Prioritization of Product Requirements using the Analytic Hierarchy Process

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Abstract: The prioritization of product requirements is an essential task during the early phases of product development, which copes with time-to-market deadlines, budgetary constraints, and personnel restrictions. Since several decision criteria, such as cost, time, and risk, as well as the customer's point of view and different company divisions have to be taken into account, the prioritization of requirements corresponds to a multi-criteria, multi-stakeholder decision problem. In this article, we propose a prioritization approach based on the analytic hierarchy process (AHP) that creates a ranking of requirements with respect to multiple (maybe conflicting) decision criteria and incorporates assessments of multiple stakeholders. The proposed approach overcomes the scalability problem of AHP by using hierarchic checklists and an efficient partitioning strategy.

1 INTRODUCTION

The prioritization of product requirements is an essential task during the early phases of product development. The priority of a requirement indicates its importance, urgency, or value for the product to be developed (Wiegers, 2003; Karlsson and Ryan, 1997). Prioritization supports the identification of key requirements of a product and, thus, helps to recognize the key issues of product design. To cope with time-to-market deadlines as well as budgetary and personnel restrictions during product development, a careful prioritization of requirements supports the determination of valuable requirements which should be implemented in a given product release (Duan et al., 2009). Moreover, priorities of requirements help to create a schedule that describes the order in which the requirements should be implemented (Pahl et al., 2007).

The point of view of different stakeholders, such as different company divisions as well as the customers and users of a product, should be incorporated in the prioritization of product requirements (Karlsson et al., 1997). With a huge number of requirements on the one hand and the different stakeholders on the other hand, the prioritization of requirements is a complex multi-criteria task that requires collaboration between the stakeholders. To cope with the *cognitive limitations of the human mind, insufficient time for deliberation, limited organizational resources for information gathering, and related problem-solving constraints* (Janis, 1989), methodological support is necessary for such multi-criteria, multi-stakeholder decisions.

To prioritize a huge number of requirements in a multi-stakeholder environment, we propose a prioritization approach based on the analytic hierarchy process (AHP). The AHP, initially developed by Saaty (Saaty, 1980), is widely applied in science and industry and its major use is the resolution of choice problems in multi-criteria environments (Forman and Gass, 2001). The benefits of AHP with respect to other multi-criteria decision making methods is its ability to incorporate *intangibles* (Harker, 1987), its simplicity, ease of understanding, flexibility, and accuracy (Forman and Gass, 2001). Since the traditional AHP requires a pairwise comparison of all objects considered (which are the requirements in our case), the number of comparisons would grow quadratically with the number of objects.

The contribution of this article is the utilization of hierarchic checklists to significantly reduce the number of pairwise comparisons in the average case and hence to overcome the scalability problem of AHP.

The next sections are structured as follows: Section 2 presents the background of requirements management and related prioritization approaches. Section 3 describes the AHP in detail and discusses existing approaches for the reduction of pairwise comparisons. The novel prioritization approach proposed is described in Sect. 4. Finally, Sect. 5 concludes.

2 RELATED WORK

In this section, key issues of the requirements management in the mechanical and software engineering domain as well as existing methods and tools for the prioritization of requirements are described.

2.1 Requirements Management

Design approaches in the mechanical and the software engineering domain, such as the VDI 2221 guideline (VDI, 1993; Pahl et al., 2007), the axiomatic design (Suh, 2001), and the rational unified process (Kruchten, 2003), emphasize an in-depth analysis of customer needs, a transformation of customer needs into well-defined product requirements, and finally the creation of a product specification in the early stages of the product development process. This process is denoted as clarification (Pahl et al., 2007).

For a prioritization that considers the customer's and the manufacturer's point of view as well as other factors, such as legal regulations, international guidelines, and lately the environmental impact of products, a collaboration between domain experts is necessary. In the mechanical engineering domain, such a collaboration is denoted as integrated product development (Ehrlenspiel, 2009) and plays a major role for a successful product development project. Besides this human-centered collaboration, Gumienny et al. (Gumienny et al., 2011) emphasize the necessity for automated information exchange and information synthesis between the collaborating experts. Therefore, an IT-supported prioritization that incorporates human-centered collaboration as well as information exchange and synthesis is favourable.

2.2 Requirements Prioritization

For the prioritization of requirements, many approaches and techniques are used in practice (Duan et al., 2009). Simple approaches separate requirements into few groups, for example demands and wishes (Pahl et al., 2007) or functional and non-functional (qualitative) requirements (Kruchten, 2003), or directly assign weights (important rates) to customer needs (Ehrlenspiel, 2009). However, these techniques primarily focus on a coarse categorization rather than prioritization.

More sophisticated value-oriented methods combine selected factors to calculate a corresponding priority. For example, Wiegers (Wiegers, 2003) proposes an approach in which the stakeholders rate the value, the cost, and the technical risk each on a scale from 1 to 9. The priority of a requirement is then calculated by $value/(cost + risk)$. In similar approaches, for example outlined by (Wassermann, 1993) and (Ehrlenspiel, 2009), the requirements are prioritized during a quality function deployment (QFD) planning process, utilizing the expected influence of customer needs on requirements in addition to the factors value, cost, and risk. These value-oriented prioritization approaches can help to select core requirements (Azar et al., 2007), but do not consider the collaboration between stakeholders.

For the prioritization of large sets of requirements, the BST (binary search tree) is proposed (Ahl, 2005). The BST is constructed by inserting less important requirements as left children and more important requirements as right children of a given node in the BST (similar to the sorting with a BST). Other approaches for large sets of requirements use automatic clustering techniques and manual prioritization of clusters for the prioritization (Duan et al., 2009; Jiang and Eberlein, 2006). Although these approaches scale well for large sets of requirements, a major shortcoming is the lower achievable accuracy with respect to other prioritization approaches.

Several authors suggest the analytic hierarchy process (AHP) (Mead, 2008; Karlsson and Ryan, 1997; Ahl, 2005; Perini et al., 2009; Regnell et al., 2001) to achieve a consistent, highly accurate, and ratio-scale prioritization of requirements. Since the traditional AHP approach is primarily not adapted for a distributed prioritization with multiple stakeholders (Regnell et al., 2001), several methods for the incorporation of assessments from different stakeholders are proposed. These include simple median, arithmetic or geometric mean calculations (Ramanathan, 2001; Saaty, 1980) and the Delphi method (Saaty, 1980; Azani and Khorramshahgol, 1990), which is an interaction approach between stakeholders to reach consensus. A key issue of AHP is its lack of scalability, because the prioritization of n requirements requires at least $n \cdot (n-1)/2$ pairwise comparisons of requirements. Several techniques for the reduction of necessary comparisons have been proposed (see Sect. 3.2). However, these techniques decrease the accuracy of the prioritization resulting.

All mentioned prioritization techniques and methods are utilizable for the relevant issues, i.e., coarse categorization, assignment of values to requirements, and fast processing of large sets of requirements. But they either lack support for collaboration between stakeholders, accuracy of the prioritization, scalability, or considering the multi-criteria environment of requirements prioritization. The approach for requirements prioritization proposed in this article tries to overcome all these shortcomings by a combination of
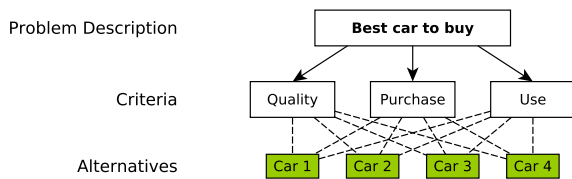
Figure 1: Example AHP criteria hierarchy for an optimal alternative selection, which is choosing the most appropriate car.

the AHP with aspects of the Delphi method and a new technique for the reduction of pairwise comparisons. Since the AHP is essential for this approach, it is summarized in detail in the next section.

3 THE ANALYTIC HIERARCHY PROCESS

The analytic hierarchy process (AHP), initially proposed by Saaty (Saaty, 1980), is a methodology which supports multi-criteria decisions in a widespread area of application, e.g., optimal alternative selection, prioritization, evaluation, or benchmarking (Forman and Gass, 2001). The AHP enables a calculation of ratio-scale weights from pairwise comparisons in a multi-criteria environment. In the following, the major steps of the AHP are explained in detail and existing approaches for the reduction of the number of pairwise comparisons are discussed.

3.1 Steps of AHP

Similar to other approaches for multi-criteria decision support, the AHP starts with the decomposition of the problem description into subproblems, followed by comparative assessments with respect to subproblems and ends with a synthesis of the assessments. Figure 1 depicts an example decomposition of a selection problem and corresponding alternatives. In general, the AHP can be divided into five major steps.

1. **Problem Decomposition and Creation of a Hierarchy of Criteria.** The first step of AHP is the identification of the decision criteria of the overall problem and the creation of a hierarchy of the criteria. Each criterion may consist of several sub-criteria. (Azani and Khorramshahgol, 1990) and (Mendoza and Prabhu, 2009) suggest an independent gathering of prospective criteria by each stakeholder, followed by the creation of the hierarchy in a joint meeting. A careful choice of stakeholders is essential is this step, including ultimately affected (primary) stakeholders as well as (secondary) stakeholders with intermediary roles.

This first step also includes the determination of possible alternatives.

2. **Pairwise Comparisons.** After an identification of possible alternatives, the pairwise comparison of alternatives with respect to criteria on the lowest level of the hierarchy and the pairwise comparison of (sub-)criteria with respect to their superior criterion in the hierarchy starts. As a result, multiple quadratic comparison matrices are created. In the example of Fig. 1, three 4x4 matrices, that contain the pairwise comparisons of the cars with respect to the criteria *Quality*, *Purchase* and *Use*, and one 3x3 matrix, that contains the pairwise comparisons of *Quality*, *Purchase* and *Use* with respect to the overall selection problem, are created. Each pairwise comparison is rated on an interval scale from 1 (both comparison objects (i.e., alternatives or criteria) *are equal* with respect to the superior criterion) to 9 (the first comparison object *extremely dominates* the second object with respect to the superior criterion). With the reciprocal values $1/9, \ldots, 1$, a lower assessment of the first object can be specified.

3. **Validation of the Consistency of Pairwise Comparisons.** The rate of consistency is measured by the consistency ratio *CR* for each comparison matrix (Saaty, 1980). The *CR* is calculated based on the maximal eigenvalue of the matrix. The ratio is equal to zero for an ideal comparison matrix and greater than zero for inconsistent matrices. Saaty proposes a consistency be satisfying, if *CR* is less than 0.1.

4. **Calculation of Local Weights.** For each comparison matrix the local weights are calculated. A local weight specifies the assessment of a comparison object with respect to the superior criterion in the interval $[0,1]$. The local weights are defined to be the values of the first eigenvector of the comparison matrix which is calculated based on the maximal eigenvalue of the matrix (Saaty, 1980).

5. **Synthesis of Global Weights.** The global weights of alternatives (i.e., the priorities) are calculated based on the local weights. For each alternative the local weight of the alternative and the global weight of the corresponding criterion are multiplied. These results are summed for all criteria on the lowest level of the hierarchy in order to calculate the global weight of an alternative. The global weight of a criterion v_j on the lowest level of the hierarchy is calculated by multiplying the local weights of the criteria on the path between v_j and the overall problem description (i.e., the root of the hierarchy).
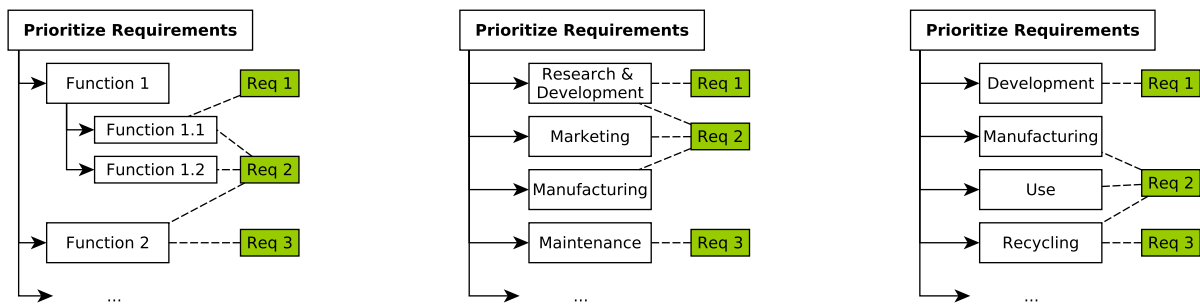
Figure 2: Examples for organizing requirements in hierarchical form. Left: Assignment to functionalities. Middle: Assignment to responsible company departments. Right: Assignment to life cycle phases.

3.2 Existing Approaches for the Reduction of Pairwise Comparisons

Wedley et al. (Wedley et al., 1993) states that there are only $n-1$ comparisons necessary for the calculation of the local weights of n comparison objects. The remaining comparisons are derived from the $n-1$ comparisons. Based on a case study, the authors recommend to compare all objects with the object with the lowest (assumed) rank to achieve the minimum inconsistency.

Since redundant comparisons are necessary to check the assessments and to measure the consistency, Harker (Harker, 1987) proposes so-called *local stopping rules*. These rules require further comparisons (beyond Wedleys $n-1$ comparisons) only if a next comparison can significantly contribute to the current local weights. An extension of this approach, described by Millet and Harker (Millet and Harker, 1990), introduces so-called *global stopping rules* that take the entire decision hierarchy into account. Comparisons of a specific branch in the criteria hierarchy are performed only if the entire branch significantly contributes to the global weights of the alternatives.

Another (local) approach is proposed by Shen et al. (Shen et al., 1992) who suggest the partitioning of the set of comparison objects into groups which have one comparison object in common. While the weights of the comparison objects in the groups are determined with the traditional approach, the weights for the entire set are directly derived from the group weights and the weight of the common object.

Weiss and Rao (Weiss and Rao, 1987) propose the so-called *use of incomplete experimental design* in which each stakeholder compares a subset of the hierarchy only and, thus, the number of comparisons is reduced for each stakeholder. The authors also suggest the *deletion of certain attributes* in order to reduce the size of the AHP hierarchy a priori.

The approaches mentioned reduce the number of comparisons in arbitrary AHP decision problems and accept a minimum increase of inconsistency. In contrast, the approach for the reduction of pairwise comparisons proposed in this article tries to preserve the accuracy of the global weights. Furthermore, the approach proposed can be combined with the approaches outlined in this section.

4 AHP APPROACH FOR THE PRIORITIZATION OF REQUIREMENTS

The requirements prioritization approach proposed in this section utilizes the AHP to incorporate multiple criteria and multiple stakeholders for the prioritization of requirements. The approach provides techniques for the effective reduction of necessary pairwise comparisons of requirements based on the hierarchic structuring and partitioning of requirements.

4.1 Hierarchic Structuring of Requirements

A partitioning of requirements into groups with similar concerns is often used to manage a huge number of requirements. As described by (Pahl et al., 2007; Ehrlenspiel, 2009; Kruchten, 2003), tree structures are appropriate for such a partitioning. A partitioning according to the major functionalities of the product (Fig. 2, left) is frequently used, because functionalities can (hopefully) be developed independently and integrated afterwards (for example specified by the V-model (Boehm, 1979; VDI, 2004)). Pahl/Beitz (Pahl et al., 2007) propose so-called *partial requirements lists* that contains requirements related to different company departments (Fig. 2, middle). Since life cycle oriented development becomes mandatory for technical products, also a partitioning into life cycle phases can be helpful to structure requirements (Fig. 2, right). Because of cross-cutting concerns,

requirements may belong to more than one concern and, thus, should be part of several groups of requirements (e.g., *Req 2* in Fig. 2). For example, the requirement "increase energy efficiency", may belong to the life cycle phases manufacturing, use, and recycling as well as to several company departments, such as marketing, management, and Research & Development.

Ehrlenspiel (Ehrlenspiel, 2009) and Pahl/Beitz (Pahl et al., 2007) incorporate life cycle, organizational, and functional aspects of product requirements in order to create a hierarchic structure. These checklists contain general aspects of a product to be developed and can be used to validate the completeness of a requirements specification as described in (Reichel et al., 2011).

For the requirements prioritization with AHP, we propose to use checklists to efficiently reduce the number of pairwise comparisons by utilizing the tree structure of the checklist as criteria hierarchy (step 1 of the AHP). For each criterion on the lowest level of the hierarchy, only the requirements that are directly related to the criterion are rated (step 2 of the AHP). The local weights of the requirements that are not related to the criterion are assumed to be zero. This assumption is reasonable, since all requirements that are not related to a criterion should be prioritized as low as possible when only this criterion is considered. The modified assignment of alternatives to criteria on the lowest level of the hierarchy extends the conventional AHP approach with the goal to reduce the number of pairwise comparisons while preserving the accuracy of the priorities resulting.

4.2 Prioritization of Requirements

The prioritization of requirements start with the determination of a criteria hierarchy as described in Sect. 3.1 (step 1) in order to decompose the overall prioritization problem. The prioritization utilizes a checklist described in Sect. 4.1 as criteria hierarchy, since it provides the necessary problem decomposition. If such a checklist is already used for the preceding clarification of requirements, as proposed in (Reichel et al., 2011), the reuse of the checklist for the prioritization is beneficial, especially because the hierarchic structure of the checklist (i.e., the criteria hierarchy) is determined by all stakeholders concerned and the product requirements are already assigned to the corresponding checklist items (i.e., criteria).

If a checklist is not used in the requirements clarification so far, it has to be created by all stakeholders concerned. The creation process of a checklist highly depends on the product type and the number of stakeholders involved. For a small number of stakeholders, an informal meeting can be sufficient to create the criteria hierarchy. However, for large groups a methodological approach, such as the Delphi Method (Azani and Khorramshahgol, 1990) or a value-based multi-stakeholder approach as described by (Mendoza and Prabhu, 2009), is recommendable to obtain the point of view of all stakeholders. After the creation of the criteria hierarchy, all requirements have to be assigned to corresponding (sub-)criteria. With a huge number of requirements to be assigned it is feasible that the stakeholders assign subsets of the requirements simultaneously. Since the assignments have a strong impact of the priorities resulting, all assignments should be reviewed by other stakeholders.

In the next step of the prioritization, pairs of requirements and pairs of criteria are compared. This step starts with the pairwise comparison of requirements with respect to the criteria of the lowest level, followed by the pairwise comparison of criteria with respect to their superior criterion. As proposed by (Forman and Gass, 2001; Schoner and Wedley, 1989), this bottom-up approach should be used if the independence of requirements and higher-level criteria could not be assured, i.e., the weighting of higher-level criteria depends on the given requirements.

In order to limit the number of pairwise comparisons for each stakeholder on the one hand and to achieve a high accuracy of the prioritization on the other hand, two strategies are used for the comparisons.

1. **Partitioning.** In the partitioning strategy, different groups of stakeholders compare different sets of requirements with each other. The strategy is primarily used to reduce the number of comparisons for individual stakeholders and to transfer pair comparisons of requirements of a similar domain to the corresponding domain experts. The partitioning strategy may decrease the accuracy of the prioritization, since not all stakeholders are involved in the comparison of all requirements. However, a pairwise comparison of requirements related to a specific domain by an expert not familiar with the domain may also decrease the accuracy. This strategy corresponds to the *use of incomplete experimental design* by Weiss and Rao (Weiss and Rao, 1987) for the prioritization of requirements.

2. **Consensus.** In the consensus strategy, a group of stakeholders (e.g., experts of different domains) assess the same set of requirements (or criteria) independently. For this well-known strategy, we propose to use the following indicators to determine a significant deviation of stakeholder comparisons.

(a) The pairwise comparisons of two stakeholders result in different orders (ranks) of the local weights of the compared objects;

(b) The euclidean distance of the local weight vector of the criterion is above a user-defined limit;

(c) A sensitivity analysis determines, that the deviation of stakeholder comparisons has a significant influence of the priorities resulting (the sensitivity analysis in AHP determines the influence of single pairwise comparisons on the global weights).

While the indicators (a) and (b) can be calculated based on the given local weights, the indicator (c) requires pairwise comparisons for the entire hierarchy to calculate the priorities resulting.

The independent comparisons are either unified using the geometric mean proposed by (McCarthy, 1992) or, if the indicators exceeds a user-defined limit, an additional interaction between the stakeholders to achieve consensus for the particular comparisons is necessary. This strategy is primarily applied to consolidate the accuracy of the prioritization with respect to all stakeholders.

We propose the usage of the partitioning strategy for the comparison of requirements by the corresponding domain experts. Therefore, the task of pairwise comparisons of requirements with respect to criteria on the lowest level is distributed among the domain experts. The following pairwise comparisons of criteria with respect to the corresponding higher-level criteria is done by using the consensus strategy.

After the completion of the pairwise comparisons, a consistency check, according to step 3 of the AHP, validates the consistency of the comparisons. If an inconsistency is found (i.e., a consistency ratio above 0.1), the comparisons have to be revised by the corresponding stakeholder. The comparison matrices which are created with a consensus strategy by different stakeholders have to be unified as described in the consensus strategy. An exceeding deviation not necessarily implies that the geometric mean of dissonant comparison matrices is not sufficient for the unification of the matrices, but the corresponding stakeholders should be aware of deviant comparisons and be potentially able to correct the comparisons.

The final steps of the requirements prioritization are the determination of local and global weights (steps 4 and 5 of the AHP). According to Sect. 4.1, the local weights of requirements with respect to criteria on the lowest level of the hierarchy are determined by calculating the eigenvector of the corresponding comparison matrix for related requirements and by assuming a weight of zero for unrelated requirements. The eigenvector method is also used for the determination of all local weights of criteria with respect to their higher-level criterion. Based on the local weights the global weights, i.e., the priorities of the requirements are determined as described in Sect. 3.1.

When requirements are modified after the completion of the prioritization, the corresponding comparison matrices have to be revised by the stakeholders assigned. If the modification of requirements also affects the assessment of related criteria, the comparison matrices of the superior criteria have to be revised additionally.

The determination of the criteria hierarchy as well as the determination of the relations between requirements and the criteria on the lowest level of the hierarchy are the crucial decisions for the achievement of valid priorities. Therefore it is arguable whether a checklist hierarchy utilized during the clarification of requirements (as described in Sect. 4.1) can always be applied for the requirements prioritization. An adaption of the hierarchy may be necessary. However, the relations between requirements and checklist items (i.e., criteria) created in the clarification are highly consistent, since the relations are already utilized to validate the completeness of requirements specifications (Reichel et al., 2011).

5 CONCLUSIONS

The approach for the prioritization of requirements proposed in this article utilizes the analytic hierarchy process (AHP) for an efficient and precise determination of priorities. The overall prioritization problem is decomposed into subproblems that require the pairwise comparison of requirements with respect to single decision criteria of the overall problem. Due to this decomposition, multiple domain experts can participate in the process, either by weighting requirements and criteria of their own domain only or by weighting requirements and criteria in a corporate decision to achieve consensus. We propose several indicators for the determination of a significant deviation of expert assessments. In addition to both strategies for the incorporation of experts, an approach for the reduction of necessary pairwise comparisons of requirements is proposed. The reduction approach is based on the assumption that local weights are equal to zero for requirements which are not related to criteria on the lowest level of the AHP hierarchy. The prioritization approach proposed improves the scalability of the AHP and, thus, can be applied for the prioritization of medium and large sets of requirements.

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REFERENCES

Ahl, V. (2005). An experimental comparison of five prioritization methods - investigating ease of use, accuracy and scalability. Master's thesis, Blekinge Institute of Technology, Ronneby, Sweden.

Azani, H. and Khorramshahgol, R. (1990). Analytic Delphi Method (ADM): A strategic decision making model applied to location planning. *Engineering Costs and Production Economics*, 20(1):23 – 28.

Azar, J., Smith, R., and Cordes, D. (2007). Value-oriented requirements prioritization in a small development organization. *Software, IEEE*, 24(1):32 –37.

Boehm, B. (1979). Guidelines for verifying and validating software requirements and design specifications. In *Proc. of European Conf. of Applied Information Technology*, pages 711–719.

Duan, C., Laurent, P., Cleland-Huang, J., and Kwiatkowski, C. (2009). Towards automated requirements prioritization and triage. *Requirements Engineering*, 14(2):73–89.

Ehrlenspiel, K. (2009). *Integrierte Produktentwicklung. Denkabläufe, Methodeneinsatz, Zusammenarbeit*. Hanser Fachbuch, 4th edition.

Forman, E. and Gass, S. (2001). The analytic hierarchy process - an exposition. *Operations Research*, 49(4):469–486.

Gumienny, R., Lindberg, T., and Meinel, C. (2011). Exploring the synthesis of information in design processes - opening the black-box. In *Proc. of the 18th Int. Conf. on Engineering Design (ICED2011)*, pages 446–455.

Harker, P. T. (1987). Incomplete pairwise comparisons in the analytic hierarchy process. *Mathematical Modelling*, 9(11):837 – 848.

Janis, I. (1989). *Crucial Decisions: Leadership in Policymaking and Crisis Management*. Free Press.

Jiang, L. and Eberlein, A. (2006). Analysis of requirements engineering techniques using clustering. In *Proc. of the 13th IEEE Int. Conf. on the Engineering of Computer-Based Systems (ECBS 2006)*.

Karlsson, J., Olsson, S., and Ryan, K. (1997). Improved practical support for large-scale requirements prioritising. *Requirements Engineering*, 2(1):51–60.

Karlsson, J. and Ryan, K. (1997). A cost-value approach for prioritizing requirements. *Software, IEEE*, 14(5):67–74.

Kruchten, P. (2003). *Rational Unified Process: An Introduction*. Addison-Wesley Longman, Amsterdam.

McCarthy, K. (1992). Comment on the analytic delphi method. *Int. Journal of Production Economics*, 27(2):135–136.

Mead, N. (2008). Requirements prioritization introduction. Technical report, Carnegie Mellon University, Software Engineering Institute.

Mendoza, G. and Prabhu, R. (2009). Evaluating multistakeholder perceptions of project impacts: a participatory value-based multi-criteria approach. *Int. Journal of Sustainable Development & World Ecology*, 16(3):177–190.

Millet, I. and Harker, P. (1990). Globally effective questioning in the analytic hierarchy process. *European Journal of Operational Research*, 48(1):88 – 97.

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H. (2007). *Engineering Design. A Systematic Approach*. Springer London.

Perini, A., Ricca, F., and Susi, A. (2009). Tool-supported requirements prioritization: Comparing the AHP and CBRank methods. *Information and Software Technology*, 51(6):1021 – 1032.

Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. *Environmental Management*, 63(1):27 – 35.

Regnell, B., Hst, M., och Dag, J., Beremark, P., and Hjelm, T. (2001). An industrial case study on distributed prioritisation in market-driven requirements engineering for packaged software. *Requirements Engineering*, 6(1):51–62.

Reichel, T., Rünger, G., Steger, D., and Xu, H. (2011). IT support for the creation and validation of requirements specifications - with a case study for energy efficiency. In *Proc. of the 18th Int. Conf. on Engineering Design (ICED2011)*, volume 10, pages 167–177.

Saaty, T. (1980). *The Analytic Hierarchy Process*. McGraw-Hill, New York.

Schoner, B. and Wedley, W. (1989). Ambiguous criteria weights in AHP: consequences and solutions. *Decision Sciences*, 20(3):462–475.

Shen, Y., Hoerl, A., and McConnell, W. (1992). An incomplete design in the analytic hierarchy process. *Mathematical and Computer Modelling*, 16(5):121 – 129.

Suh, P. (2001). *Axiomatic Design. Advances and Applications*. Oxford University Press, New York.

VDI (1993). VDI 2221 - Systematic approach to the development and design of technical systems and products. Beuth Verlag Berlin.

VDI (2004). VDI 2206, Design methodology for mechatronic systems. Beuth Verlag Berlin.

Wassermann, G. (1993). On how to prioritize design requirements during the QFD planning process. *IIE Transactions*, 25(3):59–65.

Wedley, W., Schoner, B., and Tang, T. (1993). Starting rules for incomplete comparisons in the analytic hierarchy process. *Mathematical and Computer Modelling*, 17(4-5):93 – 100.

Weiss, E. and Rao, V. (1987). AHP design issues for large-scale systems. *Decision Sciences*, 18(1):43–57.

Wiegers, K. (2003). *Software Requirements*. Microsoft Press, 2nd edition.