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The focus of this study is the effective prioritization of customer requirements in collaborative product development. The CR priorities are often retrieved by questioning and interviewing targeted customers. But the targeted customer might not always be easily questioned, because they might not always be obvious or clearly known. If customers might be known, they might not be able to distinct the priorities for CR's, because everything is important to them. Moreover concerns of the developer's organization and the society might not get the necessary attention and it might be asked too much from the customer to trade off all customer requirements (CR's) by their own. Because the resources for an extensive customer interviewing might lack anyway the stakeholders might prioritize the CR's on their own.

Efforts have already been undertaken to support cross-functional stakeholder groups in finding priorities of CR's. Most of the investigated methods lacked the ability to distinct the importance of CR's by a relative amount or were not able to integrate the interdependency of stakeholders in other ways than a tiresome negotiation processes. With the proposed Urn-Scheme approach the stakeholders register their own individual priorities based on their perceptions of what the relative priorities of the CR's might be. Furthermore the method supports the stakeholders in considering the opinions of all other stakeholders.

The extent of taking others and own opinion into account is based on quantified social interdependencies, i.e. in this study measured trust and trustworthiness into the capability of every voter to understand costumers' perceived desired product quality. The summed up trustworthiness in prioritizing CR's of every stakeholder is used in a further step to finally transform the individual priorities to relative priorities of CR's from the whole group.

With the amplification of votes from the stakeholders, who are trusted to prioritize better than others, an improvement of the decision making process will be achieved. A careful developed, easily to understand mathematical framework builds the fundament for manifold analysis of the obtained voting results, e.g. consensus analysis, priority significance check. Moreover the framework makes the proposed method transparent and the obtained results well documented for later reference.

Quality Driven Collaborative Decision Making for Product Development Under the Influence of Trustworthiness

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Stefan Meier, Author

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I dedicate this work to my parents,

Trudi and Peter Meier,

who I hold in many ways as good examples for my life.

QUALITY DRIVEN COLLABORATIVE DECISION MAKING FOR PRODUCT DEVELOPMENT UNDER THE INFLUENCE OF TRUSTWORTHINESS

1 INTRODUCTION

High quality in general has not only been the goal to increase economic profit, but to enrich the quality of human life in the long run. But what is to be understood as Product Quality? Based on a survey published in *Time* (Nov. 13, 1989), product quality is perceived by the consumer through its associated performance attributes in *Reliability*, *Maintainability*, *Durability*, *Looks*, *Design*, the use of latest *Technology* and the number of *Features*. Although the consumer might be the most important customer group, they are not the only one to be satisfied. There are further external and internal customers[1], which have also concerns. If these further customer categories are considered as well, the understanding of product quality should be extended accordingly. We may therefore interpret product quality as embodiment of concerns from consumers, the developer's organization and of the society (Fig. 1.1).

It is a product developer's aim to address these concerns through collecting and analyzing customer data and formulating the costumer requirements by incorporating consumer, organizational and societal concerns (Fig. 1.2). The stakeholders will have to perceive what is important to all costumers, in order to prioritize CR's.

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[1]Internal customers might be e.g. stakeholders, marketers and organization strategist, manufacturer, assembly and shipping personnel and service personnel, whereas further external customers might be e.g. suppliers, standards organizations, environmental organizations, insurance and health organizations and the society in general [Ullm. 2003].

Figure 1.1 Concerns from Different Customers Embody Product Quality

The stakeholders generate individual priority lists based on their individual understanding of customer's concerns. There will therefore exist several different opinions what is most important to the customer. In a common process the different opinions are unified by a wearisome negotiation process including all stakeholders. Instead of this troublesome negotiation process, we introduce a unifying procedure based on trust in prioritizing as a social factor among the stakeholders to facilitate the group decision making to a unified CR priority list (Fig. 1.2). The unified relative CR priorities are used to develop engineering strategies and solutions to yield a real product that satisfies the customers' needs through usage. Every step shown in Figure 1.2 may affect the quality of the final product from early on.

The challenge that a product developer faces at the early design stage is what attributes the product has to have in the form of Customer Requirements (CR's) without neglecting a customer category. Given practical constraints, such as budget, personnel and time, not all customer requirements may be equally treated and/or fully satisfied. A trade-off among the CR's is needed to achieve high product quality and yet remain within the given constraints. In order to make a trade-off between CR's, their relative importance for the product quality ought to be known. As a result, the relative importance helps the stakeholders to determine an engineering strategy and with that the generation of technical solutions. Once the relative importance among CR's is known, the resources for the product development might be allocated accordingly and further design decisions based on these results e.g. selection of alternatives can be made.

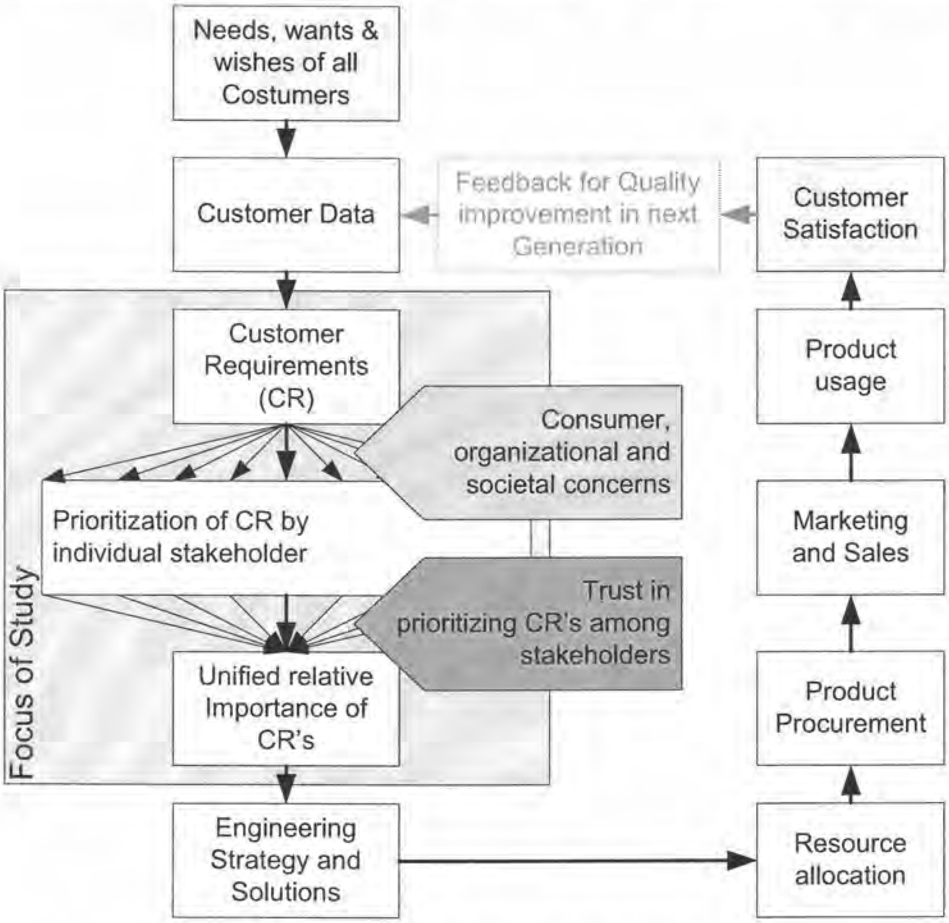

Figure 1.2 Major Aspects Contributing to Product Quality and Costumer Satisfaction

Efforts have been made to extract information and knowledge on customer requirements directly from customer data. In Quality Function Deployment based methods [Cohen 1995], the negotiation is merely based on analysis of customer inquiries, where the majority is taken as reference. Cohen [Cohen 1995] proposes several techniques to extract CR's and their relative importance from customer interactions but he also points out the necessity to let these inquiries be performed by professional market research firms in order to get reliable data. In our point of view the uncertainty using only customer data for the negotiation process might not only stem from the data collection method, but from the difficulty to choose the correct targeted or average customer and even more from the customer's indecisiveness of how important a product attribute is for him/her [Lai 1998] relative to others. Moreover lack of resources might limit the investigation of data from the customers about the importance of specified CR. In reality, the group of stakeholders has to negotiate the final relative importance themselves. Their judgment will be based on their understanding or perception of the targeted market and their interpretation of the customer data to weight the requirements of all customers appropriately. The stakeholders may have different understanding and interpretation of the customer data, which leads to different prioritization of CR's (see Fig. 1.2). It is important that a method is available to unify the prioritization results of CR's perceived by individual stakeholders, so that a group decision can be reached.

Several existing approaches have been found in the literature facilitating group decision-making. In a collaborative decision making environment, a simple way is majority voting if only two items have to be compared. If there are more than two alternatives to vote for, plurality voting is used in the sense of majority voting. Majority rules might have the limitation, that a poor alternative might win [Moul. 1988], although it would loose in pairwise comparisons with every other alternative. The Borda count and Condorcet Winner [Moul. 1988] method emerged early on as technique to rank different alternatives; both eliminate partly the shortcomings of plurality voting. The Analytical Hierarchy Process (AHP) [Saaty 1982], uses a thorough pairwise comparison based on a scale value, i.e. this item is six time more important than this one. Pairwise comparison methods tend to be very time consuming because all permutations of items have to be examined. Less time consuming are approaches using multiple voting rules [Froyd]. Multiple voting rules use different mechanisms to select the preferred winner. The rules might be based on an assigned scale value and by building of the mean over all voters or on a score related to the achieved rank and then summed up over all stakeholders. In the multivoting approache each stakeholder gets a fixed amount of votes, which he/she might distribute among the items to prioritize. Nominal group techniques (NGT) are applying multiple comparison rules. These techniques provide a step-by-step structure from the generation of a CR pool up to prioritization of CR's.

For almost all the prioritization methods found in the literature the stakeholders have the same influence on the outcome. In our point of view this is a limitation, because differences among stakeholders exist in many perspectives and should be considered when prioritizing CR's. The uncertainty of perceiving what CR's are more important and the nature of negotiation carry the problem from exact engineering into the playground of social, psychological, and cognitive effects. The task of prioritizing CR's asks for knowledge about the requirements of external and internal customers, as well as specific knowledge about the product itself. The stakeholders have to be committed to the product quality, be interested in the success of the product and ought not pursue egoistic motives. Otherwise the prioritization might be manipulated or not handled with the necessary respect. The collaborative decision making process therefore ought to account for difference in experience, expertise, interests, commitment, motivations, objectives and power. These factors are all part of the social sphere the stakeholders emit. People are naturally paying attention to such differences in the way e.g. they interact, listen to advice or rely on each other. Therefore it is suggested that in order to make effective collaborative decisions the differences among stakeholders have to be considered and social effects to be accounted for in a CR's prioritizing method. In one of the paper preceding this thesis [Meier 2004], trust has already been introduced as a key social factor in group decision making. Trust is well suited for the purpose "differentiating stakeholders" as it spans over different levels of stakeholder's personality, i.e. expertise, integrity and benevolence. In the proposed trustworthiness (TW-) measurement method the difference in capability among stakeholders to understand the customers' perceived desired product quality is quantified and serves as a basis for combining each stakeholder's individual prioritization.

In this thesis a complete method with mathematical framework is presented in order to find relative importance of CR's. Hereby an Urn-Scheme is used to record the transformation of individual priorities to updated priorities, moreover to a group unified set of priorities. The integration of organizational and societal factors, particularly trust and trustworthiness has been attempted.

2 BACKGROUND REVIEW

2.1 Quality related Background

The focus of this study is to increase the product quality through a better integration of what is important to the costumers. It is therefore necessary to understand what product quality in the eyes of the costumer stand for. The following section will further examine the terminology and deeper meaning of product quality.

2.1.1 DEFINITION OF QUALITY

First of all it has to be understood, that product quality is not depending on one but all steps along the product development process. Product quality cannot be manufactured into a product, it has to be build into it. We might define product quality like following: "*The product quality is a composite of factors that are in the responsibility of the design engineer. Thus the decisions made during the design process determine the product's quality as perceived by the customer*" [Ullm. 2003]. In other words product quality consideration starts with starting the product development.

The central question of the first steps in the product development is to find out what the customer wants and perceives as product quality. In order to know "what" the customers want, the targeted customer has first to be determined. In Ullman three main categories of customers are distinguished, i.e. *Consumer, Producer* and *Marketer/Sales* personal. The three categories will all contribute to the list of necessary product features. Please note that even if the consumers will form the largest customer group, they are not the only one. Therefore product quality will not only be determined by consumer requirements, but also by manufacturing (manufacturability, use of standard parts, resource conservatism, existing facilities etc.) and managerial aspects, which have to be considered as well (attraction, corporate image, cost generation etc.). An often neglected quality attribute of a product is its societal and environmental acceptability. Because of the scarce world resources environmental concerns will become major product quality focuses in future. The challenging task of integrating all customers with all their concerns (refer to Fig. 1.1) in a product development, is what stakeholders are doing at an early stage.

Once the targeted customers are determined, it has to be analyzed, what these customers perceive as product quality and formulize product specifications in form of Customer Requirements (CR's). This might happen by performing customer surveys, interviews, using focus groups, making observations etc. An often used approach to determine what customer wants is to examine what satisfies them. Hereby Kano's Model of Customer Satisfaction gives hand to proceed methodically. Kano divides product attributes into three categories: threshold (basic), performance and excitement, i.e. needs, wants and whishes of the customers. A competitive product meets basic attributes, maximizes performance attributes and includes as many excitement attributes as possible at a cost tolerated by the market [Ullm. 2003 and Otto 2001]. In other words if basic attributes are met, performance maximized and many excitement attributes realized the customer will be highly satisfied with the product and therefore perceives the product as a high quality product.

In a formulation process the explicitly spoken, but also often implicit vague descriptions of the customers are broken down in simple expressions of requirements and product specifications, i.e. customer requirements (CR's).

2.1.2 CUSTOMER REQUIREMENTS VERSUS ENGINEERING REQUIREMENTS

Customer Requirements are simply stated description of needs, wants and whishes of the customer derived from interactions with customers. Hereby the statements are not yet bound to any targets but to actions, which have to be fulfilled and satisfied. The words of customers might be used and the statements are usually in an affirmative form. Terms like easy to lift, is compact in size, moves fast etc. are used to circumscribe the required feature of the product. The purpose of CR's are to describe the task of a design without determining or fixing the included functions. The customer is only interested that the product fulfills his/her requirements, usually the "how" is from little interest to him/her if the purposed function is fulfilled properly. The formulation of CR's incidentally avoids to restrict designs by terminology to a certain concept in order to not anticipate the creative designing process.

The attributes described by the CR's, might be product features of many functional attributes together, e.g. moving fast is a function of e.g. traction, power and radius of used wheels. In other words CR's ought only describe the "what" and not the "how". This is the main difference to Engineering Requirements (ER's) and actually is the reason why CR's are needed. A collection of CR categories in [Ullm. 2003] helps to gather and structure the CR's.

In contrast to the CR's the ER's are already focused on how the CR might be satisfied or described in more physical ways. In a designing effort the CR's have to be translated into ER's which will lead to a rigid set of design specifications. While translating CR to ER, the CR has to be understood well and might first be described by engineering units. In the example of moving fast as CR, the CR might be translated into traction → force (N), power → torque (Nm) and radius of wheels (m). If there are difficulties to describe the CR by units, it might indicate that this CR is not yet fully understood or might have to be further decomposed. Sometimes the determination of ER's already involve a lot of designing work and might therefore not be manageable at such an early stage. In such a case the translation process might be lead ultimately into the concept stage. The translation process from CR's to ER's is a further step of building quality into the product. The link between quality at an early stage is the perception of what the customer will satisfy. This is what CR's describe and which are translated into ER's. A method which uses this chain of logic in order to build quality into the product is presented next.

2.1.3 PRIORITIZATION OF CR'S

An accepted method how quality is built into the product is the quality function deployment (QFD). QFD supports the fundamental processes at an early stage of product development with strong integration of the customer's voice (VOC) [Akao 1990, Cohen 1995]. QFD helps to develop specifications or goals for the product, how the competition meets the goal, what is important to the customer and numerical targets to work towards [Ullm. 2003]. QFD provides a method to convert the customer requirements into engineering specifications.

Given constraints on resources (e.g. time, money and personnel) it is not only necessary to know what the customer requires, but how relative important it is for him/her. The initial distinction between the customer requirements (CR's) based on Kano's model are the categories wants (i.e. like-to-have), needs (must-have) and desires (i.e. wish-to-have) [Lai 1998]. The customer him/herself might not be capable to rank the importance of the customer requirements further more than these categories. For the customer everything might be important and yet the CR's have to be traded off.

In Engineering Design only little research has been found prioritizing customer requirements. The selection of alternatives and design concepts has in comparison attracted a lot more attention for research around making engineering decisions. Nevertheless provided methods, especially matrix methods based on weighted sums have been favored searching relative importance of CR's. Good examples for such methods are the planning matrix integrated in Quality Function Deployment (QFD) or the Analytical Hierarchy Process (AHP) introduced by Saaty [Saaty 1982].

QFD proposes the use of the planning matrix, where as the *costumer importance*, the *satisfaction of the customer*, the *competitive satisfaction performance*, the *goal*, *improvement ratio*, *sales importance*, are used to find a normalized weight [Cohen 1995] of each CR. In extensive customer inquiries the weights of each CR might be found. Cohen suggests letting a professional market research organization perform these surveys rather do this by the development team themselves. Ullman describes several techniques to assess either ordinal or relative importance with the customer together [Ullm. 2003]. The key requirements for extensive customer inquiries are a) the targeted customer has to be clearly determined and b) there have to be sufficient resources to gather the data. Often in engineering projects neither of these requirements are fulfilled. An alternative to extensive customer inquiries is that the cross-functional stakeholder group decides on the importance of each CR on their own [Cohen 1995]. In such a case it is necessary that the voice of all customers are adequately represented within the group of stakeholder group. Using stakeholders' judgment and perception for the final prioritization might lead to errors in CR priorities, what might lead in the worst case to rejection from the targeted customers. Therefore a good prioritization methodology is needed which minimizes this risk.

Although QFD provides a very structured way of transforming customer requirements into engineering specifications, it doesn't specify means on how group interactions and CR's trade offs might be carried out. Furthermore, there is a lacking of negotiation strategies based on the stakeholders' interactions with each other, which has prevented the QFD methods from providing sufficient support to collaborative decisions on CR and its prioritization needed at the early design stage. According Lai et al. [Lai 1998] only an effective group decision making process may apply to achieve correct CR's and their ranking in a case where the stakeholders will make the final prioritization by their own. The following sections reviews further literature on making effective group decisions in order to find CR priorities.

2.2 preferential Voting

Finding the relative importance of CR's involves two main problems: (a) how are the different concerns of the customers represented best in a methodical way to find relative importance of CR's and (b) how is that done in a satisfying way by stakeholders with different perception of what is important to the costumers? According these two questions literature has been studied trying to answer them, where as the second problem has been emphasized because whatever method is used to solve (a) a way of how combining different stakeholder opinion is still needed.

The literature review has been extended to literature concerning *Social Choice*, where prioritizing methods are encountered for voting, ranking and prioritizing purposes. The main issue to answer question (b) is how individual orders of preferences might be combined to one single order or in our case to one set of relative importance. In other words what major effect is used to combine the opinions of the stakeholders? The majority of the found methods in Social Choice are using an averaging approach over all stakeholder votes, or building sums of votes and the item with the biggest score wins. In the following sections findings are documented more detailed.

2.2.1 EXISTING APPROACHES IN PREFERENTIAL VOTING

The so-called voting rules are fundamental underlying mechanisms to resolve a conflicting situation. We are interested in understanding how different preferential voting rules might be applied to solve a prioritization problem. Usually a voting rule is chosen according to the preferences of the stakeholders in advance.

Figure 2.1 summarizes voting rules found in our investigation. A major difference among voting rules is how many items are simultaneously compared. If two items are compared with each other, pairwise comparison rules are applied, where it does not matter if more than two items exist, but if all items have to be compared with each other until the voting result is obtained. Rules in the other main group compare clusters of similar preferred items, i.e. multiple comparisons. Pairwise comparison rules are generally more accurate, where as multiple comparison rules are much faster.

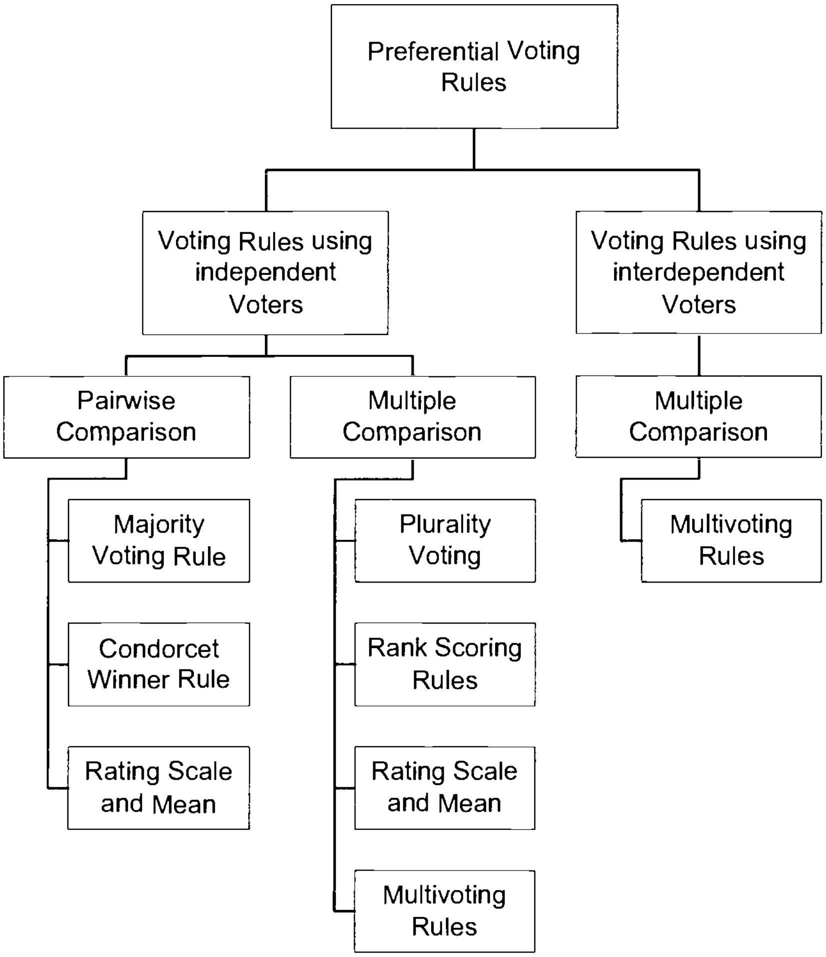

Figure 2.1 Overview of Different Voting Rules

Another difference addresses if the voters are assumed to be independent or interdependent. Usually voting rules are specifically designed to guarantee the independence and neutrality of the voters. But situations exist (particularly in engineering problems) where the group agrees to bestow the more experienced, and/or the more knowledgeable, and/or more authoritative group members with more voting power. In such cases independence or neutrality of the voters might thus be interfered with the aim to obtain a voting result that better considers the objective, such as maximizing customer satisfaction.

2.2.2 PAIRWISE COMPARISON RULES

2.2.2.1 Majority Voting Rule

Voting is basically understood as democratic process to find the preference of the majority or approval of the majority. The majority voting rule implies that between two items, the one with more votes will win. In the case of two items to choose from, the majority vote is unambiguously the fairest [Moul. 1988] in Social Choice. A good example of majority voting rules are political elections and voting for measures. Despite its long use and wide spread in our society, majority voting has limitations when applied on more than two items. Considering these limitations, plain majority voting should only be used for pairwise comparisons between two decision alternatives.

2.2.2.2 Condorcet Winner Rule

In order to surpass the limitation of plurality vote, Condorcet (1785) suggested to select the alternative as the most important, which wins over every other alternative in a pairwise comparison. The Condorcet Winner is usually found by letting the stakeholders rank the items individually. The resulting item sequences are then separated and each equal sequence counted. In pairwise comparisons between all items the one item with the more wins over all sequences has to be found. This search has to be repeated over all permutations. The Condorcet Winner is the item which had most pairwise wins. Although the method provides an accurate and fair result, a vote might not produce a Condorcet winner and usually take a long time to be performed. The method as well does not account for only slight differences among candidates, it applies rigid ranks, which might eliminate nonlinear preferences among candidates.

2.2.3 RATING SCALE AND MEAN

Rating scale and mean building reduces the limitations according the rigidity of ranks and is robust against rank reversal by elimination or adding of items from and/or to the list. Usually rating scale voting is applied by assigning a value from a specified scale to an item to be voted for and calculating the mean of the values voted by all stakeholders. In this way no direct comparison among the items has to be performed. In a pairwise modification of this voting rule a ratio scale value, is collaboratively assigned to a pairwise comparison. In other words the stakeholders compare two items and have to chose a discrete scale value of how many times more important item A is over item B. In the popular Analytical Hierarchy Process (AHP) every discrete item is pairwisely compared in this way. The scale in AHP ranges from one to nine and its reciprocal values, i.e. one for equally important and nine for a lot more important and 1/9 if much less important with any values as intermediate levels. At the beginning of applying AHP a decision criteria hierarchy is defined. This might be done with brainstorming possible criteria and then using an affinity process to structure the criteria into a hierarchy, i.e. criteria decomposition. The prioritization might start from any level of the hierarchy, but usually it makes sense to start at the bottom. The items for comparison are arranged in an $N \times N$-matrix, where N is the total number of items to be prioritized. Then the ratio scale values are assigned to each element in the matrix. If e.g. the row item is 3 times more important than the column item, the according element in the matrix will receive the value 3 but if it is opposite, then the element will be 1/3. Then the next element in the matrix has to be agreed upon by the stakeholders. All diagonal elements are obviously one, i.e. equally important the pairwise comparisons are only performed once, i.e. the values in the matrix are reciprocal symmetric to the diagonal of ones. All these comparisons are strongly focused on a specific criterion of the initially chosen hierarchy level. The priorities of all items corresponding to the examined criterion are found by summing up the elements in a row of each item and normalize them to the total sum of all these sums. For every other criteria on this hierarchy level, a new pairwise comparison matrix has to be filled out and its normalized priorities calculated. The priorities of each criterion are then summed up, whereas the weights for the criterion are also found by a comparison matrix [Saaty 1982].

If there are a lot items to be compared, the use of the AHP is extremely time consuming. Different approaches tried to simplify the procedure, hence to use the accuracy but limit the scope of AHP. Karlsson et al. [Karl. 1997] applied the AHP on items considering Cost and Value as only criteria. The priority results are then displayed in a 2D diagram, i.e. Cost-Value-Chart. The chart has three sectors, i.e. high (high customer value, low cost), medium and low priority (high cost, low customer value). The visualization of the relative priorities is very clear and supports the decision analysis. Similar work was proposed by Park et al. [Park 1999], where priority and risk are compared of each attribute. The group consensus is found by the statistical mean. The proposed charts are divided by different priority bins (i.e. priority classes) to record relative importance of the attribute. The kinds of priority bins are chosen for different issues, e.g. Return on investment, Risk reduction. Prioritization equilibrium between the voting model and bin model is then searched for.

The big disadvantage of all pairwise comparison rules are the high time consumption of comparing pairwise all items. Although the methods might deliver consistent results the slow and tiresome process to get to the priorities might not be practical for finding relative priorities at an early stage. Furthermore there is not a documented way how a stakeholder group might get to an agreed comparison value other than building the mean or the sum of individual votes; the initial problem how to combine different stakeholders' opinions interdependently to one is not resolved. Therefore and because of the big time-consumption the authors decided not to use a pairwise comparative approach. In contrast to the pairwise comparison, multiple comparison rules are faster because of the reduced amount of comparisons necessary. The following section is dedicated to multiple comparison rules.

2.2.4 MULTIPLE COMPARISON RULES

2.2.4.1 Plurality Voting

If majority vote is used where more than two items have to be compared, it is called plurality vote. Every stakeholder writes his favorite item or candidate on a paper and the item with the most numbers wins the election. Around 1783 Borda and Condorcet manifested already that plurality vote might elect a poor candidate which might loose in pairwise comparisons with some of the other items. They demonstrated that majority vote should hence only be used in a pairwise comparisons.

2.2.4.2 Rank Scoring Rule

Borda (1781) [Moul. 1988] suggested in order to surpass the limitation of the plurality vote rule by using a rank scoring rule, which today is known as Borda count. Stakeholders have to rank the items or candidates according to their liking. Borda proposed if there are *N*-items to rank, the best rank should get *N*-1 points, the second best *N*-2 and so on. The candidate with the most points would win the election. Borda linked the rank to a scoring system by a linear relation, i.e. if there are nine candidates to vote on, voter A might rank candidate 3 most favorite, therefore in voter's A ballot, candidate 3 would get 8 rank points. The next ranked candidate would get 7 and so forth. Slight differences in importance in voter's A ranking are lost due to the rigid score system of the Borda count. Modifications of the Borda [Fox 1987] count are using larger point difference between the ranks and might assign different slopes to different stakeholders in order to consider a "power" hierarchy among stakeholders. Limitations of the original Borda count might be rank reversal if an item is eliminated from a list [Scott 2003] and Borda count might be prone to manipulation from coalitions among the stakeholders [Fox 1987]. In our case the linear relation between rank and score limits the Borda count rule on ordinal results only and might not account for slight preference differences, hence we are not able to use it to find the relative importance of CR's.

2.2.4.3 Rating Scale and Building Mean

Rating scale and building mean, as already introduced in the section of pairwise comparisons, might surpass the limitations of plurality voting as well. In an often applied version of this rule, every stakeholder gets cards between 1 and 9, one for not important and nine for very important. Then each item is voted on, by holding up the card of the preference each stakeholder wishes to express for the item. The total amount of points or the mean is recorded for each item. At the end a Pareto chart might reveal the differences among the importance of items [Fox 1987, Gundy 1988]. The mean and the distribution will be used to draw conclusions about the absolute priorities and consensus of the voted items. The use of a rating scale gives an absolute new character to the voting results, because the items have not necessarily to be compared with each other. This makes the voting process fast. In some cases this might also be used to manipulate or even distort the voting result. Stakeholders might use their influence to vote every item with 9 or 1, i.e. gamesmanship and honest voting might get lost or the stakeholder might perceive everything as very important and don't make any importance distinction themselves anymore. The rating scale doesn't support the necessary trade off process among CR's, which would be actually needed to prioritize CR's. Therefore the discrepancies in importance among items might get averaged out or lost during the voting.

In summary neither Borda count nor Rating Scale might be used to express relative differences in the importance as we plan to achieve. Nevertheless rating scales or rank scoring rules are already applied for group techniques, e.g. Nominal Group techniques (NGT). The straight forward structure and the possibility to generate a list of items, to narrow this list down and to prioritize its items lead to a wide acceptance of NGT [VanD. 1974]. Although it is a group technique it emphasizes the contribution of the individual and therefore protects the more timid group members. NGT's major application in the field of product development might be the generation of a CR pool. The generation of items is based on an individual brainstorming, followed by a collection of all stakeholder's lists. Then the items are compared to each other. For this purpose each stakeholder ranks silently the items according his/her liking. The item most important to the stakeholder will get the highest score. The scoring system has to be agreed in advance. The scores for each item are then added up and a Pareto chart might be drawn to display the result. The way of voting might be adjusted to the decision making procedure of the group [VanD. 1974]. Because conflicting negotiations don't interrupt the decision process; the NGT is fast and ensures the participation of every stakeholder. A slight modification to even shorten this time consumption and to protect the individual creativity even more [Fox 1989], introduced the Improved NGT (INGT) [Fox 1987]. The main difference to the standard NGT is that participants submit their suggestions for the collection of items in advance of the meeting. Because of that each participants will invest some time to create own thoughts about the problem. The decision making process through NGT usually has a high group acceptance and provides creative solutions. NGT has already been applied for QFD purposes. Recognizing the need for a quality related effective group decision making, i.e. prioritization method in QFD Lai et al. [Lai 1998] have proposed a modification to NGT, which integrates communication among team members and preference for CR's of each individual team member. Despite the wide possibilities of application of NGT and INGT, the limitations inherent in the used voting rules restrict the group technique in practical use for finding the relative importance of CR's.

2.2.4.4 Multivoting Rule

The main limitation of rank scoring rules in order to find relative priorities, i.e. the rigid rank-score relation, is surpassed by multivoting rules. In multivoting [Froyd], i.e. Point Assignment [Fox 1987] each stakeholder is assigned the same amount of votes, which he/she distributes openly over all compared items. The importance is found by summing up the number of votes an item has gotten. Usually to prevent gamesmanship the total votes placed at one item is restricted. The way the votes are recorded might be sticking dots ore beans. A variant version uses different colors of sticking dots for every stakeholder. With assignment of different colors to each stakeholder the capability to comprehend and analyze the voting result is improved compared to unique colored dots or beans [Gundy 1988] and an imbalance in voting might be spotted instantly. Multivoting provides fast results and the group acceptance and involvement is good. Multivoting will make it possible that not only ordinal information is determined but also the relative difference might be recorded. By distributing different amount of sticking dots or beans to some stakeholders, difference in voting power might be realized. Using such an open process might not always support neutral voting. Late voters might get influenced seeing the votes of previous voters. It might be necessary to hide every stakeholders vote or e.g. shield the glasses for the beans [Fox 1987]. A modification of the Nominal Group Technique found in the Team Training Workbook from Arizona State University [Bell. 1994] uses the NGT as basis, but instead of using a rank score or a rating scale rule, a multivoting rule is applied. Another way how multivoting rules might be applied in a design environment shows the priority matrix. The priority matrix, uses group negotiated and weighted criteria to prioritize items [Bell. 1994], similar to the planning matrix previously referred to. In an L-shaped matrix the items which have to be compared are allocated in rows, where each criterion gets a separate column. Multivoting rules might be applied to first vote for every item with respect to each criterion and then the relative weights for the criteria might be determined also by multivoting. Weighted sums might be calculated for every row across all criteria. These results might be normalized by the total sum of the weighted sums. This normalized value might then be denounced as the relative importance values.

The documentation through a prioritization matrix is orderly and is always reproducible.

In summary the multivoting rule provides a fast and transparent comparison technique without restricting the voter into a rigid rank score relation and takes relative discrepancies in the perceived importance by the stakeholders into account. The only limitation of multivoting rules, as well as all other investigated methods, is that none of them goes beyond the independent use of votes. Therefore we might conclude that although the methods involve all group members they actually only correspond to a mathematical aggregation of opinions of individual decision maker and the needed negotiations are suppressed or have to be performed additionally by the stakeholders themselves. The use of synergies, hidden stakeholder hierarchies and knowledge about product quality within and among the group of stakeholders is not supported.

The sole mathematical combination of individual priorities might lead to a fair win of the majority opinion. In Social Choice this might be desirable, in "Product Development" Choice the aim is to maximize the product quality and this might not always be achieved by following the opinion of the majority. Some of the stakeholder might be better qualified to perceive what CR's are important, might have more knowledge about the customer, or might have a stronger intuition etc., thus such differences might be used to improve a sole mathematical combination of votes. Without considering that group of voters might act interdependently and might have different capabilities to actually prioritize CR's, the actual collaborative part is missing. So problem (b) is actually the search for a method which not only provides a framework to aggregate individual and independent votes but also to incorporate hidden information about the interdependence of the group members without having to perform tiresome actual negotiations. The only obstacle to do so, is to determine a fair way to measure such differences among stakeholders. The following section presents a method which already has this difference of stakeholders in mind and shows a way how votes might be gathered with protection of the individual sovereignty but with taking interdependency into account.

2.2.5 INTERDEPENDENT VOTERS

The difference between independence and interdependence is that the sum of achievements of independent parts, does not reach the level of achievements from interdependently connected parts. Interdependency is the motivator to work in groups and teams. The carriers of interdependence are group dynamics and synergies among participants which are used to foster the individual performance. Such interdependent effects are applied in Successive Proportionate additive Numeration, or renamed Social Participatory Allocative Network (SPAN) voting [Fox 1987, Gundy 1988]. It was presented in the 70'es by MacKinnon et al. [MacK. 1966a, MacK. 1966b, MacK. 1969, MacK. 1976] as a method, which determines relative differences between options and considers difference among stakeholders. Each stakeholder gets a certain number of votes as in multivoting, e.g. 100 points which he/she may distribute either to items or to a fellow stakeholder. In the second round this step is repeated until all points are distributed over the items and no stakeholder has any votes left. The stakeholder themselves decide how much they perceive the other stakeholder to be special capable of voting and might pass own votes to them. Every stakeholder does that in the amount he/she is willing to rely on the others judgment. In this way an individual not necessarily dominates the vote, but the stakeholders might assign higher voting power to individuals they perceive to be more capable of voting. SPAN already includes the basic group dynamic elements; we are looking for in the investigated methods. Unfortunately the method does not provide a controlled way for differentiating voting influence of stakeholders, that makes the method prone to manipulation and jeopardizes the validity of the found result [Gundy 1988]. Personal factors, e.g. charisma, decisiveness, confidence, liking might be mistaken as special expertise by stakeholders and the voting power might be assigned arbitrarily. In an extreme way a "dictatorship" of an individual might be the result and therefore the group advantage would be eliminated. The danger of uncontrolled bias and the integration of not specifically measured interpersonal effects could negatively influence the quality of the voting outcome, i.e. the prioritization.

This limitation showed the necessity to measure this interdependency in order to prevent arbitrarily allocated voting power. Therefore factors of interdependency in teams and organizations had to be studied and that's why social network literature has been reviewed. The findings revealed that social networks really are able to describe interdependencies among stakeholders and consequently might provide a way how to measure these interdependencies. The following sections review the findings in detail. Hereby important elements within studies of social network have been used to shape own ideas and the own approach.

2.3 Human Social Dynamics (HSD)

2.3.1 SOCIAL NETWORK AND TRUST NETWORK

A key to understand interpersonal relations among stakeholder or even across an organization is to analyze the underlying social networks. Trust and power [Cross 2002], Affect production, politics and culture [Wald. 2001], Trust, open communication and joint problem solving arrangements [Noor. 2002] are only a few networks to mention reflecting relationships between actors. In the literature the terminology of social network is used to describe a set of actors connected over a set of ties to each other [Borg. 2003]. The actors, i.e. "nodes" might be persons, teams, organizations, concepts etc. "Ties" are the type of connections between the nodes or pair of nodes. There might directed (e.g. advice), undirected (e.g. physically proximate) ties or the ties might be dichotomous (e.g. presence of friendship) or valued (e.g. scale of strength of tie). For each set of ties (e.g. friendship ties) a binary social relation is constituted and for every relation a different network defined (e.g. friendship network, advice network, communication network). The functionalities are different in each network, i.e. centrality in a conflict network doesn't imply the same as centrality in the trust network. Borgatti et al. identified different areas where network research is recently enhanced. A large body of work is founded in social capital, which is the organizational network research where forms and implications of networks on different issues as for example team performance; power, leadership etc are investigated.

Found literature points out the significance of such ties and the impact of changes to those networks [Katz 2003]. Krackhardt et al. [Krac. 1993] identified communication, advice and trust as the most common networks in organizations. They showed in an example how controlled changes to these networks have changed the performance of the exemplary organization significantly. In strategic decision making trust in the final decider is critical for the outcome and acceptance of the decision [Kors. 1995 and Eise. 1989]. McAllister [McAl. 1995] documented trust as determinant for that interdependent actors work effectively together. Trust is therefore a key value for team work. The role of trust stands out, because it affects many other interpersonal issues, i.e. communication, sharing of information, sharing of knowledge, sharing of responsibilities and tasks. Trust directly influences the quality of team work and its performance. It influences the way we listen to, share information with, respect and rely on each other. A lack of trust affects communication, cooperation and decision making [Meier 2004] of the team. In the following sections trust is further examined.

2.3.2 TRUST AS KEY FACTOR IN HSD ENVIRONMENTS

2.3.2.1 Definition of Trust

Encyclopedia Britannica: *In law, a relationship between parties in which one, the trustee or fiduciary, has the power to manage property, and the other, the beneficiary, has the privilege of receiving the benefits from that property.*

Merriam Webster Online Dictionary, *1 a : assured reliance on the character, ability, strength, or truth of someone or something b : one in which confidence is placed*

2 a : dependence on something future or contingent : HOPE b : reliance on future payment for property (as merchandise) delivered : CREDIT

3 a : a property interest held by one person for the benefit of another b : a combination of firms or corporations formed by a legal agreement; especially : one that reduces or threatens to reduce competition

The literature review revealed the existing discordance about the exact definition of trust, its antecedents and outcomes. A clear and accepted model was presented by Mayer, Davis & Schoorman '95 [Mayer 1995], who define trust as willingness to be vulnerable to the actions of another party. These actions might be cooperation, sharing sensitive information, letting the other party taking control over issues which are important to the trustor[2]. The development of trust and mistrust is related to previous outcomes of this vulnerability. If previous trust has been confirmed by a successful outcome the willingness to be vulnerable will be higher the next time. The opposite effect will occur if the outcome has been disappointing [Mayer 1995].

Rousseau et al. [Rous. 1998] performed an extensive literature review and found that most definitions of trust are centered on "willingness to be vulnerable" and "confident expectations", whereas confident expectations are similar to positive expectations. Therefore Rousseau et al. concluded trust as: "*Trust is a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another*". In the statement of Rousseau et al. the requisites for trust are already named, i.e. risk and interdependence. The next section is focused on what are requisites so that trust is able to be developed.

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[2] Trustor (who trusts the trustee)

2.3.2.2 Requisites for Trust

Initiated by Deutsch [Deut. 1958] is the comprehension that risk or having something invested, is a requisite for trust. Rousseau et al. [Rous. 1998] define two fundamental conditions based on their extensive literature review. Risk and interdependence are both needed to foster trust (i.e. risk stemming from the uncertainty of the outcome and interdependence as necessary reliance between parties to reach positive outcome). Variations in both risk and interdependency along the interactions will alter the level of trust. In the second part of their paper, Rousseau et al. manifest trust not as control, but as substitute for control. In other words if control of the outcome is not possible, a way still to make a decision is to trust. Gillespie (2003) [Gill. 2003] summarizes it more to the point: "trust begins where rational prediction ends".

Determining the priorities of CR's by a cross-functional stakeholder group involve both requisites. Interdependency because without participation of all stakeholders, important concerns might be missed and the risk, because errors in prioritization of CR's might indirectly lead to product rejection. Trust is therefore well suited to express the tie between stakeholder, while they perceive the view of the customers in order to prioritize CR's.

In order to use the trust network among stakeholders in a mathematical framework, trust has to be measurable. Therefore the literature review also includes studies concerning the perceptive measurement of trust and trustworthiness.

2.4 Trust measurement

2.4.1 A MODEL OF TRUST MEASUREMENT

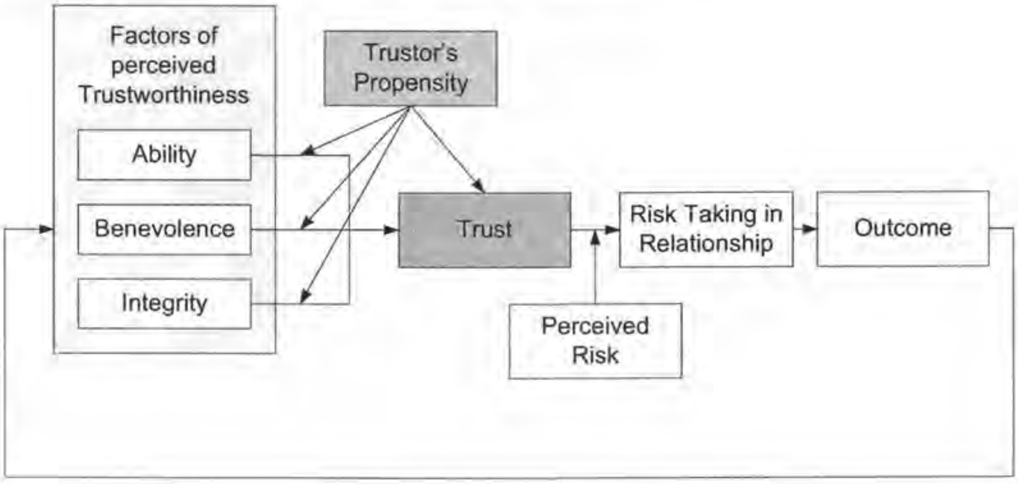

Figure 2.2 Model of Trust [Mayer 1995]

In the presented model of Mayer et al. 95 [Mayer 1995], i.e. figure 2.2, trust might be composed by the own general willingness to trust (i.e. own propensity) and how trustworthy the trustee is perceived by the trustor. The proposed model of trust by Mayer et al. is a causal loop (Fig. 2.2) with trustworthiness and propensity fostering trust. The loop points out that before the trustor usually takes the risk of being vulnerable, he checks if the trustee is trustworthy enough in his eyes.

This leads to the definition of perceived trustworthiness. Mayer et al. 95 [Mayer 1995] propose that perceived trustworthiness is comprised of ability, benevolence and integrity. Ability is that group of skills, competencies, expertise and characteristics that allow a party to have influence within some domain. Benevolence is the extent to which a trustee is believed to want to do good to the trustor, aside from the own egocentric profit motive. Integrity is defined as the trustor's perception that the trustee adheres to a set of principles that the trustor finds acceptable. All three factors are combined in an idiosyncratic way between individuals and situations.

More empirical work e.g. [Mayer 1999 and Gill. 2003] showed that although trustworthiness is a significant determinate for trust, it is not equally to trust. Gillespie offered several reasons for why it is conceptually wrong to assume measuring trustworthiness is measuring trust. The most obvious reason is that judging somebody's trustworthiness does not require risk, vulnerability or interdependency, but trust does. There was also only light empirical evidence for correlation between trust and trustworthiness as factors. It seems that both are depending on distinct other important constructs. According her findings a valid instrument for trust has to measure trust as willingness to be vulnerable or trusting behavior (e.g. sharing sensitive information, delegate responsibilities, share own ideas, express critics) in order to measure trust. She noted a general lack of reliable measures for organizational trust and a gap between definitions and instruments.

2.4.2 INSTRUMENT OF MEASURING TRUST AND TRUSTWORTHINESS

In order to be able to correlate trust and trustworthiness, or to team performance or a positive outcome, trust and trustworthiness have to be measured. In a quasi field experiment Mayer et al. [Mayer 1999] measured trust and trustworthiness related to a managerial issue (i.e. Performance Appraisal System). Zolin et al. [Zolin 2003] used a similar tool to measure trust in a distributed, cross-functional Architecture, Engineering and Construction project to relate trust in A/E/C-teams to their performance. In both cases a specifically designed and adjusted questionnaire were used for the measurement.

[Gill. 2003] introduced the "Behavioral Trust Inventory" (BTI) which measures the willingness of being vulnerable. She successfully demonstrates that in order to be measurable, the items in the questionnaires have to be bound to interactions between trustor and trustee. This reasoning explains her strong concentration on trust behavior, rather on a concentration on trustor's judgment of the trustee as found in e.g. Mayer et al. (1999). In preliminary interviews of triads (Project manager and two subordinates) she extracted two main domains of trust behavior. These were Reliance ("*relying on another's skills, knowledge, judgments or actions, including delegating and giving autonomy*") and Disclosure ("*sharing work/related or personal information of a sensitive nature*") [Gill. 2003]. Based on those findings and further interviews she extracted a general trust measurement from initially 50 items down to 15 questions.

The literature review of preferential voting, HSD-factors and trust/trustworthiness indicated a doable way of how a social effect might be measured and on this way might add value in an effective group prioritization process. The following chapter will further explain how the reviewed studies and own ideas might be translated into a consistent and rigorous methodology.

3 METHODOLOGY OVERVIEW

3.1 Objective and Requirements for the Method

The objective of the developed method is to improve the relative prioritization of Customer Requirements by a group of stakeholders in cases where extensive customer inquiries are not performed or the final decision is made by the stakeholders.

The literature review revealed following description of requirements for such a method. The method has to provide a way to record relative priorities rather than rankings. The method should support the stakeholders to consider consumer, stakeholders' organizational and societal concerns. It also has to take into account the way the individual and group of stakeholders interpret the customer data. The method has also to provide a way to combine individual interpretation of what is important in order to find final priorities, which all stakeholders accept as group decision. It would need to distinguish the voting power of stakeholders, because there exist differences in experience, expertise, commitment, purity of motives among the stakeholders. An offered way to measure and quantify these differences is measuring the tie strength in social networks and in specific by measuring trust in understanding customers' perceived desired product qualities. Moreover the developed method should be more effective, i.e. more accurate and less time consuming, more transparent than existing methods and should provide tools to interpret the results.

3.2 Technical and Social Connectedness in Product Development

The basic idea of the presented study stems from the concept of connectedness, where everything relates to others and everyone ties to others. Although these connections are more obvious on the technical-physical side of the product development, they also exist on the human-social side of the development process. Connections make possible that tasks, goals and performances are achieved, which for an individual part (artificial or human) would not be achieved to this level. The interdependence discussed in section 2.2.5 is one part of this being connected. Through the connectedness individual parts are becoming a system. Figure 3.1 shows two intertwined systems, i.e. technical and social system, while a product is developed. Where as both systems are individually already well studied, the connection and influence from one system on the other and on the product development has yet only attracted little attention.

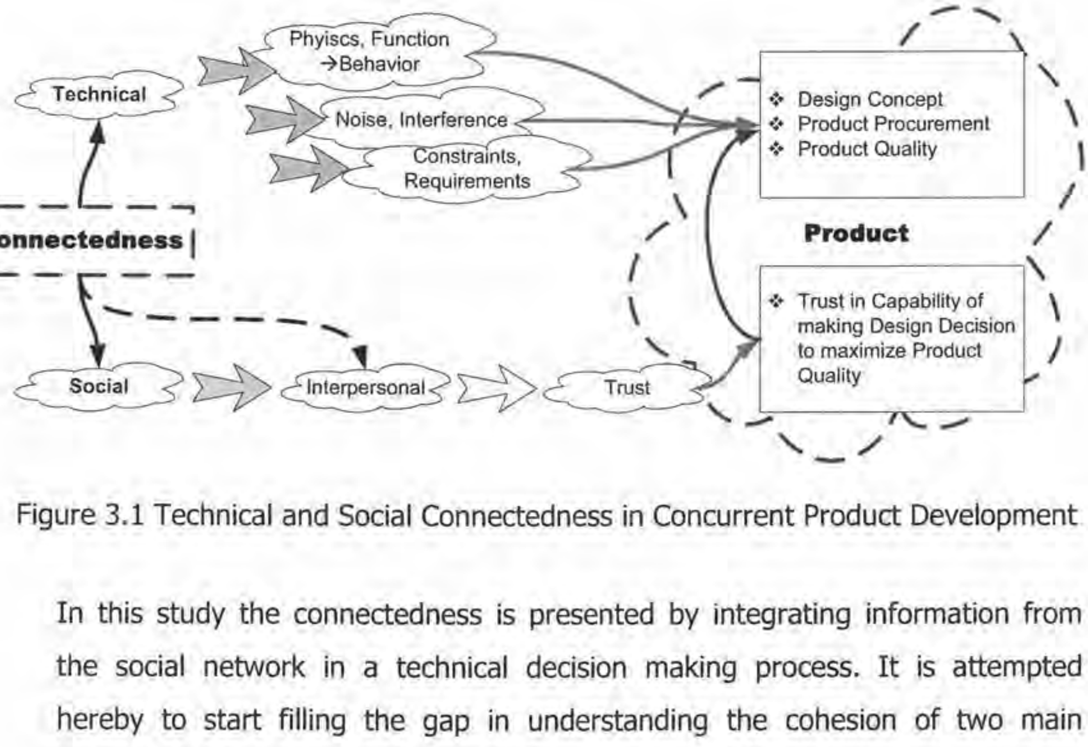

Figure 3.1 Technical and Social Connectedness in Concurrent Product Development

In this study the connectedness is presented by integrating information from the social network in a technical decision making process. It is attempted hereby to start filling the gap in understanding the cohesion of two main systems facilitating the design process.

3.3 Approach: Prioritizing Customer Requirements (CR) with Consideration of Stakeholder Trustworthiness

The proposed methodology (as shown in Fig. 3.2) helps to derive the relative importance of CR's as an embodiment of concerns from consumers, the developer's organization and societal concerns (see Fig. 1.2). Figure 3.2 shows three major phases, i.e. three columns at the early design stage, including defining CR's, finding relative importance, and relating CR's to engineering Requirements (ER's). The focus of our study is the middle column. The method starts with a pool of CR's resulted through stakeholders' brainstorming or other techniques, and expects to deliver a set of relative priorities of CR's determined by the group, from which the ER's are to be derived. Within the middle column, following the horizontal direction rightward, the proposed approach has two stages, an individual prioritization of CR's (Step 1 and 2) and the group task of combining all individual priorities (Step 3). In a collaborative environment not only a single developer, but multiple stakeholders are involved. Each of them might bring a different set of expertise, experiences, preferences and concerns with him/her. Because of their different backgrounds and interests they might all perceive the relative importance of CR's differently. If we assume that each stakeholder might have different perspectives, the result would be *N*-different priorities for every CR, where *N* the total number of stakeholders is. At that instant two questions rise:

(1) How are the stakeholders individually developing their priorities?

(2) How are these individual priorities unified into one final group decision?

Our proposed work translates these two questions in a three-step approach: (1) generation of individual priorities, (2) updating individual priorities and (3) unifying the individual priorities. The following three sections explain further details and how the proposed work plans to achieve a group prioritization of customer requirements.

In step one the stakeholders are treated as independent decision makers. The independent generation of the individual priorities might guarantee that the full amount of expertise, knowledge, intuition etc. inherent in the stakeholders is used to integrate concerns in the CR's prioritization process. In that way the participation of the stakeholder is ensured and the broad base of concerns of the stakeholders is represented in the priorities (please refer to section 4.1.1 for technical details of this step). As we have seen in the literature review, the prioritization of CR's might not be based solely on costumer data, because usually not all concerns (see Fig. 1.1) are adequately represented or easily recognized in these data, therefore the prioritization process may not rely on raw customer data or its direct translation exclusively.

The prioritization is a careful tradeoff among different customer concerns, stakeholders' organization and societal concerns. The individual stakeholder might therefore try to perceive what requirements especially lead to high product quality based on his/her knowledge and experience with all customers. He/she might consider gathered customer data in his/her judgment. He/she might study unique product qualities compared to competitors. He/she might try to match corporate strategy and image with his/her perception of product priorities. Finally the developer would carefully examine if his/her product priorities might not harm any societal concerns (please refer to fig.3.2). In our proposed work, we intend to summarize the individual's process to incorporate the voice of customer, developer's organization, and society into his/her prioritization of CR's through following process: (1): Customer and market driven prioritization; (2): individual preference based adjustment of the priorities; (3): the knowledge based adjustment of the priorities to represent the organizational and societal concerns, as shown in Fig. 3.2. With this described *first step*, the stakeholders individually generate their own priorities, in the following two steps these individual priorities are led to collective priorities.

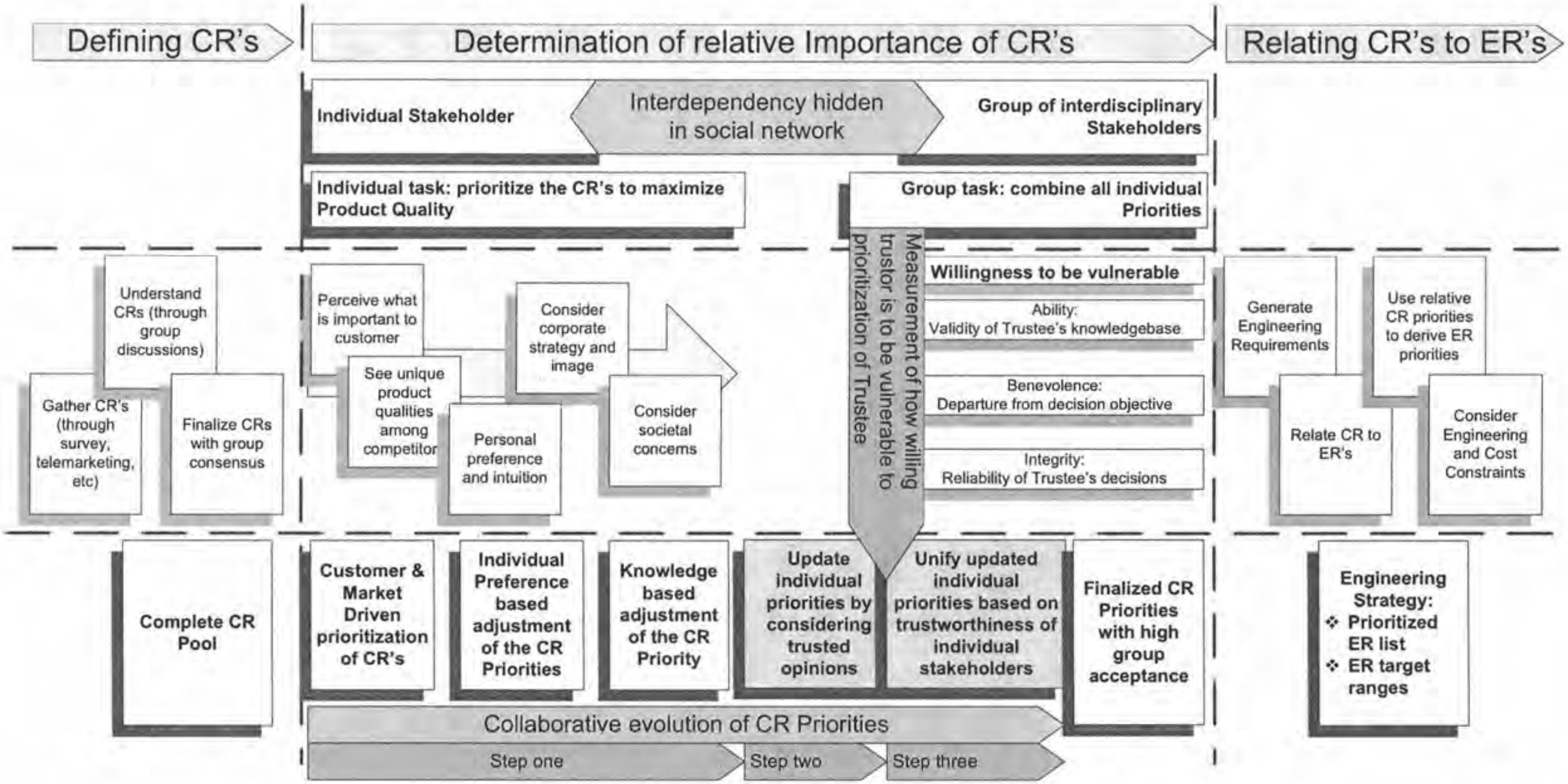

Figure 3.2 Determination of Relative Importance of CR's After Defining a CR's Pool and Before Relating CR's to an Engineering Strategy.

In Step 2, the stakeholder considers the opinion of the other stakeholders to the extent he/she trusts their capability to understand the customers' perceived desired product quality. With that step the stakeholders employ the interdependencies among the stakeholders hidden in the social network. The individual stakeholder uses social dynamics to determine the extent he/she is willing to rely on a specific stakeholders' and his/her own opinion. Hereby the individual priorities are updated by a weighted sum consisting of all other stakeholders' and own individual priorities. The applied trustworthiness (TW-) measurement quantifies the willingness of the trustor to be vulnerable to the capability to prioritize CR's of all stakeholders including the trustor him/herself. The developed TW-measurement is a comprehensive multi item survey with items concerning expertise, experience, commitment, motivation, consistency and rationality of the trustee (Meier et al. [Meier 2004]). In the literature review of social dynamics trust has been found to be comprehensively constituted of ability, benevolence and integrity somebody has towards somebody else's actions. Hereby trust might be very objective and possibly concentrated on a specific issue. In the case of prioritizing CR's the specific objective is trust in the trustee's capability to understand customers' perceived desired product quality. Trust and trustworthiness seems to serve well for the purpose of quantifying opinions and judgment of fellow stakeholders. Despite the first independent step in the decision making process, the second step uses the interdependency of the decision maker based on his/her own social network towards all other stakeholders. That explains parts of the second stage in Figure 3.2 towards finding relative importance of CR's and why trust has to be measured in order to represent the interdependencies of the stakeholders. If this step would fail, the level of a single independent developer could not be passed and the qualities and advantages of an interdisciplinary stakeholder group would be neglected (technical details for the second step are shown in section 4.1.2). Once the individual priorities are updated with weighted priorities of all stakeholders, these new i.e. updated priorities will be combined and unified in a third and last step.

In Step 3, the interdependency among the group members is also used to unify the updated priority lists. Where in the second step the TW-measurement is used to quantify the willingness of each stakeholder to rely on the opinion of all other stakeholders and him/herself, the same measurement is used in the third step to quantify how much the group is willing to rely on the judgment of every individual in that group. This bidirectional effect of the interdependency is shown in Figure 3.2 with a two-way arrow between the individual and the group. Based on the proposed measurement of the interdependency among stakeholders, weights are calculated for summing up the individual, updated priorities in order to arrive at unified priorities (please refer to section 4.1.3 for more technical details). The updated priorities are, as explained in the previous paragraph, a weighted sum of individual priorities. The specific focus of the proposed TW-measurement does not include measures of how well the trustee is perceived to trust other stakeholders and yet in the third step the measurement is indirectly used to do this by applying the TW-measurement results on the updated priorities. Although this seems contradictory a close analysis of the measurement instrument makes clear, that this is legitimate. The stakeholder measures trust in the capability to understand the customers' perceived desired product quality concerning all others and him/herself. Hereby the built trust of the stakeholder towards others will be related to his/her own capability understanding the customers' perceived desired product quality. Therefore the authors make the assumption that trust in his/her capability correlates to the trust in him/her to evaluate others doing the prioritizing. In other words the more trusted a stakeholder is prioritizing CR's according the measurement, the more he/she is trustworthy to tell if other stakeholders are trustworthy for the prioritizing of CR's or not. Therefore the use of the same measurement seems not only legitimate but also to be an improvement of the method efficiency.

At the end of these three steps not only the transition from individual opinions to a collective opinion is performed based on the hidden interdependencies, but also the opinions are combined based on how much the stakeholders are willing to take the judgment of the individual group members into account. In this way the method provides a structured, transparent way to derive the relative importance of CR's departing from a complete CR pool in a multi-stakeholder collaboration design environment. The results of the method might then be used to develop an engineering strategy and to allocate resources to achieve the design objectives.

3.4 Updating Urn scheme as Carrier of the Process

Borrowing a theme from classical probabilistic and statistics[3], we propose an Urn-Scheme to carry the three steps, i.e. individual prioritization, updating of individual priorities and unifying the updated individual priorities to find the relative importance of CR's.

Every CR gets an urn assigned, which might be visible to or hidden from the stakeholders. Each stakeholder gets also a specific number of balls (n_i), e.g. five times the number of CR's, and according individual liking he/she might put more or less balls (x_{ik}) in the k-th urns corresponding to the k-th CR he/she considers to be more or less important (fig. 3.3).

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3 Urn schemes are a simple way to facilitate results from probability theory [John. 1977]. Usually an urn model is constituted by a number of urns containing different color of balls in it. For experiments (Trials) balls are picked out of the urns and possibly returned according certain rules. By using the observed probability of any specified outcome of experiments simulation might be performed. Usually the interest is aimed at *Distribution of balls of various kinds in the urns* and the *waiting time distributions until a specified condition is satisfied* [John. 1977]. Urn schemes might be applied for Occupancy Problems, Stochastic Replacements, Genetics, Capture-Recapture Models, Sampling systems, trial-and-error learning, simulation of technological dynamics in homogenous and inhomogeneous Economic environments, dynamics of competing "populations" [Silv. 1994].

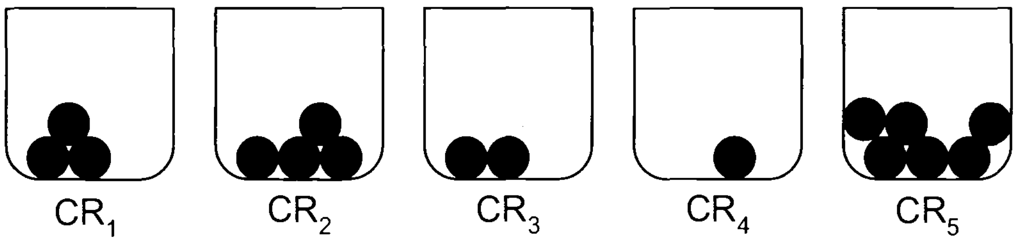


Figure 3.3 Urns are Used to Register the Stakeholder's Voting

Once all balls are distributed by each stakeholder, each stakeholder's urns are being updated by prioritizations of fellow stakeholders through a weighted sum of all other stakholders' individual priorities including his/her own. The weights for building the sum are based on trust towards all other stakeholder and him/herself in the capability to understand costumers' perceived product qualities.

Finally when all urns have been updated in this way, each one's urns of every CR are combined by another weighted sum, whereas the trustworthiness of each stakeholder is used as weight in this study. The following section will discuss technical details behind the whole method and how the weights are integrated.

4 METHOD

4.1 Numerical Framework of Updating Urn-Scheme

Figure 4.1 shows the sequence of steps to be undertaken in order to find the relative importance of CR's as proposed by the method. The overhead in Figure 4.1 symbolizes the individual prioritization and the stakeholders' interaction before they fill out the comprehensive survey about trust in prioritization, i.e. trustworthiness (TW-) measurement. As already specified in section 3 the overhead is followed by individual prioritization (4.1.1), updating of individual priorities (4.1.2) and unifying individual priorities (4.1.3). Where as the weights for the two later steps are coming directly from the TW-measurement. Once the final relative priorities are calculated, the group might discuss the result and see whether a decision based on the voting is already possible.

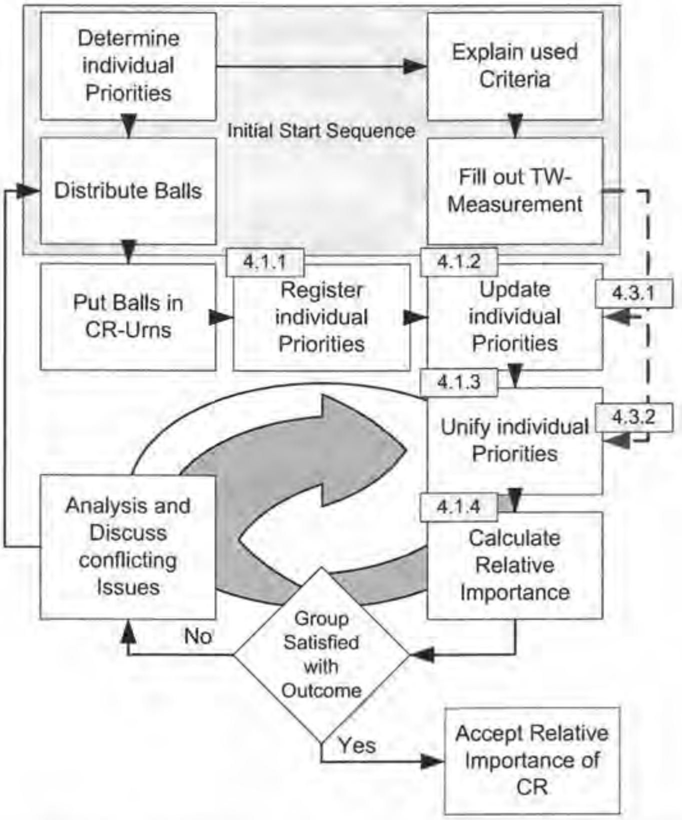


Figure 4.1 Prioritization Using an Updating Urn-Scheme

If no group satisfaction is achieved after the initial run or if the relative importance calculated are rejected by common sense, new amount of balls might be distributed and since the stakeholders have talked previously about why they have chosen their priorities in their way, some of the stakeholders might change their priority distribution. This might be repeated until either more satisfaction is given or the group of stakeholder agrees to adjourn the final decision to gather new data on conflicting issues. Interpretation and displaying tools for the calculation results are presented in section 5.

4.1.1 REGISTRATION OF INDIVIDUAL PRIORITIES

After every stakeholder has put his/her assigned balls (n_i) in his/her urns, the amount of balls in each urn are counted (x_{ik}).

$$n_i = \sum_{k=1}^{M} x_{ik} \text{ , } i = 1 \ldots N \tag{1}$$

The index i is used for the i-th stakeholder and N the total number of stakeholders and the index k represents the k-th CR and M the total number of CR's.

4.1.2 UPDATING INDIVIDUAL PRIORITIES

So far only individual priorities have been considered, but often in case of important decisions we tend to discuss the problem with other people. In case of prioritizing CR's, other stakeholders' opinions might be taken into account to the extent of how much stakeholders trust each other to be capable in understanding customers' perceived product quality. The priority function (Eqn. 2) takes priorities from all stakeholders into account by updating the individual priorities by a weighted priority sum of all stakeholders' priorities including the own individual priorities.

$$x_{ik}^{updated} = \sum_{j=1}^{N} x_{jk} \cdot \theta_{ij} \tag{2}$$

where $\sum_{j=1}^{N}\theta_{ij}=1$, $i=1\ldots N$, and $k=1\ldots M$ is. The function displays the updated priority from *i*-th stakeholder of *k*-th CR, i.e. the updated amount of balls. The function is build by summing up the individual weighted amount of balls (x_{ik}) for the *k*-th CR and the weighted amount of balls of the trusted fellow stakeholders (x_{jk}), whereas θ_{ij} are weights (Eqn. 6) used for building the sum (please refer to section 4.3 for more details about the weights).

4.1.3 UNIFYING INDIVIDUAL PRIORITIES OF CR'S

The combination of the updated individual priorities of every CR is again a weighted sum, whereas the weights are based on the trustworthiness each stakeholder has received from the whole group (Eqn. 3).

$$x_k^{comb}=\sum_{i=1}^{N}w_i\cdot x_{ik}^{updated}, \qquad (3)$$

where $\sum_{i=1}^{N}w_i=1$ and $k=1\ldots M$. Hereby x_k^{comb} is the number of balls which finally are allocated to the k-th CR combined over all stakeholders and the Eqn. 7 shows the calculation of the normalized weights (please refer to section 4.3 for more details about the weights).

4.1.4 RELATIVE IMPORTANCE OF *K-TH* CR

The relative importance of each CR is found by a normalization of x_k^{comb}, displayed in Eqn. 4.

$$RI_k=\frac{x_k^{comb}}{\sum_{i=1}^{M}x_i^{comb}},\ k=1\ldots M \qquad (4)$$

The relative importance gives a measure for how the *k*-th CR is perceived by the stakeholders to contribute to the overall product quality. In the following section the determination and use of the weights, i.e. θ_{ij} and w_i is presented in detail.

4.2 Trust Measurement

Making an agreement or resolving a conflict a group usually applies a democratic voting process, i.e. spreading the voting power equally among the stakeholders. Considering real world experience, we know that the real voting power is usually not equally spread. The difference among stakeholders might be that there exists a difference in financial risk, an experience and expertise difference or a distribution in interest and commitment. Such factors should be considered for making an effective group decision, i.e. finding the priorities of CR's. The difference relevant in finding priorities of CR's, is the stakeholders' capability to understand the customers' perceived desired product quality based on his/her own perception and judgment.

4.2.1 TRUST USED TO PRIORITIZE CR'S

In order to be able to quantify this difference, a measurement instrument had to be developed. The significant stakeholder difference will be concerning expertise, experience, commitment, motivation, consistency and rationality, whereas the concerns mentioned in Fig. 1.1 have to be included as well. The revision of social dynamics literature has shown that trust/trustworthiness measurement might consist of the overall assessments of somebody's ability, benevolence and integrity towards a specific issue. In the case of prioritizing CR's this special issue might be the customers' perceived desired product quality. Trust might hence be well suited to measure a stakeholders' capability to prioritize CR's with the notion of understanding customers' perceived desired product quality in mind. Therefore trust is applied as the underlying social factor to carry the comprehensive measurement.

The literature review revealed also two necessary requisites which make trust come into play that is risk and interdependency. Both requisites are found in prioritizing CR's. The risk is represented by the uncertainty, what customer really value as product quality and interdependency is given by the collaborative setting of the stakeholders.

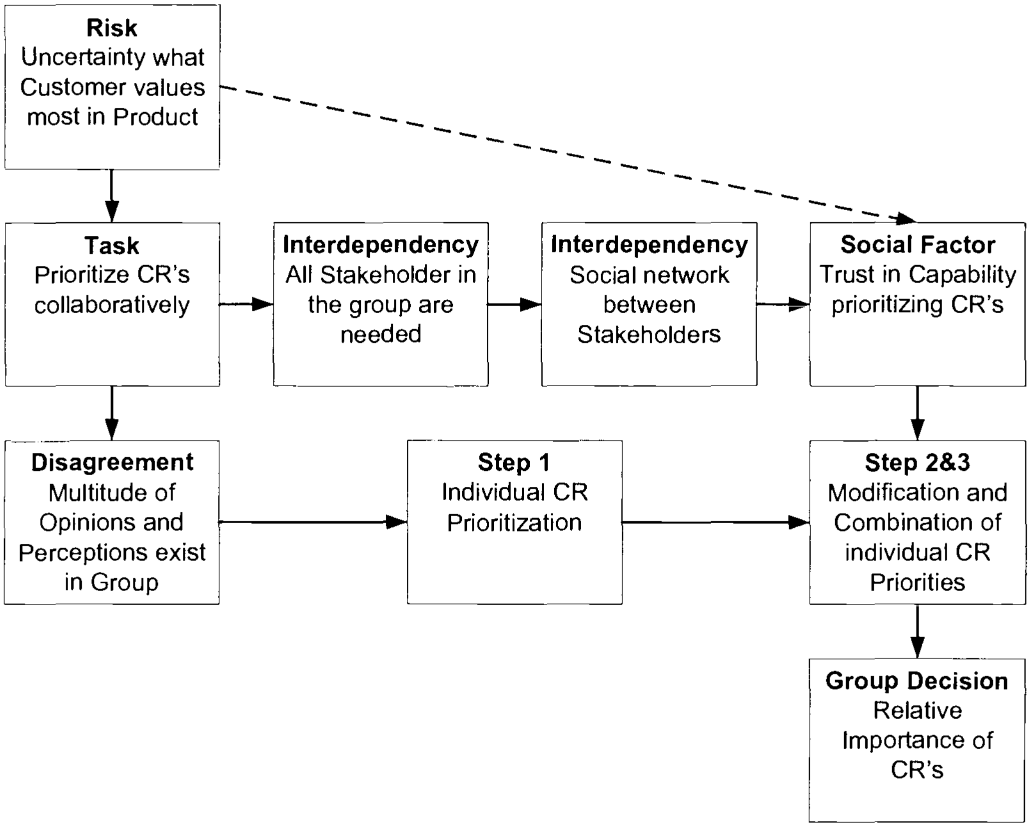


Figure 4.2 Effect-Chain connecting Trust with finding relative Importance of CR's

Figure 4.2 shows the connection between prioritization and trust in an effect-chain finding relative importance of CR's. Because stakeholders interpret and perceive the importance of CR's differently, uncertainty will come with the determination of CR priorities. According the literature review, trust begins where certainty ends. Trust is applied to justify the risk someone is taking. In the case of finding CR priorities the risk is to emphasize the wrong CR's, i.e. relying not on the most capable stakeholder, which might lead to a product rejection with the targeted customers, i.e. risk in Fig. 4.2. So the comprehensive trustworthiness (TW-) measurement will focus on the trust stakeholders have into the expertise, experience, benevolence and integrity of a fellow stakeholder that with his/her priorities the feared rejection will not happen. In other words TW-measurement evaluates the trust a stakeholder has into the capability of another stakeholder understanding the customers' perceived desired product quality. Borrowing trust for the purpose of weighting stakeholder's priorities will help to emphasize the voting influence of the more capable stakeholders on the prioritization of product attributes, i.e. modification and combination of CR priorities in Fig. 4.2.

In concurrent product development, a cross-functional team works together to design the product. The complexity and nature of today's products force the product developers to work interdependently together. It is assumed that the same interdependency exists in the product stakeholder group, where every stakeholder's expertise is needed to find the right set of priorities, i.e. interdependency in Fig. 4.2. Therefore it is important that the first step of the method, i.e. individual prioritization is carried out carefully. By using information from the social network to combine the individual priorities, it is assumed that the acceptance of the final result will be higher, than using another voting process.

A further argument of using trust to evaluate a peer's capability in prioritizing is that trust is less sensible to manipulation. Trust is build over several interactions and is always related to previous outcomes. Therefore beautiful led arguments at a meeting are getting less important than the connection on interpersonal basis, which is build through several different channels and over time.

4.2.2 ADJUSTED TRUST MODEL

The broad acceptance of the trust model of Mayer et al. (1995) convinced the author to use this trust model, where trustworthiness and propensity to trust cause trust. Although the model seems adequate to serve as framework, the definition of trust and trustworthiness might be adjusted considering the findings of most recent empirical work ([Gill. 2003] and [Mayer 1999]). Figure

4.3 shows the adjusted model. It considers the required measurement of willingness to be vulnerable and that action instead of judgment has to be focused.

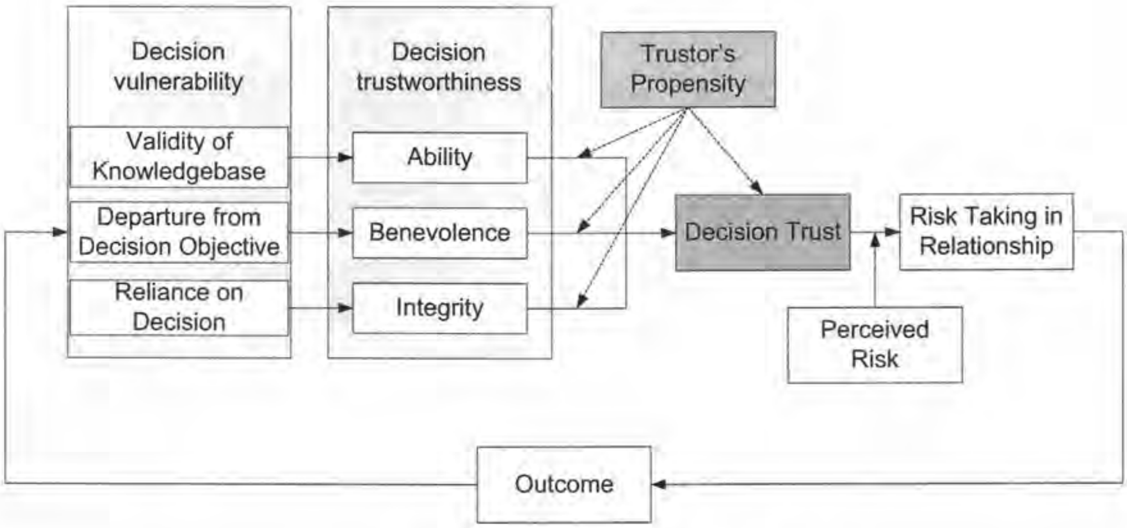


Figure 4.3 Adjusted Trust Model

Like the perceived trustworthiness the decision trustworthiness is constituted by ability, integrity and benevolence of the trustee. The main difference is that the items are derived from a specific term of decision vulnerability. The vulnerability of the decision "prioritizing CR" is identified as threefold, i.e. invalidity of knowledgebase, departure from decision objective and reliability in trustee's decision.

The first category of vulnerability of the decision may stem from an invalid or incomplete knowledgebase, which serves the trustee as background for his decision and development of his/her set of criteria. The proper knowledgebase enables the trustee to make meaningful decisions. Using inadequate information the ability of the decision maker would be compromised. Two knowledgebase have been identified to be involved in the prioritization process. Knowledge about the customer and knowledge about the product environment, e.g.

application, use, environmental concerns, competitors, market situation and organizational strategy have been identified. Both knowledgebase are related to the expertise and experience of the trustee with the product and its environment. Invalidity of either knowledgebase would set off trustee's decision criteria. The knowledgebase has been rated very important in order to make a meaningful decision, therefore 50% of the survey questions focusing this first vulnerability.

The outcome of the decision might be also harmed by trustee's departure from the decision objective, which in this case is to maximize the customers' perceived desired product quality. The relative importance of the CR will be used to allocate resources. The stakeholder might be tempted to manipulate the CR ranking and pursue egoistic motives, in order to profit from the outcome. Egoistic motives might not be the only reason for a trustee's departure from the decision objective. The trustee might be distracted by other responsibilities and might therefore only be able to commit little resources to the project. If the stakeholder does not have time and interest to use his best judgment and all efforts to develop a valid set of decision criteria, her/his contribution will be of inferior quality. The same statement is valid for how much the stakeholder cares to develop a high quality product. Therefore the authors propose three fields of vulnerability related to the decision objective. There are trustee's selfish motives, his/her commitment to the project and his/her care for the product quality. Overall the vulnerability to the trustee's departure from the decision objective is weighted with 30% of all questions of the survey. This vulnerability reflects the benevolence of the trustee towards the project and the product quality.

The last identified field of vulnerability of the decision process concerns the reliability of trustee's decision. With 20% of the overall survey questions the reliability of the decision is rated as least risky. It is assumed that all stakeholder use a valid set of criteria to decide upon the importance of each CR. Where the quality of the set of criteria was in question in the two previous categories, trustee's integrity towards his/her set of criteria is focused here. Two major areas of questions have been formulated, i.e. trustee's rationality and consistency. The focus of these questions is, whether the trustee would reach the same priorities over and over. It is important to integrate this vulnerability, because trust integrates experience from previous interactions between trustor and trustee. If the trustee is not consistent or does not use rational arguments, the decision might always have a different outcome and thus the experience with the trustee might once be positive, the other time negative. The assessment of rationality and consistency does not contradict subjective or intuition based decisions. The way of how the trustee has developed his rational is not in question, but if he/she has a set of criteria and if he/she sticks to this set. Subjectivity and intuition might support the trustee by reducing the uncertainty involved in prioritizing the CR. In fact subjectivity and intuition might be the only way to bridge the uncertainty in finding CR properties and might distinguish the real expert from the novice. The vulnerability of the reliability regarding the trustee's decision connects to Integrity/Rationality of the trustee (please refer to Fig. 4.3).

There will be no survey items related to the trustor's own propensity to trust. The propensity describes the general willingness of a trustee to trust somebody else. As you will see in section 4.3.1, the propensity will be taken care of by the way how the stakeholder's trust towards the other stakeholders is aggregated.

4.2.3 MEASUREMENT INSTRUMENT FOR TRUST

The proposed composition of the comprehensive measurement is based on the adjusted model of trust. The actual number of questions is split in half between the trust in expertise (i.e. Knowledgebase) related to customer and product environment and the trust into the personal character and the trustee's behavior towards the product. With this double focus not only the vulnerability of trustee's ability to understand the perceived product quality but also the vulnerability related to trustee's benevolence and integrity are included. In other words, the instrument measures if the trustee has the possibility to develop a proper set of criteria and if he/she sticks to it. The way the trustee develops the set of criteria is purposely excluded, because the method shall not hinder the stakeholder in developing his/her individual priorities. Otherwise there might be losses of concerns and criteria prioritizing CR's, what might reduce the quality of the prioritization method.

4.2.3.1 Taxonomy of Survey Questions

In contrast to Mayer et al. the proposed survey is strongly focused on trustworthiness of somebody doing something and not mainly the trustworthiness of this somebody. In our case the doing is prioritizing CR's in order to enhance the product quality. The delicate difference to the original survey lies in the fine pointing of the questions of the survey towards the objective. It is to understand that hereby not only the ability is affected, but the benevolence and integrity as well (Fig. 4.4).

Figure 4.4 shows the taxonomy of the survey and how the vulnerability topics finally are represented for the aggregation of the trust score from the trustor to trustee. Because the voice of customer has to be investigated and incorporated in the assessment of trustee's prioritization, the vulnerability stemming to the customer knowledgebase has gotten most weight with 30%. With this amount of weight it is almost assured that stakeholders with a close relationship to the targeted customer have strong influence in the priority assessment. Within the vulnerability related to trustee's understanding of the environment of the product, the weights are spread between stakeholder's own familiarity with the product (7.5%), stakeholder's understanding of the corporate strategy (7.5%) and stakholder's concerning of societal impacts of the product (5%).

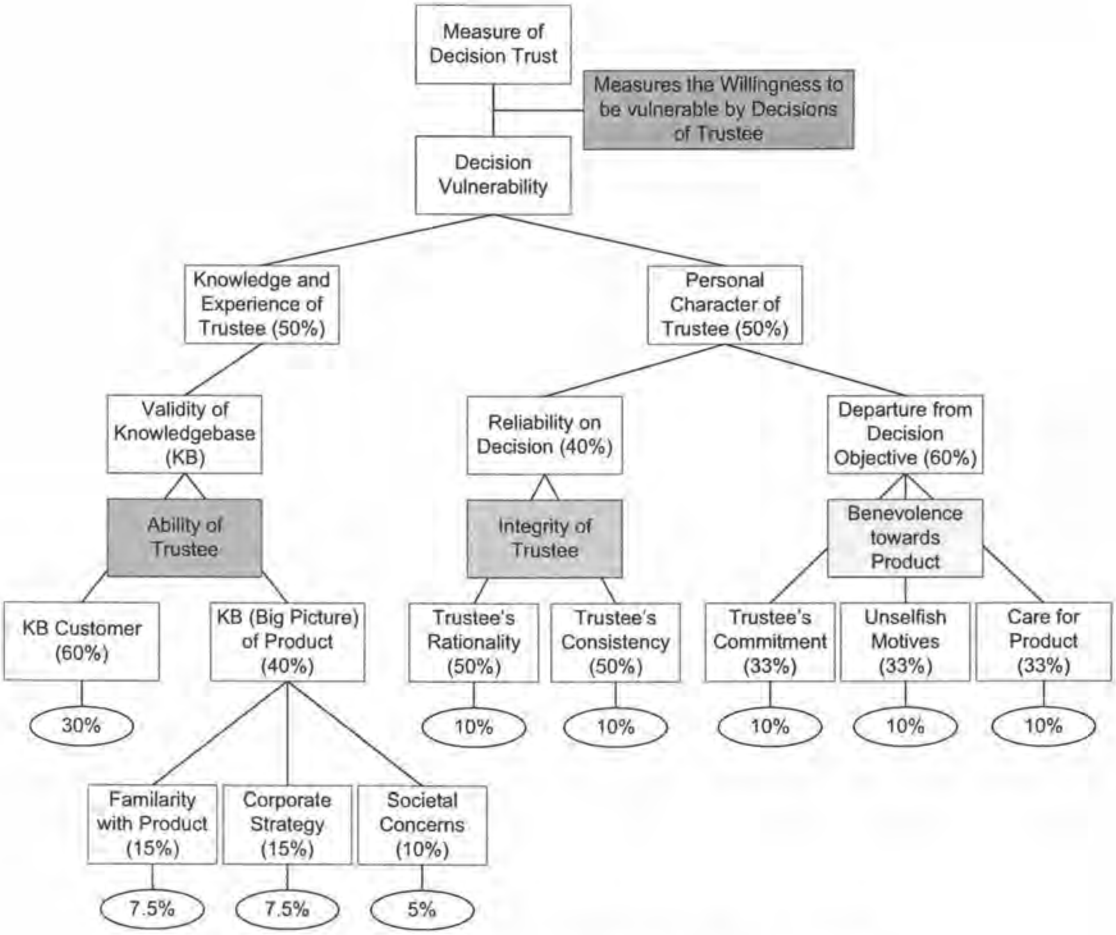


Figure 4.4 Taxonomy of Survey Questions

The survey items relating to the personal character of the trustee is not evenly split, because the vulnerability relating to the benevolence of the trustee towards the product and its quality might be bigger, than the one stemming from the integrity of the trustee. Hereby it is assumed that the membership of the stakeholder group already implies a certain degree of professionalism and integer behavior. The risk of inconsistency or irrationality of the trustee is therefore much smaller than the risk stemming from trustee's departure from the decision objective caused by either selfish motives, decision distractions or the carelessness of the trustee towards the product quality.

4.2.3.2 Final Composition of Survey

The survey is using a 7 point Likert [Like. 1932] scale ranging from 1 "Disagree strongly" and to 7 "Agree strongly". The draft proposes 30 items, with 30 as low and 210 as high score of the survey. The final score is then reported either by mean or median and transferred into a percentage score (please refer to next section).

All foci of the questions are related to product quality. The higher a trustee's scores the more is he/she trusted to be capable of prioritizing the right CR's. Table 4.1 describes how the survey is finally composed and a set of questions is suggested for each question group.

Table 4.1. Composition of the Survey Questions for Trust Measurement in prioritizing Customer Requirements

	Category	Question groups (I)	Nr. of Questions	Overall Weight (w)	Suggested Questions:
Specific quality related Expertise of trustee 50% (Ability)	**General Knowledge based (KB) 60%**	Stakeholder's familiarity with targeted customers	9	30 %	[Stakeholder X] has several opportunities to gather information and experience how the product quality is perceived from our targeted customers.
					[Stakeholder X] is subjected to main customer complaints and improvement suggestions.
					In my point of view [Stakeholder X] understands and incorporates the voice of the customer in his priority assessment.
					I fully accept how [Stakeholder X] represented the interests of our target customer.
					In my point of view [Stakeholder X] tried hard to be fair in considering all desires of our targeted customer.
					I'm very convinced about the quality of [Stakeholder X]'s consideration of main customer's need.
					[Stakeholder X] has worked a lot with our main customer and knows the main customer well.

Table 4.1 (Continued)

Specific quality related Expertise of trustee 50% Ability (continued)	General Knowledge based (KB) 60% (Continued)				I'm totally willing to rely on [Stakeholder X]'s judgment of CR priorities based on his expertise stemming from his/her work with targeted customers.
					I am not afraid to be vulnerable relying on the prioritization of [Stakeholder X] because he interacted a lot with our targeted customer on issues related to the product quality.
					In my point of view [Stakeholder X] has sufficient knowledge about the main customer, that he is able to represent main customers interests well.
					[Stakeholder X] made a big effort to gather data of our main customer relating to this product and its quality.
					[Stakeholder X] understand well the purpose of our product through the eye of our customer. He knows their "wants" well.
	Using KB for Quality decisions on the targeted product 40%	Stakeholder's familiarity with product and its unique qualities 15%	2	7.5 %	[Stakeholder X] has a lot of experience with our product (experience, experiments, own use etc.).
					[Stakeholder X] understands to see our product and its application in a clear picture and sees how the unique product quality is carried through the whole product.
		Stakeholder's understanding of corporate strategy 15%	2	7.5 %	The position of our brand in the competing market is well studied by [Stakeholder X].
					[Stakeholder X] understands well on what image and strategy our products are based and considered this while decided the importance of each CR.
					[Stakeholder X] has much knowledge about the latest level of technology used in our kinds of product and has a good feeling for trends.
		Stakeholder's societal concerns 10%	2	5%	[Stakeholder X] has a good knowledge about future legal or environmental restrictions, which might diminish the customer perception of the product quality and chose his/her priorities of CR accordingly.
					[Stakeholder X] considered the possible societal implications while choosing the priorities of CR.

Table 4.1 (Continued)

General perception of trustee and its chosen priorities	Personal character 50%	Benevolence 60%	Stakeholder's commitment and loyalty 33%	3	10 %	[Stakeholder X] is very committed to this project and want to develop a high quality product
						There is no doubt about [Stakeholder X]'s loyalty to the project and product quality.
						[Stakeholder X] can commit his entire efforts to this project and is not distracted by many other activities.
			Stakeholder's selfish motives 33%	3	10 %	There is no gain for [Stakeholder X] involved by manipulating the priority list.
						Pure quality motives guided [Stakeholder X] through the prioritization process.
						[Stakeholder X] would never jeopardize high product quality by pursuing selfish motives.
			Stakeholder's care for product quality 33%	3	10 %	[Stakeholder X] is very concerned about the welfare of the product quality.
						[Stakeholder X]'s highest priority is to create a high quality product.
						[Stakeholder X] would not knowingly do anything to harm the product quality.
		Integrity 40%	Stakeholder's rationality 50%	3	10 %	Sound product quality principles seem to guide [Stakeholder X]'s choice of priorities for the customer requirements.
						[Stakeholder X] uses his/her rational well to map product quality criteria to CR's.
						The high clarity of [Stakeholder X]'s set of criteria of CR's stands out.
			Trustee's consistency 50%	3	10 %	There is no doubt, that [Stakeholder X] sticks to his/her set of criteria
						[Stakeholder X]'s actions and behaviors are very consistent with his/her developed set of criteria.
						[Stakeholder X]'s choice of priorities for CR does not depend on his/her mood, the weather or other arbitrary influences because he/she uses his/her carefully developed decision rational.

4.2.4 TRUST VALUE BASED ON LIKERT SCORE

The author suggests that all questions are mixed up and the trustor fills out the survey for each other stakeholder, i.e. trustee and the score of the Likert scale [Like. 1932 and Gliem 2003] of each survey item is added up. We define the trustworthiness score in Eqn. 5, the trust score in Eqn. 6.

$$tw_{ij} = \sum_{k=1}^{M} SQ_k \text{ , } i,j = 1\ldots N \tag{5}$$

where the index *i* represents the trustor, *j* the trustee, *SQ* the Likert scale score of the *k-th* survey question answered by the *i*-th trustor on the *j*-th trustee. *M* represents the total number of survey questions and *N* is the total number of stakeholders. The mean trust value, Tr_{ij} of the *i-th* trustor on *j-th* trustee is calculated by Eqn. 6.

$$Tr_{ij} = \frac{tw_{ij}}{M} \text{ , } i,j = 1\ldots N \tag{6}$$

Another way of performing the survey would be to actually only take a selection of each question group, but at least two of each[4], take the mean of this group and multiply it by the question group weight. The Tr_{ij} values will then be the sum of all this weighted means of each question group, illustrated by Eqn. 7 and Eqn. 8.

$$tw_{ij,l} = \sum_{k=1}^{M_l} SQ_k \text{ , } i,j = 1\ldots N \text{ , } l = 1\ldots 9 \tag{7}$$

$$Tr_{ij} = \sum_{l=1}^{9} w_l \cdot \frac{tw_{ij,l}}{M_l} \text{ , } i,j = 1\ldots N \tag{8}$$

The index *l* is used to indicate the survey question group (shown in the 4th column of Table 4.1); M_l is therefore the number of questions answered from

[4] The more items used for each group, the less measurement uncertainty is involved in the group [Like. 1932]

this question group. The overall weight of the question group is represented by w_l (shown in the 6th column of Table 4.1). The use of Eqn. 7 and Eqn. 8 enhances the analysis capability of the gathered data, because results of each group might be ascertained individually and examined. The difference in using either way is not statistically significant (two sided t-test on 80 random samples, resulted in a t-statistics of -1.396 and a p-value of 0.166).

A linear transformation is then applied to transform Tr_{ij} from either Eq. 6 or 8, into a value between 0 and 100 using Eqn. 9.

$$T_{ij} = \frac{100}{7-1} \cdot Tr_{ij} - 16.667 \, , \; i, j = 1 \ldots N \qquad (9)$$

where 7 is the high score of the used Likert scale and 1 the low score.

4.3 Weights for the updating Urn-Scheme

As specified in the previous section the proposed comprehensive TW-measurement is based on the trust of a stakeholder into the capability of another stakeholder and him/herself to understand the customers' perceived desired product quality. The TW-measurement considers differences in expertise, experience, commitment, motivation, consistency and rationality among stakeholders. Each stakeholder uses the TW-measurement to evaluate each fellow stakeholder and him/herself, how he/she is willing to be vulnerable relying on the prioritizing of every other stakeholders' and his/her own judgment. As result of this assessment a trust-network might be drawn (Fig. 4.5). The trustworthy relation between two stakeholders is represented as an arrow, i.e. tie. The trustworthy value from the survey is attached to the trustee, i.e. strength of tie, so that looking at a person (P_i) instantly reveals how trustworthy the person is perceived by the group to prioritize the CR's

Although the measurement instrument is strongly focused it might partly be analyzed towards inconsistencies of group coherence. Hereby in specific the trust stemming from the personal character might interest and if coalitions have been built in order to manipulated the voting result.

The use of the trust measurement is delicate in the sense of group cohesion. The information of the trust-network might indicate group deficiencies and might give help to improve the group performance. Nevertheless the obtained information should not be used against individual stakeholders nor should be used to evaluate group members. Therefore the results of the measurement method should either be kept confidential or made anonymous.

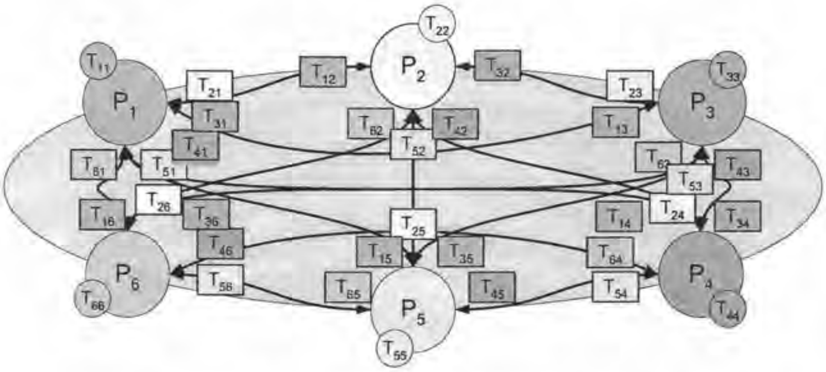


Figure 4.5 Trust-Network Among Stakeholders

The results of the TW-measurement are bidirectional and therefore an *N×N*-Matrix might be recorded, where *N* stands for the total Number of stakeholders. The results from the Eqn. 9 are used as values for the tie strengths.

$$[T]=\begin{bmatrix} T_{11} & T_{12} & .. & T_{1j} & .. & T_{1N} \\ T_{21} & T_{22} & .. & T_{2j} & .. & T_{2N} \\ .. & .. & .. & .. & .. & .. \\ T_{i1} & T_{12} & .. & T_{ij} & .. & T_{iN} \\ .. & .. & .. & .. & .. & .. \\ T_{N1} & T_{N2} & .. & T_{Nj} & .. & T_{NN} \end{bmatrix} \quad (10)$$

The trustworthy *N×N* -matrix (Eqn. 10) aggregates the results of the survey in the form that each trustor gets a row with the index *i* and each trustee a column with *j* as index, whereas the diagonal elements are stemming from the measurement the stakeholders are filling out for themselves. The elements in each row represent the magnitude the *i*-th trustor trusts the other stakeholders and him/herself to prioritize, the elements in the *j*-th column represents the amount the *j*-th trustee is considered to be trustworthy to prioritize. All elements in Eqn. 10 are between 0 and 100.

4.3.1 WEIGHTS FOR UPDATING THE INDIVIDUAL PRIORITIES (θ_{IJ})

The trustor's own propensity to trust has the effect that the trust scores of one stakeholder about his/her trustees is not directly comparable to another's stakeholder trust scores. Therefore the measurement value coming from the survey (Eqn. 10), are normalized using the overall sum of a row as denominator for each element in the row (Eqn. 11). This normalized value will then flow into the priority function (Eqn. 2) of the according trustor. We define the normalized trust value for the *i*-th trustor towards the *j*-th trustee:

$$\theta_{ij} = \frac{1}{\sum_{k=1}^{N} T_{ik}} \cdot T_{ij} , \qquad (11)$$

where $i, j = 1 \ldots N$. Using the normalization procedure for every trustor the trust matrix is eventually normalized as well. Hereby it is to underline that every trustor has its own normalization denominator, which relates to his own propensity to trust.

4.3.2 WEIGHTS FOR UNIFYING THE UPDATED INDIVIDUAL PRIORITIES (W_I)

In the normalized trust-matrix (Eqn. 11) the elements in each column represent the magnitude of how much the other stakeholders perceive the *j*-th trustee as trustworthy. The vertical sum of the normalized elements of the trust-matrix will give the magnitude of how much the whole group trust the capability of the *j*-th trustee to prioritize. The normalized trustworthiness values, i.e. the vertical sum of each column of the normalized trust-matrix is defined in Eqn. 12, which are then used as weights in Eqn. 3:

$$\frac{1}{N}\cdot\left[\sum_{i=1}^{N}\theta_{i1},\sum_{i=1}^{N}\theta_{i2},\ldots,\sum_{i=1}^{N}\theta_{iN}\right]^{T}=\left[w_1,w_2,\ldots,w_N\right]^{T} \qquad (12)$$

The normalization is based on the division by *N*, because each row in the normalized trust-matrix equals to one (Eqn. 11), i.e. $\sum_{j=1}^{N}\theta_{ij}=1$ and the total number of rows is equal to the total numbers of stakeholders, i.e. *N*. Applying Eqn. 12 on all columns, we finally will get the trustworthiness value of all stakeholders.

5 POSSIBLE SCENARIOS AND DISCUSSION

5.1 Results Interpretation

The normalized relative importance RI calculated for each CR (Eqn. 4) corresponds to the collectively found CR priorities. Define

$$RI_{Equi} = \frac{1}{M} \tag{13}$$

as equal importance index representing the expected importance when all M CR's are equally important. A Pareto chart showing both RI_k and RI_{Equi} is helpful for visualizing the difference in importance of CR. Seeing the relative importance being displayed raises the question, on how much of difference in relative importance is significant in reaching a final CR priority list? Examining theoretically possible outcomes we distinguish two cases, i.e. clear and clustery distinction of CR priorities. There are also two additional analysis tools introduced, a significance check and the relative importance scale, which in addition to the relative importance value complete the assessment provided by the proposed method.

5.1.1 CASE 1: CLEAR DISTINCTION

The relative importance of the CR's are clearly distinguishable for any pair of CR's (Fig. 5.1), i.e. there is no problem establishing a clear CR hierarchy.

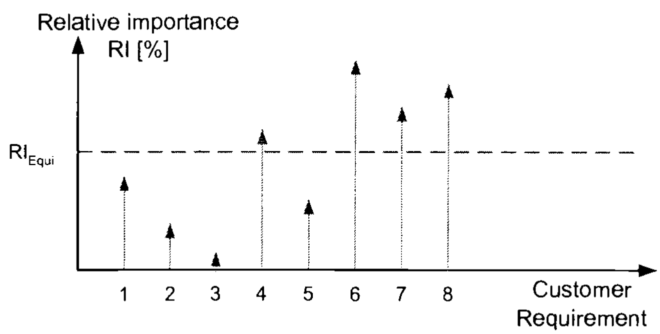


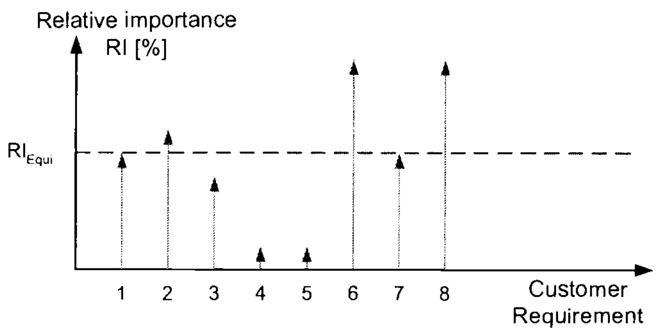
Figure 5.1 The Run of the Prioritization Method Shows a Clear Distinction Between CR's

A decision based on this result is possible and might result in a clear allocation of resources. This case would be a desirable outcome of the decision procedure and would lead to high stakeholder decision satisfaction.

5.1.2 CASE 2: CLUSTERY DISTINCTION

In this case the found relative importance for some or all CR's are almost non-existent (Fig. 5.2). This case might reveal a power struggle between the majority of stakeholders and the holder of the largest trustworthiness or a combination of these two scenarios. It might also show indecision or be the effect of gamesmanship. The result in this case will be that even though the prioritization process has been run, only clustery distinction of relative importance of CR's is possible. Note that in an extreme situation, there will be no distinguishable CR's priorities as shown in Fig 5.2-(b).

(a) Clustery distinction



(b) No distinction

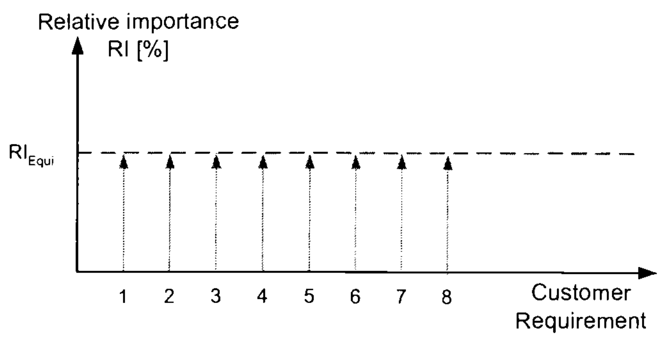


Figure 5.2 The Pareto Chart Reveals a Clustery Importance Hierarchy

In such situations an analysis of where the votes came from, e.g. using different colors of balls might give insight which stakeholders have chosen so much of priority for a certain CR and might be invited to explain their prioritization. Using different colors of balls would also reveal gamesmanship. The further explanation of the stakeholder in question might help to reevaluate the whole situation. After such an analysis every stakeholder might get additional balls to update his/her votes. This process should be repeated until a distinguishable list of priorities is obtained or until no additional information is valuable enough to sway any stakeholder's opinion. Only then, the resources should be allocated according to this final priority list.

5.2 Relative Importance Scale

In order to get a qualitative representation of the results, we introduce a relative importance scale. Define a relative importance index (RIn_k) for the *k*-th CR as

$$RIn_k = \frac{RI_k}{RI_{Equi}}, \tag{14}$$

which indicates the relative importance of the *k*-th CR over the average importance of all *M* CR's (in percentage). In other words, putting RIn_k of the *k*-th-CR into the relative importance scale (Fig. 5.3) shows its importance compared to other CR's and also compared to the average of relative importance.

Figure 5.3 The Relative Importance Scale

Differences in individual priorities, but also clusters and formations of equally important CR's are made clearly visible in this scale. The simple visualization helps to communicate the importance of the customer requirements downwards. The decision autonomy of designers is greatly enhanced, because they are able to base their decision on a clear visible priority order.

5.2.1 SIGNIFICANCE OF THE RELATIVE IMPORTANCE

To determine whether the resulting priority list can be considered as final, we need to examine if the list is distinguishable as discussed in 5.1. If the priorities in the list are clearly distinguishable (Case 1), then stakeholders can allocate resources accordingly. On the other hand, if the list results in Case 2, then additional discussion should be initiated. Table 5.1 provides a simple way to determine the result and its corresponding action. It is clear that when the minimum discrepancy of any two CR's exceeds a hurdle rate δ, predetermined by a decision maker, the resulting priority list should be clearly distinguishable and resources can be allocated accordingly. If some or all discrepancies fall below δ, then additional conversations among stakeholders should be conducted. Another round of voting using the proposed Urn-Scheme is expected. Note that RI_i (RI_j)can be used in place of RIn_i (RIn_j) in Table 5.1 with a rescaled δ to achieve the same action.

Table 5.1 Significance Check of Discrepancies Among any two Relative Importance Indexes of CR's

Case	**Decision Rule**	**Description**	**→ Action**
1 clear distinction	$\min\lvert RIn_i - RIn_j \rvert > \delta$	All discrepancies between any two CR's relative importance are significant.	A final priority list is obtained and resources can be allocated accordingly.

Table 5.1 (Continued)

2-a clustery distinction	$\min\lvert RIn_i - RIn_j \rvert \le \delta$ and $\max\lvert RIn_i - RIn_j \rvert \ge \delta$	Some discrepancies are significant and some are indistinguishable.	Communication among stakeholders should continue and additional information should be collected for subsequent voting.
2-b no distinction	$\max\lvert RIn_i - RIn_j \rvert < \delta$	None of the discrepancies is significant.	

Note: $1 \le i, j \le M, i \ne j$ and δ is a hurdle rate to determine the significance of the discrepancy between two CR's relative importance.

5.3 Hypothetical Case Study

5.3.1 SETTING

In this case study an office chair is developed. The stakeholders identified eight customer requirements, they have to prioritize. The budget for the development of the chair is set at 50'000 $ in man hours. The group decided to make the hurdle rate for the significance of difference among the relative importance depending on this budget. They decided to set the hurdle rate to 50$ which is the internal value for one hour of development work for a standard product, so δ is equal to 50/50000=0.001.

5.3.2 POOL OF CR'S

Before the proposed method is used, the group of stakeholders collects customer requirements. They might use an NGT to narrow down the list, before they apply the Urn-Scheme.

After some discussion the group of stakeholders had 8 CR, which are reflecting the wished for CR's of all customers.

Table 5.2 Pool of CR's

CR Nr.	Description	CR Nr.	Description
1	Chair has Soft cushioning	5	The chair is adjustable in height and sitting angle
2	Chair is modular upgradeable (arm wrest, head wrest, food wrest etc.)	6	It has a cooling/heating unit attached
3	All materials of the chair are recyclable	7	The workmanship of the chair has high quality
4	The design of the chair supports different sitting positions.	8	All welds have to be welded by the new welding robots of the new manufacturing line

5.3.3 INITIAL PRIORITIZATION

After the stakeholder agreed upon the customer requirements they individually generated priorities. All stakeholder received hundred balls to distribute in the urns which have been made ready for this purpose. Although there exists an official power hierarchy, they decided against using different amount of balls.

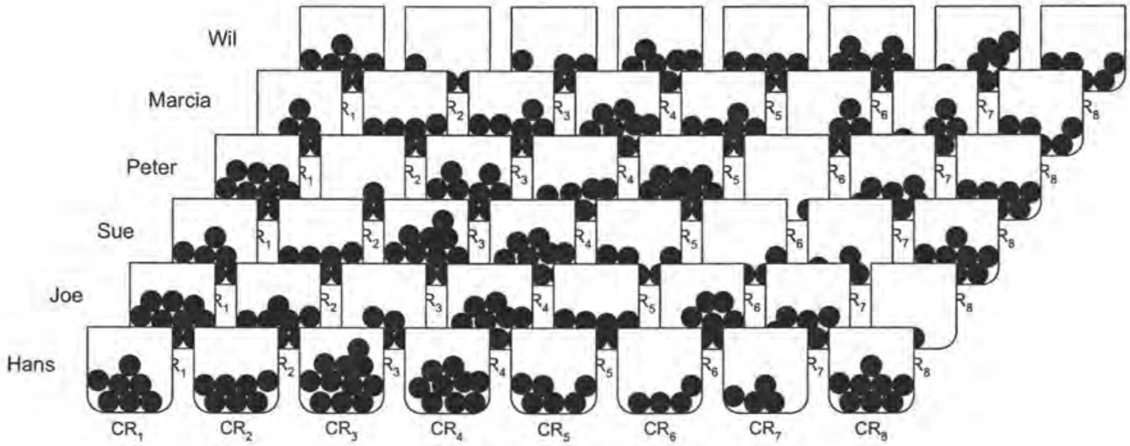


Figure 5.4 Hypothetical Distribution of Individual Priorities in the Urns

Once the stakeholders have made up their minds, they individually distribute their hundred balls into the corresponding urns of the prioritized CR's. Figure 5.4 shows the registration of all individual votes. In reality there might only be one urn for each CR, but the individual votes (x_{ik}) will still be registered individually.

While the meeting facilitator counts the balls, the stakeholders fill out the TW-measurement. From this first step an initial Pareto chart might already reveal some trends in the prioritization.

5.3.4 SOCIAL NETWORK DETERMINED BY TW-MEASUREMENT

The results of the TW-measurement are used not only to draw a trust network among the stakeholders, but they also will flow as weights into the mathematical framework. Hereby individual trust, i.e. outgoing tie strength from trustor to trustee will be used to update the individual priorities. The trustworthiness, the relative sum of all incoming tie strengths, will be used to unify the individual priorities to one set of relative priorities.

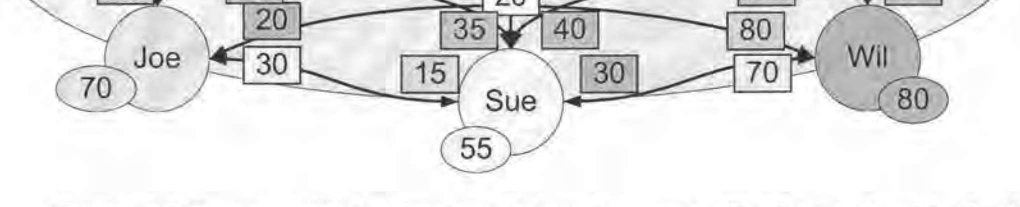


Figure 5.5 Trustworthy Network with Out-/Incoming Tie Strengths Attached

5.3.5 TRUSTWORTHINESS OF STAKEHOLDERS

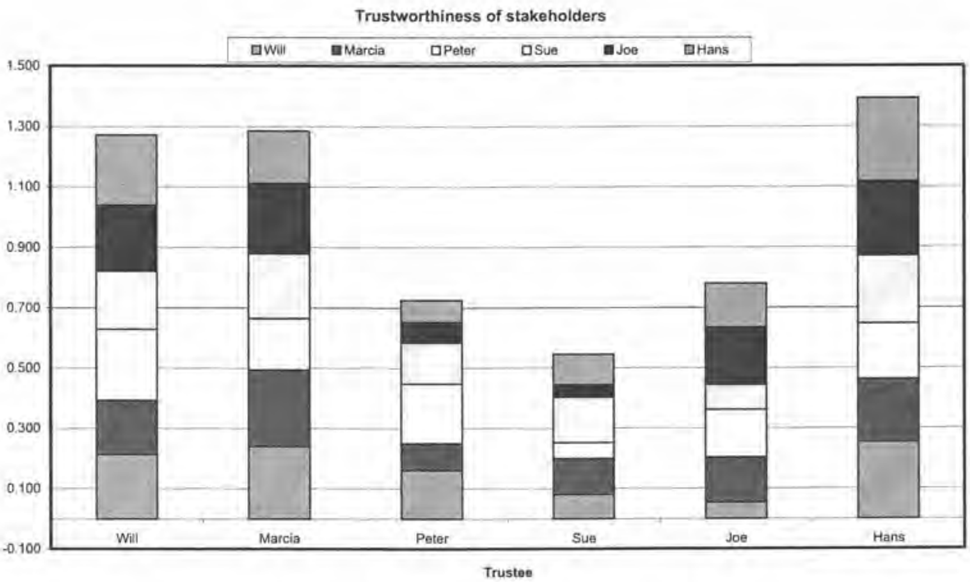


Figure 5.6 The Pareto Chart of the Trustworthiness of Each Stakeholder Reveals Differences Among Stakeholders

Figure 5.6 displays the existing difference in trust towards each stakeholder prioritizing CR's. The chart shows how much stakeholders trust each other to have good perceptions of the CR priorities. In this specific case two extreme stakeholders groups are identified. Hans, Wil, Marcia as the more trusted, Sue, Joe and Peter as less trusted to prioritize CR's.

5.3.6 OUTPUTS OF THE URN-SCHEME

5.3.6.1 Individual Priorities

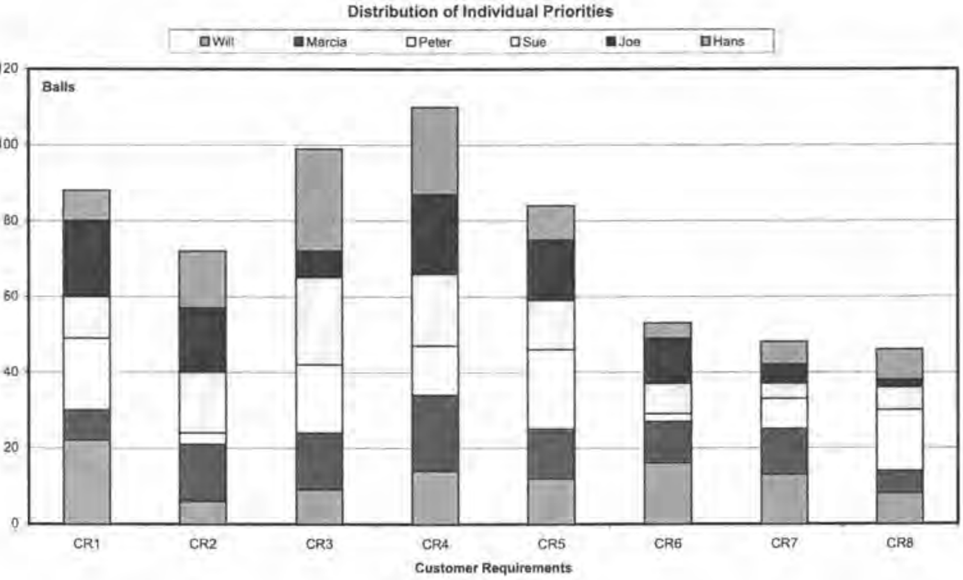


Figure 5.7 Pareto Chart of Individual Priorities

In the scenario the individual votes, i.e. number of balls for the CR's are well differentiable. The ranking based on the individual priorities would reveal CR 4 most important, CR 3, CR 1, CR 5, CR 2, CR 6, CR 7 and CR 8 as least important. The variances as indicator for consensus are between 12 and 51. Using a block chart in Fig. 5.7 reveals who has voted how much and how much of Balls each CR has gotten. The block chart displayed like this, corresponds to the Urn-Scheme using balls with different colors.

The analysis of the variances in Fig. 5.8, i.e. spread of votes of the individual prioritization reveals CR 7 with 12 as smallest variance, i.e. best consensus and CR 3 with a variance of 51, i.e. worst consensus among the stakeholders' individual voting.

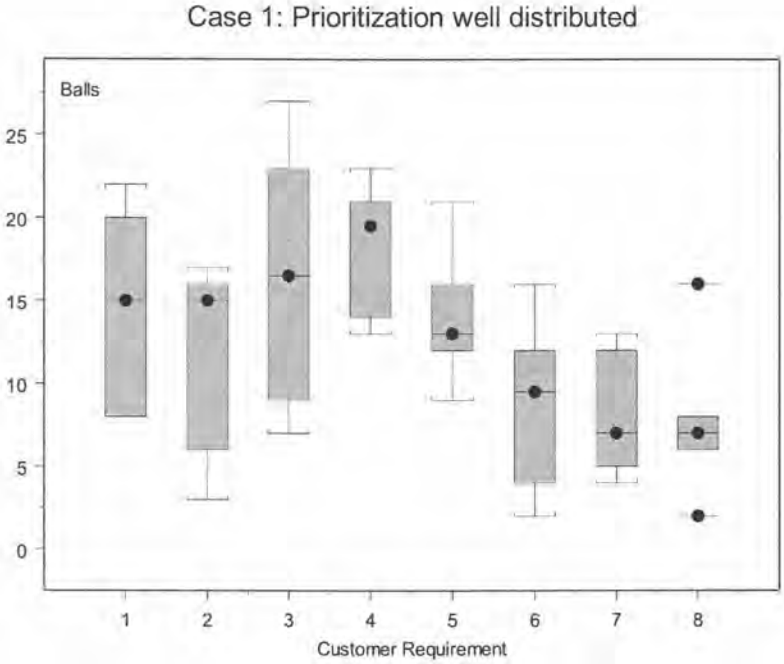


Figure 5.8 The Box Plot Shows the Median and Distribution of the Individual Prioritization

5.3.6.2 Relative Importance after using the Method

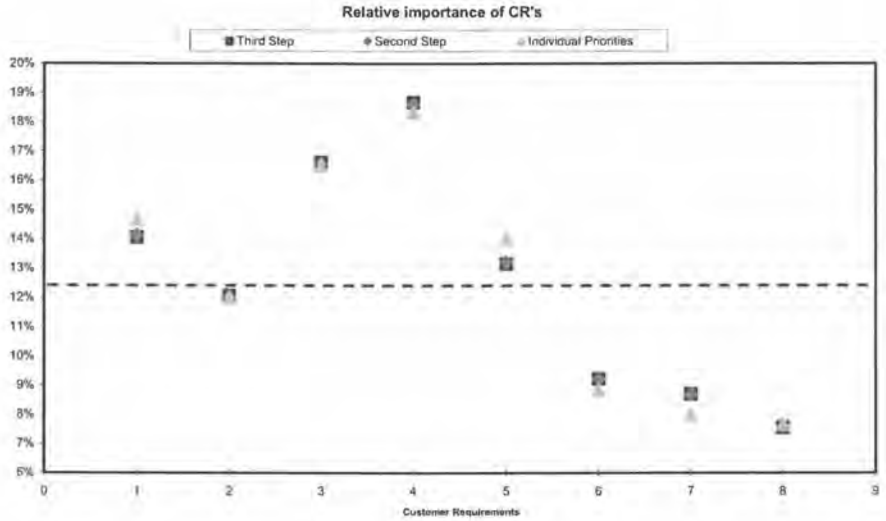


Figure 5.9. Individual, Updated Individual and Unified Individual Relative Priorities

The Pareto Chart in Figure 5.9 shows all three steps of relative priorities together, i.e. unified indiv. Priorities of the third step, the updated indiv. Priorities of the second step and the relative indiv. Priorities right after putting balls in the urns. In the hypothetical case study all relative priorities are close to each other. In some cases there might be large gaps. Close relative priorities of all three steps might only be the case if the more and less trusted stakeholders agree in the individual priorities. Looking at the Pareto Chart reveals that the individual prioritization corresponds more or less group prioritization. Although there were slight changes in the relative values the absolute ranks of the CR's didn't change.

5.3.6.3 Relative importance Scale

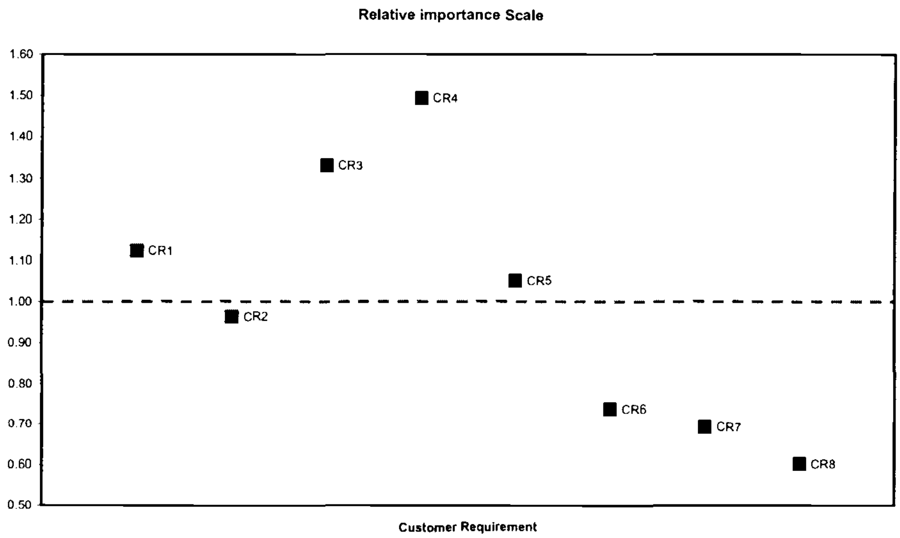


Figure 5.10 Relative Importance Scale

The prioritization in this case study shows that initially existing sound distribution of individual priorities are carried over to the group prioritization. Using the relative importance scale, CR 4 and 3 might be concluded as highly important, whereas CR 7 and 8 are least important. Such a case would make an instant prioritization possible, without having to perform another round of voting.

5.3.6.4 Significance Check

A check of the differences in the relative importance (Table 5.3) reveals that all differences among the RI_k are above the hurdle rate δ, which indicates that all differences in priorities are rated significant (see Table 5.1).

Table 5.3 Significance of Difference in Prioritization

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	MaxDif	MinDif
CR2	0.020							0.020	0.020
CR3	0.026	0.046						0.046	0.026
CR4	0.046	0.066	0.020					0.066	0.020
CR5	0.009	0.011	0.035	0.055				0.055	0.009
CR6	0.048	0.028	0.074	0.095	0.039			0.095	0.028
CR7	0.054	0.034	0.079	0.100	0.044	0.005		0.100	0.005
CR8	0.065	0.045	0.091	0.111	0.056	0.017	0.012	0.111	0.012
							Max	0.111	0.028
							Min	0.020	0.005

Such a clear distinction make a group prioritization possible and the RI_k in this case might instantly be used to plan and develop the Engineering strategy and to allocate the man-hours accordingly.

5.3.7 DANGER OF SELECTIVE TRUST

The stakeholders might have decided to limit the influence of the other stakeholders opinions on those which are trusted more than the average by the individual and group. Such a limitation of influence might be called selective trust. In some cases, where an accepted expert group might exist among all stakeholders this might be useful. Using the data of the case study the results in the relative importance displayed in a Pareto chart would look differently now.

The difference between the relative importance using all opinions or only the ones with more than average trustworthiness has the effect that bias coming from the integration of trust in prioritizing is getting bigger, i.e. distances between individual priorities and group priorities are increased (Fig. 5.11).

The danger of using selective trust might be, that the group decision process becomes a decision process of a certain minority. Herby the concerns from the less trusted stakeholders might be neglected.

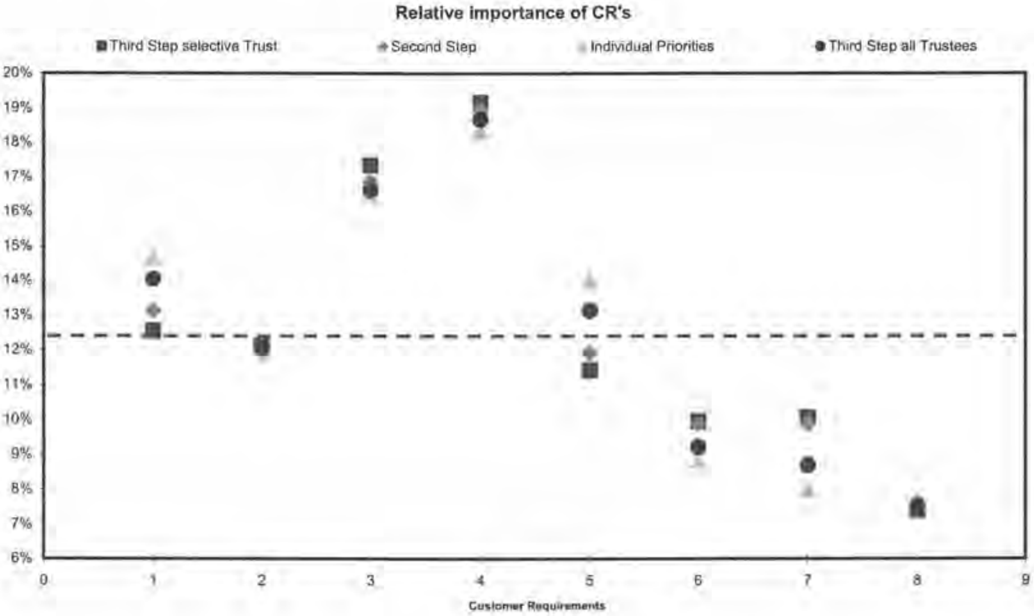


Figure 5.11 Pareto Chart with Relative Importance of CR's with and without Selective Trust

Fig. 5.11 shows that selective trust even might change the ranking of the relative importance of CR's. This might be ok, if the expert minority is accepted by the group and the group is aware of the effect using selective trust.

In Fig. 5.12 the comparison between the relative importance scales with and without using selective trust is shown. The gap between CR 7and 8, CR 3 and 1 have been made very distinct by only relying on the more trusted stakeholders. It also reveals that CR 6 and 7 are almost prioritized equally important by this minority. Using selective trust might reveal trends of priorities in case of indecisiveness or in case where clear prioritization didn't evolve. It opens another possibility to analyze the received results.

Using selective trust might hold the risk that important concerns are neglected. To minimize this risk while using selective trust, the concerns of all stakeholders, especially those from the less trusted should be carefully discussed in advance.

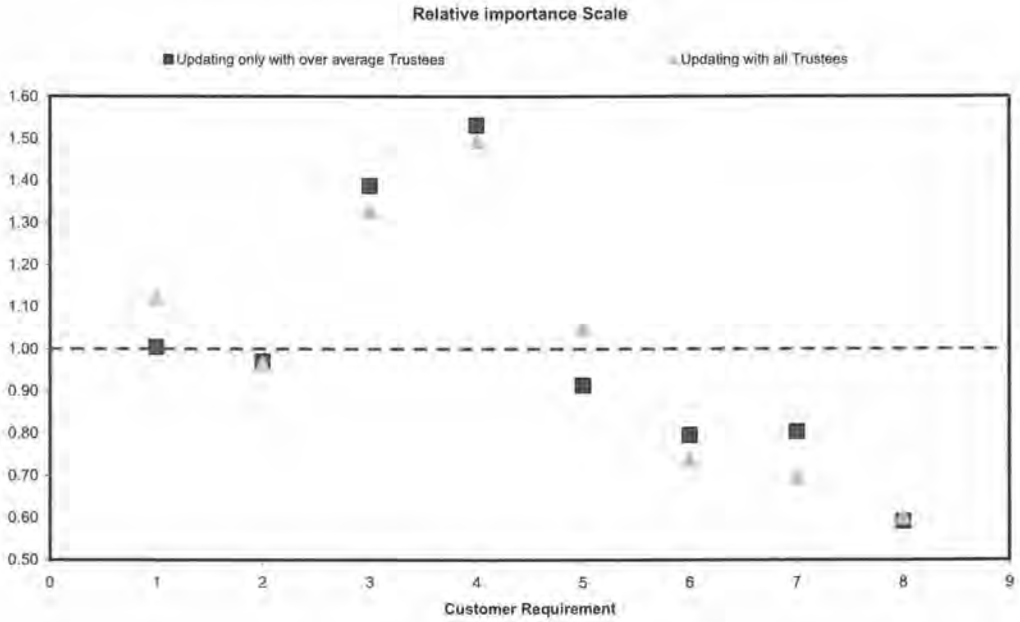


Figure 5.12 Relative Importance Scale with Selective Trust and without

5.4 Further Analysis Capability

5.4.1 DEGREE OF CONSENSUS AND GAMESMANSHIP

Using different color of balls for each stakeholder the extent of consensus of the made decision would instantly be visible, while putting balls into the urns. Balance of decisions or heavy emphasize stemming from single stakeholders would be quickly detected. In case of heavy emphasize the specific stakeholder could be interviewed and his/her reason for his/her decision discussed.

The balance of colors throughout the urns will also reveal the extent of consensus among the stakeholder, if it is rather split among different CR or if there seems to be a sound distribution of agreement.

The same effect might be achieved on a numerical/graphical way. Hereby the balls each CR's has gotten from every stakeholder shall be examined. The fastest way to see the extent of consensus, is to look with what variance the stakeholders have put balls into the CR's urns. But the variance might not detect gamesmanship. So for examining both, extent of consensus and individual prioritization it might be necessary to use following instruments. Denote

$$IP_{ik} = \frac{x_{ik}}{n_i}, \tag{15}$$

as individual priority ratio, where $i = 1...N$, $k = 1...M$, n_i the total number of balls is, which the *i-th* stakeholder has gotten. *N* is the total number of stakeholders and *M* the total number of CR's. IP_{ik} indicates the individual priority in percentages. Define

$$RC_k = \frac{\sum_{i=1}^{N} IP_{ik}}{N}, \tag{16}$$

where $k = 1...M$. RC_k displays the average amount of individual priority the *k*-th CR received from all stakeholders in percentages. Displaying IP_{ik} and RC_k next to each other in a Pareto Chart reveals two things, i.e. extent of consensus and stakeholder which voted as outlier. Repeating these calculations for all CR's the method will fast give an impression about the consensus achieved in the group decision making.

Using the setting and data of the case study in section 5.3, Fig. 5.13 shows two sets of IP_{ik} and RC_k for CR 3 with a variance of 51 and CR 7 with a variance of 12. The Pareto Chart of CR 3 shows a wide distribution of votes around the RC_3. it reflects the worst consensus in this case study. There are three stakeholders which might be interviewed about their reason for the strong positive or negative prioritization of CR3, i.e. Hans, Joe and Wil. Hans and Wil are among the more trusted stakeholders, it might be therefore interesting to compare and discuss their arguments for the opposite prioritization.

The individual priorities of CR 7 are closer together as indicated by the low variance of the CR votes. There are no significant voting outliers and there seems to be an agreement about the priority of this CR.

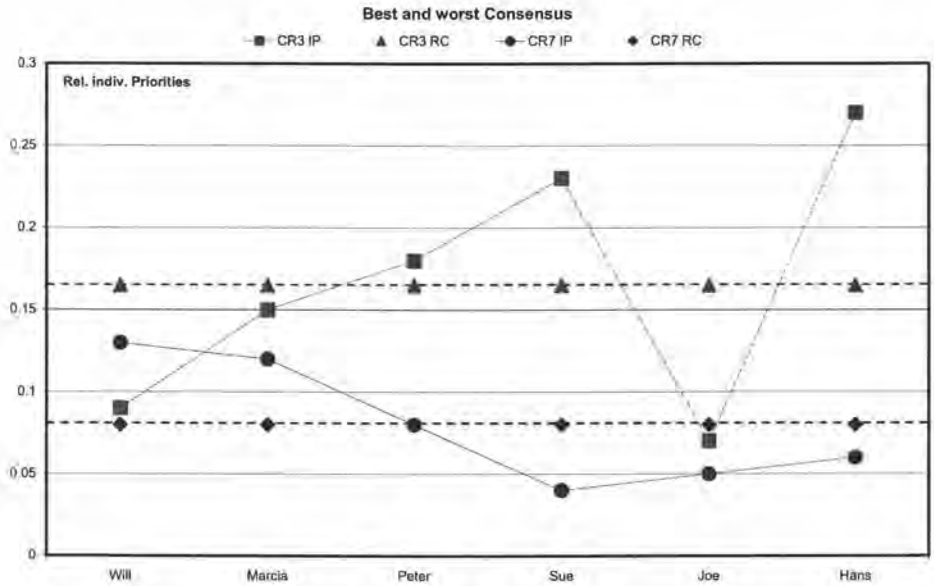


Figure 5.13 Analysis of Individual Prioritization of CR 3 and CR 7

5.4.2 BIASES

5.4.2.1 Power

As specified previously voting power differences coming from e.g. power hierarchy might be considered directly by giving more votes, i.e. balls to the specific stakeholder. Once the relative priorities of each CR has been calculated, it might be interesting to know what influence the difference in power has effected. In a few steps this power biases might be calculated with the gathered information using the proposed method.

First Eqn. 16 has to be calculated, which will give the un-weighted average individual importance for all CR's as if all stakeholders would be equally important. Denote

$$RC_k^{power} = \frac{\sum_{i=1}^{N} x_{ik}}{\sum_{j=1}^{N} n_j}, \tag{17}$$

where $k = 1 \ldots M$, *N* the total number of stakeholders, *M* the total number of CR's and n_j the number of balls the *j*-th stakeholder has gotten initally. Eqn. 17 describes the relative importance of the *k*-th CR using a power distinction among the stakeholders. The difference between the results of Eqn. 16 and Eqn. 17 is the difference in relative priorities coming from power. Because Eqn. 17 uses the total number of balls in the denominator, the influence of the stakeholders with more balls take effect. Their distribution will have more influence on the overall prioritization, than before with individual priority ratios.

The difference in relative importance will only come from the difference in power.

5.4.2.2 Bias from the Integration of the Trust in Prioritizing

Similar to the power bias, the isolated influence of the trust integration in the method might also be calculated.

Eqn. 16 will again be used as unbiased individual relative importance of the k-th CR. For the isolation from the power influence coming from different amount of balls the whole method is run through, but instead of using x_{ik} as input in Eqn. 2, Eqn. 15 is put there. The end result will be the relative importance of every CR, but without interference from the predetermined power hierarchy. The difference between Eqn. 16 and the newly calculated relative Importance RI_k is the difference in relative importance coming from the integration of trust in the prioritization.

5.4.2.3 Combined Bias

To make the picture complete it might be interesting to specify the departure caused by both integrated elements, i.e. trust and power.

In the first step the relative importance would again be calculated with the average of individual assigned priority ratios (Eqn. 16).

In the second step the relative importance using the full method described in section 4 might be calculated. The difference in the resulting values would stem from the combined influence of integrating difference among stakeholders in power and trust in prioritizing.

Concluding this section, it might be noted, that the relative importance results of the method, might always be accompanied by a tolerance value based on power-bias, trust in prioritizing-bias and combined bias. So that the existence of the difference in priorities are addressed. If there is an enormous amount of biases around a relative importance value, there might exist inconsistencies. Therefore using such a tolerances might reduce the risk that inconsistencies remain undetected. The numerical results of the bias tolerance might also be displayed in a Pareto Chart together with the initially received RI_k (refer to Fig. 5.9 and 5.11 where the trust bias is displayed by the distance between relative priorities of the first and third step).

5.5 Verification and Validation

The theoretically presented method has yet to prove its value in the real design practice. The validation and optimization will be based on pilot tests and field tests, before the method might be applied in real design practice. The verification and validation of the proposed method will be split in two main parts, i.e. validation of the prioritization method and validation of the TW-measurement.

Table 5.4 Validation Process

Validation Process			
Pilot tests	• Laboratory environment • Subjects selected randomly from Student body or existing project groups • Dummy Prioritization		
Prioritization Method	Individual and Group Prioritization of Dummy Items, Comparison to Expert prioritization	• Validate Core Assumptions by Hypotheses tests	*Accuracy (Difference to Expert prioritization), Time consumption, Time of Negotiation*
TW-Measurement	Evaluation of Items by qualitative Inquiries about Items in either web based or printed form of survey	• Item refinement (Wording & Terminology) • Item clean up (Check for redundancy, Clarity of Items, Integrity of Items) • Eliminate or reword problematic items • Reliability of survey items	*Constructive Critics, Fulfillment of Question Purposes, Calculation of Cronbach's Alpha for each Question Group*
	Confirmatory Factor Analysis (CFA) on Covariance Data	• Model Validation (and if necessary Elimination or Integration of new Variables) • Reliability of Items	*Goodness of fit of theoretical Model mapped on empirical Data, Factor Loading*
	Multivariate Regression Analysis on empirical Data (Fit among estimations and calculated values)	• Consistency of adjusted Trust-Model • Calibration of Question Group Weights	*R-mean squared, p-Value*

Table 5.4 (Continued)

Interpretation of results from Pilot tests in order to prepare the Field test and to improve the TW-measurement. Findings shall already be integrated in the TW-measurement so that the Field-tests already are performed with the revised TW-measurement.			
Field Tests	• Real Design Environment with industrial Partners • Group-members have Work History together • CR Priorities are planned to be measured by extensive Customer Inquiries		
Prioritization Method	Application of Method, Comparison to investigated Customer Priorities	• Measure Efficiency of Method • Compare with AHP/Borda Count	*Accuracy, Time consumption, Time of Negotiation, overall Satisfaction of Stakeholders*
TW-Measurement	Use of Survey for all stakeholders, additionally for most and least trusted stakeholders an evaluation survey for the TW-measurement shall be filled out.	• Refinement of Survey Terminology (Clarity, Wording etc.) • Qualitative Evaluation of TW-measurement by Professionals	*Critics of Professionals, Fulfillment of Question Purposes, Calculation of Cronbach's Alpha for each Question Group*
	Confirmatory Factor Analysis (CFA) on Covariance Data	• Model Validation by empirical data in a professional Environment (if necessary adjustment of Model to empirical data) • Reliability of Survey	*Goodness of fit of theoretical Model mapped on empirical Data, Factor Loading*

Table 5.4 (Continued)

	Multivariate Regression Analysis on empirical Data (Fit among estimations and calculated values)	• Consistency of adjusted Trust Model • Calibration of Question Group Weights	*R-mean squared, p-Value*
Interpretation of results from the field tests.			

The proposed validation process will have two main stages (please refer to Table 5.3), i.e. pilot tests and field tests. The series of pilot experiments and pretests will help to find possible errors in the method, help to prove major assumptions statistically and to improve the multiple item TW-measurement. The findings and experience from the pilot tests shall be used to prepare the second stage. The second stage will consist of field tests, where the method is applied in real stakeholder negotiations and with real CR's to prioritize. Industrial partners will have the advantage to test the method and contribute to a research project. With the two stage approach it is attempted to first improve the method in a controlled laboratory environment, before further resources and industrial partners are consumed.

5.5.1 VALIDATION PROCESS OF THE PROPOSED PRIORITIZATION METHOD

The validation of the proposed prioritization method shall answer two questions, (a) are the basic assumptions considered for the concept right and (b) is the aimed at improvement of the prioritization efficiency achieved?

As the proposed prioritization method applies a new concept for the prioritization of CR's, the method's basic assumptions have to be validated first. The pilot tests of the prioritization method are intended to find answers to this issue. The construct of assumption on which the prioritization method is built, shall be confirmed by empirical data one by one.

In contrast to the concept validation in the pilot tests, the field test will focus on the evaluation of the gain in efficiency, satisfaction and confidence of the prioritization process by using the proposed method, hereby a comparison between the proposed method to already accepted prioritization methods will be carried out in a professional environment.

5.5.1.1 Setting of the Pilot Tests

As specified in Table 5.3, the pilot tests will be performed in an artificial setting of a group prioritizing exercise. The group will have to prioritize items concerning a topic which some of them will have more or less expertise about, but none of them will have full expertise. The prioritization topic will ask the individual group member to apply personal opinion, judgment and trade off among the items. The experiment set-ups should be as close as it is possible to simulate the situation at an early stage before prioritizing CR's. The individual and the group prioritization will then be compared to the prioritization from real experts. Each experiment will have strict specifications and methods the group will have to apply will be provided.

Examples of prioritization experiments are found in [Bell. 1994] and described as desert or space survival experiment. Because the prioritization results are known, the accuracy of a voting process i.e. performance might be measured. Specifications and instructions for each hypothesis will follow in 5.5.1.2. Every group will only use the same prioritization method once and will not have to prioritize more than twice.

The test of the hypothesis 1-7 will follow a similar method from hypothesis to hypothesis. The accuracy of prioritizing might be measured by calculating the difference from the individual prioritization and group prioritization to the expert prioritization.

The purpose of the pilot tests is to validate fast and with a low consumption of resources major assumptions of the prioritization method. Experience and results will support the preparation of the field tests. In the following section the assumptions, which will be validated by the pilot tests are listed.

5.5.1.2 Assumptions of the Prioritization Method and Experiment Specifications

The core assumptions of the method designate the method as a new approach to prioritize CR's. In the following the assumptions are presented in Hypotheses which have to be confirmed.

H1: In matter of perceptions group prioritization is more accurate than the individual's prioritizations.

Hypothesis one has to prove that the group interdependency is needed in order to improve the prioritization of perceived and interpreted priorities.

The accuracy of the individual prioritization of the dummy list will be compared to the accuracy the group has achieved. Three negotiation levels will be compared, no group discussion beforehand, little discussion before the individual prioritization and a lot of discussion time beforehand. The prioritization will be based on multivoting method (Beans) with votes five time the number of items to prioritize. The total number of beans an item has gotten will give its rank in the group prioritization. Accuracy of individual (mean), group voting and time of negotiation will be recorded.

H2: The consideration of any difference controlled by the voter in voting power of stakeholders improves the voting result in case of perceptions.

Instead of using equal voting power the stakeholders should individual pass voting power, to the ones they perceive are able to improve the voting result best.

Before the prioritization will take place, it is made sure, that the group members get acquainted with each other. The method the groups for this experiment will have to use is based on SPAN. They will also get votes fife times the number of items to prioritize. Then they will have also three different levels of time to talk with each other about the prioritization. After that time they will have to give anonymously so many votes they want to other group members they think they will do a good job prioritizing the items. After that they will individually prioritize the items with the remaining beans they have. The total number of beans an item has gotten will give its rank. Accuracy of group voting and time of negotiation will be recorded.

H3: The prioritization of items is improved by considering quantified trust as a social dynamic factor and is even improved to the difference the voters control on their own (H2).

Letting the stakeholders control the voting power by themselves inheres the danger, that personal sympathy, individual confidence and personal power are misinterpreted as expertise, therefore using uncontrolled allocation of power as in *H2* might lead to distorted prioritization (please refer to section 2.2.5). In contrast to *H2*, *H3* will use controlled difference in voting power. Hereby the control is designed to give voting power to those stakeholders which are perceived to be more able, more committed and more integer and hence more trusted to improve the voting result.

H3 shall use the same procedure as for *H2* with the difference that the groups will use the proposed Urn-Scheme method with TW-measurement to prioritize the items. Accuracy of group voting and time of negotiation will be recorded and compared to *H1* and *H2*.

H4: The proposed method is more efficient (i.e. more accurate and less time consuming) than e.g. AHP or Borda Count using a prioritization matrix

Hypothesis 4 tries to show the advantage of the newly developed method compared to already accepted prioritization methods.

The setting of *H1* is used with the difference that randomly allocated part of the groups are either using AHP, Borda Count and the Urn-Scheme with TW-measurement method.

The interpretation of this experiment has to be handled carefully. Two issues will have to addressed, time consumption of all three methods will not directly be comparable and the dummy items are ranked and not relatively prioritized, therefore the calculation of the accuracy might get distorted. Because this experiment will be repeated in the field test with real CR's, this experiment might give first impressions and might help to prepare the field tests.

H5: The proposed method reduces the time for negotiation without reducing the accuracy.

Hypothesis 5 will have to show that using the proposed method reduces the necessary time to achieve a satisfying result. Hereby the efficiency of real negotiations without any voting rules are compared to the proposed method.

In this experiment the results from *H3* will be compared to results where the groups will have as much time as they need to prioritize the items. Every group member will have the veto power and therefore all group members will have to agree to the prioritization of the group. The instructions should point out that negotiations shall be carried out until consensus is achieved. Time of negotiation and accuracy will be recorded and compared.

H6: Finding relative priorities based on Ranking methods are less accurate than based on a multivoting approach, i.e. the Urn-Scheme

The advantage of using relative differences among individual priorities rather than a rigid ranking systems shall be validated by comparing Borda Count and a multivoting approach.

For *H6* the setting and the results of *H4* (Borda Count) and *H1* (multivoting) shall be used and analyzed for the difference in accuracy of the voting using either ranking or relative importance distinction. As already specified in *H6* the interpretation will have to be made carefully. *H6* might be repeated with a dummy prioritization where relative priorities are known rather than fixed ranks.

5.5.1.3 Measures in the Pilot Tests

The analysis of the experiments will be focused on the efficiency of the performed prioritization, i.e. the accuracy and time consumption of the examined methods. The accuracy will be measured by calculating the root sum square of the difference between the voted result and the already known solution of the prioritization. The overall time consumption will be less important because it might not be possible to guarantee the prerequisite that the different methods would use the same amount of time under any circumstances. This makes the overall time consumption not directly comparable, but trends in efficiency might still be recognizable.

Another analysis will focus on the achieved amount of consensus, i.e. variances of votes for a certain item compared to the amount of negotiation time needed to achieve the result. A regression analysis might prove any relation among extent of consensus and negotiation time needed. The accuracy of the voting will also be registered to test the specific hypothesis.

5.5.1.4 Choice of Subjects for the Pilot Tests

The choice of subjects for the laboratory test should be accidentally either by random selection of students or voluntary groups from the student body. The allocation to experiments have to happen randomly so that the conclusions drawn from the experiments will be possible to be generalized.

5.5.1.5 Setting of the Field Tests

The professional setting of the field tests will be used to validate the efficiency of the prioritization of the method in two ways, i.e. comparison to investigated prioritization of CR's and comparison to already accepted methods (Borda Count, AHP, NGT).

The proposed method determines the relative priorities, which are perceived to match best the customers' perceived desired product qualities. If the industrial partner has the possibility to measure the customers' desired product qualities through a market research investigation, the output of the prioritization might be compared to them. It is important that the result of the investigated customer priorities are not known to the experiment subjects, otherwise the experiment will be invalid. Another danger in such a comparison might stem from the problems described in the introduction, i.e. the customer might be unknown, the customer might not distinct the CR's importance and not all customers are adequately represented in these investigated data. Nevertheless by being aware of this limitation, the comparison might still reveal valuable insights.

The second comparison will also use the investigated data as standard for accurate prioritization. The group of stakeholders will prioritize the CR's with the proposed Method and with either AHP, NGT or Borda Count. Hereby the accuracy, the time needed and time for negotiations needed will be recorded. The sequence and kind of applied method has to be allocated randomly over all field test groups. The comparison will not be limited on efficiency but also by qualitative feed-back from the stakeholders by an comparison survey. The question will be about the subjective perceptions of the stakeholder towards the compared methods. Following issues should be addressed:

- Stakeholder's over all satisfaction with methods
- Simplicity in use, Practicability
- Consensus, acceptance of result
- Fairness of consideration of own perspectives
- Feeling of confidence in the results of the prioritization method

5.5.1.6 Assumptions of the Method to be validated by the Field Tests

As specified in the previous section *H3* (efficiency) and *H4* (improvement to accepted Methods) from the pilot tests will be repeated in the field tests.

5.5.1.7 Measures in the Field Tests

The difference to the investigated relative priorities will be used as measure for method accuracy, as it was used in the pilot tests. The time consumptions and time needed for negotiations will be compared along with the comparison of the results from the qualitative surveys from the stakeholders.

In order to reduce the time consumption of the experiments with the proposed method and to enhance the attractiveness for industrial partner, a software version of the prioritization method should already be available for the field tests.

5.5.1.8 Choice of Subjects for the Field Test

The selection of experiment subjects for the field test in industry and organizations, will be bound to the restrictions from the side of the industrial partners. Industrial partners with the ability to perform extensive customer inquiries to determine the "standard" for the prioritization should be considered preferable.

5.5.2 VALIDATION PROCESS FOR THE TW-MEASUREMENT

The validation of the proposed TW-measurement has two critical issues, (a) is the used and adjusted Model of Mayer et al. useful to measure the trust in somebody to prioritize CR's and (b) is the proposed measurement method reliable and consistent?

Whereas the validation process of the prioritization method is strictly carried out in two separate sequential steps, the validation of the TW-measurement will actually have three parts, but will sequentially be repeated (see Table 5.3). The three parts are integration of qualified feedback on items with a check of the scale reliability, a confirmatory factor analysis (CFA) to evaluate the consistency between the proposed measurement model and the empirical data and a regression analysis to confirm the consistency of the TW-measurement. These three parts will be first carried out on a convenience sample in an artificial setting of pilot tests and then repeated with similar settings in field tests. It is intended, that the pilot tests might already deliver critical findings to improve the TW-measurement, before it is applied in the field experiment.

5.5.2.1 Three Part Validation Process

The best validation for the proposed trust measurement method would be a comparison to an existing, already accepted measurement method. Because of the uniqueness and special focus of the proposed measurement such a comparison is not possible.

The proposed three part approach is based on literature review concerning the validation procedures for new multi item scales [Gill. 2003, Maye. 1999, McAl. 1995 and Froe. 2004]. In the first step the terminology, redundancy, integrity, clarity of the items of the survey is cleaned up by the qualitative feedback of the respondents. The first step is also used to rephrase or eliminate problematic items. A calculation of Cronbach's Alpha for each question group will reveal its reliability, whereas the $\alpha > 0.8$ should be achieved [Gliem 2003].

After this first part a Confirmatory Factor Analysis (CFA) should be used to verify the consistency of the factor model we intended to use (please refer to Fig. 5.14) and the empirical data. The CFA will be used to map the theoretical model on the empirical data. The calculation of the goodness of fit parameters of the CFA, will reveal if the proposed extended model is appropriate to use. The CFA shall give us the answer "how well the covariance matrix of the theoretical model, match the covariance matrix observed in the empirical data".

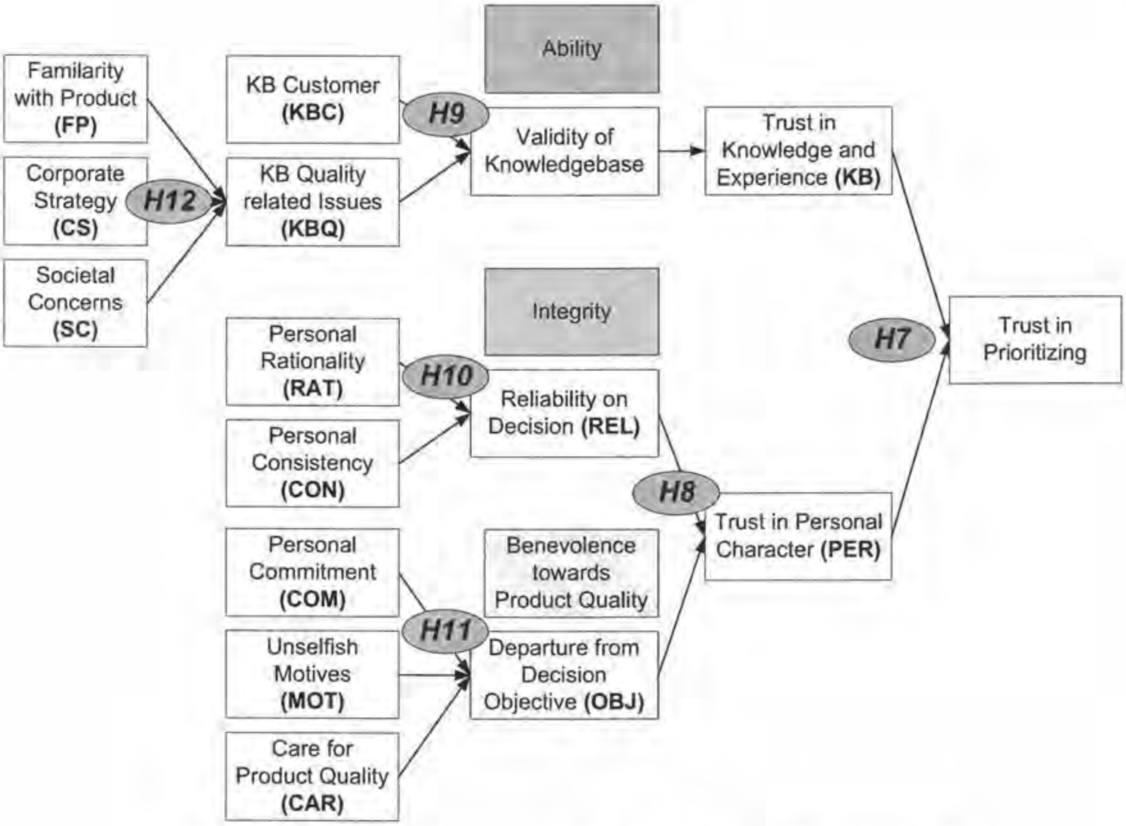


Figure 5.14 The Taxonomy Model of the TW-Measurement

Three theoretical models will be compared to the empirical data:

- The null model considers no relation among found parameters within the Covariance matrix of the empirical data.
- The basic model shows evidence that there are three main constructs within the Covariance of the empirical data (Ability, Integrity and Benevolence).
- The extended model considers nine different relation constructs within the covariance matrix of the empirical data (i.e. KBC, FP, CS, SC, RAT, CON, COM, MOT and CAR).

The goodness of fit statistics will reveal if the proposed extended model fits the empirical data well.

The last of the three validation parts is a multivariate regression analysis to examine the consistency of the proposed TW-measurement. It focuses whether the estimations of the stakeholders within the model are consistent. Hereby the Hypotheses 7-12 are analyzed one by one. The stakeholders will have to fill out an evaluation survey about the TW-measurement about the most and least trusted fellow stakeholder in their individual view (Details to the evaluation survey will follow in section 5.5.2.3). Within this evaluation survey they will have to rate their overall Trust in prioritizing, in PKB, in PER, in REL, in OBJ, in KPQ, but they will also rate their perceptions of the trustee (KBC, FP, CS, SC, RAT, CON, COM, MOT and CAR) in a seven point Likert scale with the least and most trusted fellow stakeholder in mind. These estimations will then be compared to each other with a multivariate regression analysis. If the error term in the regression model is impossibly minimized, the model might not be consistent. Using a large enough sample the inconsistencies within the individual respondents might be neglected. In this way the adjusted trust model will be examined on its consistency. If the error term are minimized in the regression analysis the weights of the variables proposed in the taxonomy of the survey will eventually be calibrated.

5.5.2.2 Setting of the Pilot Tests for the TW-Measurement

In contrast to the different specifications and instructions for the experiments concerning the validation of the prioritization method, the experiments for the TW-measurement will follow the same set up. The goal is to have a large sample size with a large qualitative feed-back for the improvement of the survey.

As shown in Table 5.4 the pilot tests concerning the survey will be performed simultaneously with the pilot tests concerning the prioritization method. Both tests will be set up as laboratory tests with student project groups with three to eight group members. The experiments of the pilot tests for the validation of the TW-measurement will simulate the overhead in Fig. 4.1, i.e. an individual prioritization and short presentation of the reasons the teammates have used to prioritize the items in the list.

Randomly allocated groups will have to prioritize either a dummy list of items or their real list of CR's of their student project. If using a dummy list the TW-measurement has to be adjusted to the dummy list of items. After the short explanations from all the group members, they will fill out individually the survey concerning each other. The participants should be felt encouraged and confident to fill out the surveys about the other group members truthfully. To limit the effect of becoming dull, the individual group members will only be asked to fill out the evaluation surveys for the teammate they trust most and least to prioritize.

The participating project groups will have to have a joined working history and the prospect to reach a goal together. The survey will be administered as a web based or a printed version where as the items will be randomly ordered, so that the question groups are mixed with each other.

5.5.2.3 Qualitative Survey About TW-Items

Along with the actual survey, a qualitative validation survey, i.e. evaluation survey about the TW-items will be passed out for two trustor-trustee assessments from every group member. In this evaluation survey, the participants will have to rate if the item is easy to understand, if the participant had trouble to answer the item and if the items fulfill their indented purpose. If e.g. the survey item asks: *I fully accept how [Stakeholder X] represented the interests of our target customer,* then validation question would ask if this question represents the trust of the participant in the capability of the teammate x to prioritize the CR's correctly. The respondents might answer these evaluation questions by a seven point Likert scale as well.

At the end of the validation survey, the participants might rate his/her over all trust in the teammates capability of prioritizing the dummy items *H7*. Then each a question to his/her trust in the personal character in order to prioritize well (*PER*), in the ability (*KB*), in the benevolence (*OBJ*) and in the integrity (*REL*) to prioritize of the trustee will follow. Additionally the respondent will be asked to rate his/her trust in trustee's Expertise about the products environment (*KPQ*). He/she will also estimate the perceptions he/she has from the trustee's according KBC, FP, CS, SC, RAT, CON, COM, MOT and CAR.

He/she will also be asked to rate how well he/she thinks the survey is capable of measuring the participant's trust in others capability prioritizing and if the participant has some constructive critics.

5.5.2.4 Validation of Taxonomy of TW-measurement

The adjusted model of trust in prioritizing (please refer to section 4.2.2) is constituted by nine independent variables, i.e. Perception variables (KBC, PP, CS, SC, RAT, CON, COM, MOT and CAR) and five dependent variables, i.e. Trust variables (Knowledge Base Product environment (KPQ), Reliability of Trustee's Decision (REL), Departure from Decision Objective (OBJ), Knowledge and Experience (KB), Personal Character (PER)). The weights for each question group are pre-set by the author, but will be iteratively validated through regression analysis in the pilot tests and field tests.

The perception variables are:

- Knowledgebase Customer (KBC, 30%)
- Familiarity with product (PP, 7.5%)
- Familiarity with Corporate strategy (CS, 7.5%)
- Familiarity with societal concerns (SC, 5%)
- Trustee's Rationality (RAT, 10%)
- Trustee's Consistency (CON, 10%)
- Trustee's Commitment (COM, 10%)
- Trustee's unselfish motives (MOT, 10%)
- Trustee's care for product quality (CAR, 10%)

The pilot tests will give a first impression if the weights of the questions groups are accurate or if they might have to be changed according the results of the multivariate regression analysis in the pilot tests. The regression analysis will be repeated in the field tests and this will complete the calibration process of the weights for the TW-measurement.

5.5.2.5 Measures for the Pilot Tests

The qualitative feedback about the items shall help to evaluate if the item is understood well and if the respondent had difficulties to answer the item. The feedback might be used to pin point items which have to be rephrased or eliminated. The ratings if the item fulfilled its purpose in the eyes of the respondents will be examined and low valued items might be changed or eliminated.

The Cronbach's Alpha will indicate the in-group-reliability of the items, where as a minimum of $\alpha>0.8$ should be achieved [Froe. 2004].

The measures from the CFA will slightly vary depending on the method applied. The output usually contains Goodness of Fit index (GFI), Root mean square error of approximation (RMSEA). The CFA results for reliability and convergent validity might further indicate if the theoretical model is appropriate.

The following Hypotheses will be evaluated by a regression analysis, wherein weights for the taxonomy of the TW-measurement might be retrieved.

H7: Trust in prioritizing is a construct from trust in somebody's knowledge and experience to prioritize CR's and trust in the personal character of this somebody to prioritize.

The regression will be used to validate the function $y_{ij} = \alpha \cdot KB_{ij} + \beta \cdot PER_{ij} + \varepsilon_{ij}$, where $i, j = 1...N$, N equals to the total amount of stakeholders and ε to the error term of the regression. Within the validation process the error term should be minimized. The value of y_{ij}, KB_{ij} and PER_{ij} is estimated by the trustor him/herself. Repeating this for all samples the weights α, β will get more accurate and might be compared to the weights proposed by the taxonomy. The following hypotheses will be validated by the same way.

H8: The trust in personal character to prioritize of the trustee is a construct of the trust in the reliability of the trustee's prioritization and trust in trustee's loyalty to the prioritization objective (high product quality).

H9: The trust in trustee's expertise and experience is derived from the ability of the trustee to get familiar with the targeted customer and the trust in him/her to understand concerns from the environment of the product.

H10: The trust in the reliability of the trustee's prioritization is a construct of the rationality of the trustee and his/her consistency in prioritizing CR's.

H11: The trust in trustee's loyalty to the prioritization objective is depending on the trustee's commitment, motivation and care for high product quality.

H12: The trust in trustee's understanding of the concerns from the environment of the product is dependent on the trustee's familiarity with the product, his/her understanding of the corporate strategy and the understanding of the societal concerns.

The consistency of the respondents estimation might be monitored by comparing the estimation of KBC, FP, CS, SC, RAT, CON, COM, MOT, CAR with the calculated values from the TW-measurement.

If it is not possible to minimize the error terms of the regression analysis or the distribution for α, β is too large, the model would either be inconsistent or not complete. In any case inconsistencies are found and therefore might be corrected specifically.

5.5.2.6 Field Tests of the TW-Measurement

As specified previously the field tests for the TW-measurement will mainly be a repetition of the pilot tests. The field tests of the experiments will not only enlarge the statistical sample size, but also the value of the validation process. In contrast to the pilot tests the professional environment will make the qualitative feed back more meaningful because of the direct insights from the industrial partners. Comments and discussion will help to improve the measurement as well as the whole prioritization method.

The results from the TW-measurement will have to be kept confidentially or made anonymous in any case, otherwise the integrity of the stakeholders might be endangered.

6 CONCLUSION AND FUTURE WORK

6.1 Concluding Remarks on Proposed Prioritization Method

In this study a method to collaboratively find the relative importance of customer requirements has been introduced. The method has the goal to improve the accuracy of relative priorities of CR's by better supporting and guiding a group of stakeholders through its decision process at an early stage. The factors that are considered in the proposed method include consumer, developer's organization's and societal concerns. The individual perception of the priorities of CR's are registered in the first step of the presented approach. Hereby the stakeholders might distinguish the importance of each single CR by relative amounts rather than fixed ranks. In the second step of the presented method each stakeholder's "individual priorities"-decision is updated through a weighted sum of all individual priorities. The weights are stemming from a specifically designed trustworthiness measurement. With the second step the stakeholders are using their interdependency to take the opinions of all other stakeholders into account to the extent they have trust into the fellow stakeholders to prioritize the right CR's. The hereby used measurement is a comprehensive multi item measurement, which evaluates the willingness of a stakeholder to rely on the overall capability of every other stakeholder including him/herself to prioritize CR's. The introduced final step of the method unifies these updated individual priorities to a set of relative priorities retrieved by the group through another weighted sum. The weights for this last step are the normalized sums of the trust every stakeholder has gotten from the group to prioritize CR's.

The developed Urn-Scheme approach takes into account that each stakeholder in a cross-functional group will have different perceptions of what is important for the product quality. The method provides also a framework to consider inherent differences in voters in their capability to prioritize, i.e. difference in ability, experience, expertise, commitment, motivation, preference and intuition of voters. The necessary distinction in voting power is based on the social network among the stakeholders, i.e. in this study on trust and trustworthiness into the capability of all stakeholders to prioritize.

The presented analysis tools help to guide necessary negotiations to those CR, which are conflicting and therefore reduce the amount of negotiations needed. The proposed relative importance scale might help to make the result of the decision making process clearly visible. Further information and negotiations on the identified conflicts about CR priorities might be in some cases necessary.

The unique advantage of the proposed method is its simplicity combined with manifold analysis capability by a minimum of needed stakeholder data what results in an optimum of method efficiency. It will help to reduce the time needed for negotiations and supports the real expertise to prioritize CR's hidden in the social network. The clear product priorities found by the weighted votes of the stakeholder might give the basis for further design decision, what enhances indirectly the autonomy of design teams downwards.

6.2 Thoughts on Further Research Efforts

As extended research effort, the investigations in the four following areas are tentatively planned:

6.2.1 EXTENSION OF THE URN-SCHEME METHOD

6.2.1.1 Power Issues

The allocation of number of balls to every stakeholder might specifically be focused. Initially all stakeholder get the same amount of balls, but in specific cases balls might be assigned according to an existing power hierarchy. The Urn-Scheme enables the user to examine the influence of power by calculation of decision bias related to power.

6.2.1.2 Degree of Consensus

The extent of the consensus among stakeholders might be analyzed by using different color of balls for each stakeholder. It might be instantly visible if the different colors are rather split among different CR's or if there seems to be a sound distribution of colors and hence the extent of consensus recognized. Besides the analysis of the consensus the color difference might also reveal the balance of the individual prioritization. A stakeholder's heavy emphasize of one CR, might instantly be recognized. In such a case the specific stakeholder might be interviewed and his/her reason for the emphasizing explained. Therefore using different colors might also reduce the sensitivity to gamesmanship of the method.

6.2.1.3 Voting Group Reconstruction

The authors suggested a guide to decide, when a distinction among the importance of CR's is significant enough (please refer to Table 5.1). There might be cases where no decision can be reached and further negotiations might not reveal the necessary consensus. For such cases the group influence and team factors shall be examined in order to understand effects leading to a flat decision outcome. This investigation might lead to suggestions how to select or build a cross-functional team that can find a good prioritization of CR's. In other words factors to form stakeholder groups might be studied to have good and balanced opinions represented about the customers' perceived desired product qualities. Empirical studies may be carried out in graduate classrooms with both engineering and business major students involved.

6.2.2 WEIGHTING METHODS

6.2.2.1 Trust-Model and TW-Measurement Improvement

Currently the model for the TW-measurement might be too strongly emphasized on decision making perceptions and too less on trust behavior.

Although the validation process might reveal this shortcoming of the TW-measurement, it might be necessary to conceptually change the model to integrate more trust behavior before it even is being evaluated.

6.2.2.2 Other Social Factors

In the proposed method each stakeholder's vote are weighted by the amount he/she is trusted by the other stakeholders to prioritize well. Although trust is able to integrate several different levels of stakeholders' personality, i.e. ability, benevolence and integrity, it might be interesting to investigate other differences as well, e.g. confidence in own judgment, communicational behavior, combinations of personal character etc. with always the maximum of perceived product quality in mind.

6.2.3 DIFFERENT DESIGN STAGE

The proposed method is used between the generation of a CR's pool and development of an engineering strategy. The method could also be used to make a final decision in other parts of the product development, e.g. the selection of concepts, selection of materials or selection supply parts. The basic urn scheme could be used with or without trust as weighting factor in order to make the decision. Trust might be replaced e.g. by expertise, know-how or other distinctive factors among stakeholders.

6.2.4 FIT INTO REAL WORLD DESIGN APPLICATIONS

The implementation of the proposed method in potential applications in e.g. risk-based design, environmental design, etc. might lead to insights whether the method leads to satisfying decisions under special conditions. In order to shorten the calculation time of the whole procedure and measuring the trust among stakeholders, it would make sense to develop a software tool for the whole voting and analysis process. The software could run on a server accessible by the different stakeholders on their terminals. The trust surveys might be filled out and each stakeholder would have put virtual balls in CR urns. The relative importance values might be calculated automatically and the results displayed in appropriate charts. The facilitator or administrator might even have access to special analysis tools like consensus examinations, balance of individual votes based on the average voting of the whole group or might display the trust network in prioritizing, etc

7 CONTRIBUTION TO KNOWLEDGE AND DESIGN PRACTICE

The focus of the proposed study is the improvement of the prioritization of customer requirements. With the integration of an interpersonal, social factor in a design methodology, a new concept has been introduced. It has been shown, that trust act as tie strength in social networks and that it therefore is one of the connecting factors in interpersonal relationships. By paying attention to trust in interpersonal connections among stakeholders, the method shows that trust also influences the technical product development. The proposed concept is based on connectedness of the two involved systems and the fact that in product development the human as well as the technical system become intertwined has been used.

A rigorous math-framework based on an Urn-Scheme approach has been developed to carry the new concept. The method makes the finding of relative priorities easier and more reliable. It opens the voting process to a great number of analysis possibilities with a minimum of required stakeholder data. The proposed method contributes to the study how social factors might influence the product development and how they might be used in a rigorous method to improve the product development process.

The goal of the method to support the prioritization of CR's aims at better understanding the customers concerns and to better integrating their desired product qualities. The method has been shown as an efficient group decision making method in design to reach this goal. The method presented a way how a cross-functional group of stakeholders might enhance their decision quality without having to pass an enduring negotiation process. By showing a way how differences among stakeholders might be fairly quantified and used in a voting process, the method opens the discussion for ways how to make very focused group decisions with emphasize of the right expertise. With the measurement of a social factor the purposed power manipulation of votes is justified and might have a high acceptance among the stakeholders, because the manipulation is based on their own judgment.

Moreover the methodical support to find CR priorities will help to enhance the decision autonomy of design teams downwards. Because once CR priorities are documented and communicated every other design decision might be based on these priorities. Overall this might lead to time savings along the product development and to a better integration of customers' desired product qualities along the way. The proposed method opens therefore the possibility of meaningful applications in design practice.

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