the development of the liver perfusion system. The application of procedures that include sending pre-information, preparing presentations, and allocating time for individual as well as group brainstorming, and application of the normative rules for group brainstorming encourage wide participation and positive interactions between the group members. They facilitated the exchange of unique and relevant information between the group members. Accordingly, the intelligence and design stage resulted in a shared definition of the problem to be solved, a comprehensive list of main and sub-requirements, and the alternative perfusion system that represented the state-of-the-art standard of liver preservation.

The group members' role of expert or novice varies over these factors being discussed. While experts can rely on intuition, novices need deliberation to understand (Wierzbicki, 1997). Therefore, sharing information to elucidate the group members' judgements regarding the product requirements and new products is indispensable in the evaluation and choice stage. The pairwise comparisons of respectively the requirements and the new products are an intuitively simple manner to structure this exchange of information. The projection of the numerical comparisons by the group members along with their names offers guidance for the discussion of the group members' disagreeing judgements. We did not use anonymous voting as is common in other group decision support systems in order to show whether the judgement stems from an expert or a novice on the specific matter, and to decrease free riding. Anonymity may decrease evaluation apprehension, yet it contradicts the group norms that built an open and trustful atmosphere. Using the geometric mean of the individual judgements as the group judgement decreases the pressure to conform. The inconsistency ratios show the need for sharing additional information. Accordingly, the discussions as being supported by these group norms, group techniques and procedures resulted in a synergetic exchange of information and a constructive formation of a critical degree of consensus. The top-down approach of discussing the importances of the product requirements before the performance of the new product solutions is important to decide most deliberately on the level of performance of the new product concept.

The new product objectives are to evoke activities that conform to the user needs, the technological and the competitive environment, the needed resources for the project, and task interdependency. Dividing the liver perfusion system into relatively independent technological modules helps the team to deal with the task interdependency. It allows the new product development team to determine the research activities that can be divided over the different groups involved in the project (Kusiak and Park, 1990). The groups with the appropriate expertise and resources can, accordingly, focus on reducing the identified market and technological uncertainties related to the separate design modules. The identification of the product requirements relevant to these design modules directs the groups to keep being oriented towards the common new product objectives. The user and development partners of the liver perfusion system were committed to perform these activities in line with their competitive objectives.

In this manner, the AHP supported the members of the liver perfusion project to focus and structure the planning stage, while leaving room for the development of creative technological solutions. The new product objectives represented creativity goals that are based on a comprehensive range of product requirements. The shared understanding of the rationales behind these new product objectives will increase the commitment to fulfil these objectives. Finding the design solutions for the diverse technological components can then be left at the control of the creative minds themselves. These objectives do not need to be applied rigidly. Due to additional insight in the problem to be solved by the new product, or changes in the context that defines this problem, it may be wise to revise the results on the product requirements. The effect of changing the importances of these requirements on the performance of the new product can be analysed in the mode for sensitivity analysis of the AHP. More thorough changes may ask for an iterated definition of the new product objectives. Furthermore, technological solutions may fulfil any of the product requirements to a higher or lower extent than intended. The team members can use the numerical outcomes concerning the importances of the product requirements, and the corresponding performance levels of the pursued new product as guidelines for making trade-offs among the performance on requirements. The new product developers need to remain aware that the new product fulfils at least a minimal acceptable level of performance of each product requirement, and remains competitively viable at the overall performance level. We advocate that the possibilities for sensitivity analysis of the AHP are expanded to analyse changes in the new products' level of performance regarding the product requirements.

Some marginal notes to the use of the AHP are related to the uncertainties involved in new product development. Due to the diverse sources of uncertainties, the judgements of the group members are based on facts, firm convictions, half-held beliefs and even contradiction. The relatively uncertain judgements are likely to be more inconsistent. The inconsistency ratio of the AHP is an indicator for further reducing the uncertainties. Team Expert Choice suggests revised scores for those judgements that are most at odd with the remainder of the judgements. Yet, the judgements proposed, which may deviate extensively from the initial ones, can be out of the range of the 9-point scale. Therefore, we advocate that those judgements are revealed of which a small revision reduces the inconsistency to the highest extent. Despite its guidance in reducing the uncertainties, a further drawback of the AHP remains that it does not show the degree of uncertainties of the judgements. The interval AHP deals explicitly with this uncertainty, by allowing the decision-makers to assign an interval estimate instead of a point estimate. This extended method is, however, more laborious to apply.

The uncertainties described decrease the accuracy of the new product objectives. Furthermore, the mathematical procedures of the AHP evoke some inaccuracy. A common drawback of the AHP is that the prioritisation technique can lead to changes of the rank order of the overall performance of the alternatives, when adding or deleting an alternative. In our context, the value of the outcomes lies in the derived overview of the importances of the product requirements, and the relative performance of the alternatives with regard to these requirements, rather than the computation of the best alternatives. Therefore, small inaccuracies in the computed overall performance of the alternatives are innocent compared to other applications of the AHP that deal with choosing the best alternative. Moreover, the verbal scale for the pairwise comparisons may induce overestimations of weights. The rank order of the weights of each set of sub-requirements and the level of performance of the product solutions are likely to agree with the perceptions of the decision makers, however, the computed differences in these weights should be considered as being reasonably accurate guidelines.

Tools for multi-criteria decision analysis provide analytic support to the evaluation of a finite number of decision alternatives under a finite number of performance criteria. By defining the pursued new product concept as one of the decision alternatives, we extent the use of the AHP to include the analysis of dynamic alternatives besides the common static alternatives. This means that in addition to the estimation of the attributes of a fixed, existing alternative, we aim to define the attributes of an alternative to be pursued. This is a new area of application of the AHP, which we consider being appropriate and which is even less vulnerable to the main criticism on the AHP of rank reversal. Accordingly, we consider the support of the AHP to the exchange of relevant information and consensus formation valuable to define objectives for new products as well. This support is worthwhile for new product development, because an adequate information exchange and conflict management between R&D, marketing and users are a prerequisite for successful new product development.

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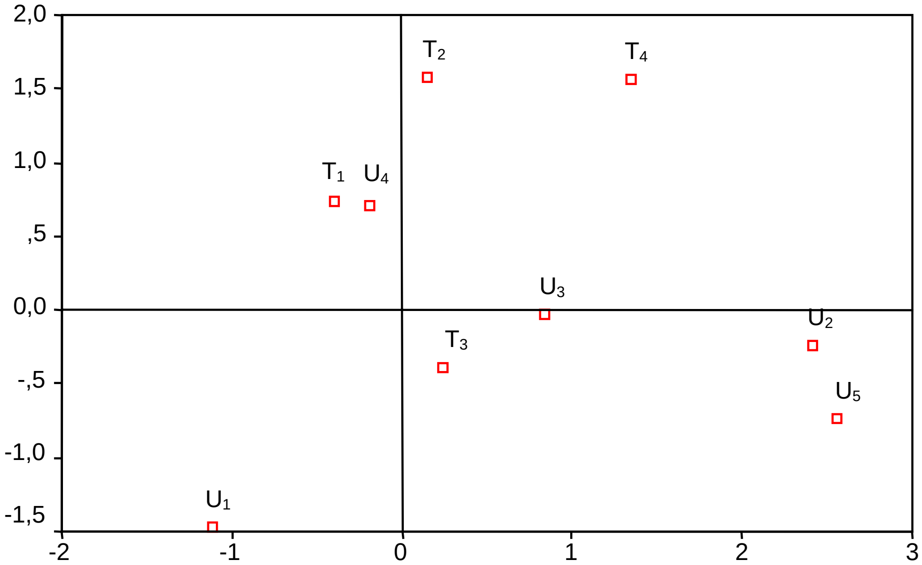
Appendix 5.1. Aggregated Euclidean distance model of individual weighting factors before and after the panel discussions (RSQ = 0.98)

A) Distances between individuals' weighting factors before the panel discussions



B) Distances between individuals' weighting factors after the panel discussions