A. Aurum and C. Wohlin, "Applying Decision-Making Models in Requirements Engineering", Proceedings of Requirements Engineering for Software Quality, Germany, September 2002. Selected for special issue.

Applying Decision-Making Models in Requirements Engineering

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Abstract: The process of requirements engineering (RE) of software systems is a complex problem solving activity involving many stakeholders and many decisions. In order to improve the overall performance level of the RE process, it is important to understand the nature of the decisions made in RE activities. This paper provides a description and explanation of RE decisions by using classical decision making models. It studies the elements of organization-oriented macro decisions as well as process-oriented micro decisions in the RE process. It also illustrates how to integrate decision-making models with RE process models. The integration helps in formulating a common vocabulary and model to improve the manageability of the RE process, and hence support the different stakeholders in the decision-making process related to RE. The main decision-makers in the RE process are identified and illustrations are given from a data set which was collected from a group of software developers.

1 Introduction

Requirements engineering (RE) has evolved into a key activity in software engineering. RE is both an organizational activity and a project activity. It is an organizational activity in terms of deciding what sort of requirements will go into products, and the final requirements that will be released. It is also a project activity when it comes to actually implementing them. This dualism of RE involves a range of decisions that have to be made to ensure effective organizational as well as project decisions. This means that decision-making lies at the heart of RE, and hence it makes sense to try to use the models that have been developed for decision-making in general over the last few decades. The objective of this paper is to map some of the accepted decision-making models to the domain of RE for software systems, and to show how these models can help us understand some of the intricacies of RE.

As already indicated, the process of RE engages many decisions. It is a complex communication and negotiation process involving customers, designers, project managers

and maintainers. The people or stakeholders involved in the process are responsible for deciding what to do, when to do it, what information is needed, and what tools need to be used [12]. The discussion between the stakeholders is generally informal and unstructured and involves many decisions and review points with iterations and design implementation activities. These decisions are generally continuous and in many cases the uncertainties in final cost, schedule, performance, and functionality are inevitable [4].

Since the RE process is a decision-rich problem solving activity, it is valuable to look at the classical theories of decision-making to better understand RE decisions. The decision-making process in management basically involves the identification of a problem, search for solutions, evaluation and selection of a solution and commitment. The process is iterative in nature and considerably similar to the software development cycle. Several researchers have offered using classical decision-making theory when explaining the design process in engineering, including software engineering. Vliegen and Van Mal (1990) report that in many cases designers focus on the creation of proper solutions rather than spending time on redoing design because of poor decision-making. The authors propose using the decision-making cycle in the design process to obtain methodological designing and progress controls. Wild *et al.,* present a methodology where the software development process is modeled as a set of decisions in which each decision relates to a problem solving activity [14, 15]. Evans *et al*., (1997) emphasize that it is important to recognize requirements as design decisions in order to achieve a fully integrated software system [4]. Aurum and Martin (1999) point out the resemblance between the activities involved in organizational decision-making and those in the RE process by referring to the classical decision-making theory [2]. Regnell *et al.* (2001) also discuss the descriptive and prescriptive research issues for understanding and supporting the RE decision-making process [10]. In general, researchers agree that the RE process is a semi-structured or unstructured complex decision-making process [2, 8].

Extensive research is being undertaken to improve the RE process. Growing interest in developing effective approaches to the RE process has directed focus on to analysis of the details of RE activities. This can be achieved by studying the decision-making process in descriptive models, before they can be improved and supportive models can be generated. Thus, if we regard the RE process as a decision-making process, which involves decisions that are continuous and iterative in nature, that leads to design and integration. This means that the analysis of RE activities is possible on the basis of decision-making models.

To interpret RE decisions it is necessary to appreciate the various aspects of the decision-making process. In order to better understand the RE process, this paper (a) overviews decision-making models, (b) examines the decision-making process in RE activities, (c) combines the decision-making models with RE activities aiming to bring a more structured approach to the RE process, (d) gives an illustration using a data set which was collected from a brainstorming session.

2 An Overview of Decision-making Models

The objective of this section is to give a brief overview of decision-making models to provide background analysis of the decision-making process in RE activities. Thus, it is important to introduce some concepts from managerial decision-making first. The following classical views are so powerful that they are still widely used in the design of decision support systems in IT industry [16].

Organizations face different types of decisions that are related to, for example, technology, products and customers. Some decisions are repeated several times during a day or week while others may occur less frequently. According to Simon (1960), based on the way in which the manager deals with the problems that confront them, decisions that are repetitive where the process is clearly identified, are called *structured decisions* [11]. Decisions that are novel where the process is ambiguous are called *unstructured decisions*. These terms refer to extremes on a continuum. This is to say that there may be decisions that are completely structured or unstructured. Others may change from novel situations to repetitive situations, depending on the degree of ambiguity in the solution to the problem [2].

In management science various parts of decision-making activities have been studied in detail by researchers. Anthony (1965) notes three types of decision activities in organizations based on the purpose of the management activity: *strategic planning, management control and operational control* [1] The boundaries between these categories are not distinct. However, in terms of information requirements, they are different from one to another. According to this model, *strategic planning* deals with decisions that are related to organizational goals and objectives. The information concerning such decisions is usually incomplete and the decision-making may extend over a considerable period of time. On the other hand, *management control* deals with decisions related to the identification and usage of resources. In the case of *operational control*, decisions deal with assuring effectiveness when performing operations within the organization. In this study, we refer to these decisions as "*macro decisions*". It is important to note that macro decisions can be structured or unstructured decisions. For instance, an unstructured strategic decision may have some familiar components in its structure. On the other hand, there may be an instance where seemingly routine an operational control decision may end up as an unstructured decision. In short, Anthony's model is concerned with organization-oriented macro decisions.

Another group of studies focus on how managers actually go about their decision-making within organizations. These models focus on more detailed activities in management. In this study, we refer to these decisions as "*micro decisions*". The literature review revealed that there are several models that explain micro decisions. A well-known descriptive model was developed by Mintzberg *et al.* (1976), based on a field study from 25 organizations [9]. This model is related to problem solving activities and it is concerned with process-oriented micro decisions. They found patterns in the decision process and described a model for complex and unstructured decisions. First, they

categorized the decisions according to the stimuli that evoked them along a continuum: opportunities, crises and problem decisions. Then they proposed a model which is more complex than normative models, and which has a structure. In this model the main phases are (1) the identification of problem, (2) development, (3) selection. According to this model, the *identification phase* concerns decisions and has two sub phases: 'recognition' and 'diagnosis routine'. The *development phase* contains two sub phases: a 'search routine' for locating ready-made solutions and 'design routine' to modify those solutions that have been found or to develop custom-made solutions. The *selection phase* contains 3 sub phases: 'screening', 'evaluating' and 'authorization'. The unstructured and open-ended decisions can be influenced by environmental attributes *e.g.* complexity and uncertainty. The internal power structure of the organization, the degree of rationality of decision maker(s), the extent of individual or group involvement, and previous policies or strategies may all have a significant impact on decisions.

In this research, we take the view that the software development process involves decision-rich activities and it is subject to organization-oriented macro decisions as well as to process-oriented micro decisions. Before studying the decision-making process in RE activities, it is worth examining RE process models. It is important to note that the issues that affect individual and group decisions, such as negotiation, consensus building, process of prioritization, judgment of choice, rationality or bounded rationality are outside the scope of this paper.

3 Requirements Engineering Process Models

There are only a few organizations that have explicitly defined the RE process, and even fewer that model both the organizational and the project (or process) levels. In many cases the process is an unstructured problem solving activity. In unstructured decisions, the alternatives are generally vague, difficult to compare and contrast or prioritize, or cannot be easily evaluated with respect to organizational goals and objectives. On the other hand, there are several normative models that explain the RE process by describing how the RE process *should* work, rather than how it *does* work [3, 7, 11]. The strength of these models lies in delivering the 'best' process results for activities that make up the process, and the order in which issues are attended to. These models take into account organizational goals and objectives. Sommerville and Sawyer (1997) point out that normative models do not transfer well from one organization to another [12]. They emphasize that in order to define a good RE process, it is important to involve stakeholders who are actually involved in the RE process itself.

Macaulay (1996) argues that the model of the RE process depends to a large extent on the customer-supplier relationship and offers seven different process models for different situations [7]. Macaulay also describes a generic model as follows: (1) concept, (2) problem analysis, (3) feasibility and choice of options, (4) analysis and modeling, (5) requirements documentation. Macaulay points out that each phase is subject to validation.

Validation results in a form that will focus attention on open issues that can be reviewed with those who provided the information.

In this study we randomly chose Macaulay's RE descriptive process model as a guideline. According to this model, the product *concept*, which might be an improvement or enhancement of the product, triggers the RE process. In many cases, it triggers the organizational level RE process, and as the concept moves into a specific project it triggers the RE process on the project level (or development process level). During the *problem analysis phase*, an understanding of the nature of the problem is developed. Another key aspect is generating an appropriate representation of the problem, which helps the requirements engineers in identifying the set of alternatives that are generated during problem analysis and solution. The third phase, *feasibility and choice of options*, is concerned with evaluating the costs and benefits of alternative solutions and negotiations. The fourth phase, *detailed analysis and modeling*, is concerned with a more detailed analysis of the requirements. Once this process is finished, then the *requirements specification document* can be completed. As pointed out earlier, in this model a validation process takes place at the end of each phase.

Being an effective software developer does not imply that the person necessarily understands his/her decision-making process. In order to improve the overall level of effectiveness the RE process, it is important to understand the nature of the decisions made. One approach is to record past cases of activities in the RE processes, and analyze the decisions in each activity. Another approach is to decompose each process into sub-processes and study the decisions within these sub-processes. In each case it is important to consider the stakeholders' point of view when comparing, generalizing and classifying decision models into different categories. The following section, uses Macaulay's RE process model, to takes the latter case and examine the decisions involved in the RE process in light of a management context. The advantage of recording each activity and decision is that, this provides structure for what is often an unstructured process in the early stages of RE activities. For instance, if a problem is resolved and the decision is recorded then the project manager (PM) will have a better idea of project progress. If the problem is not solved, then PM will focus on allocating human and non-human resources to solve the problem. This way, the PM will have increased control over the scheduling of activities [14]. In other words, this approach gives us a more efficient structure for managing RE processes. This structure can hopefully be used as a requirements control throughout the life cycle.

4 Combination of Models

In this section we examine RE decisions. To better understand RE decisions the elements of both micro and macro decisions are projected on to the RE process as illustrated in Table-1. Section 4.1 discusses the mapping of macro decisions onto the RE process and Section 4.2 presents the mapping of micro decisions onto the RE process. Macro and

micro decisions are of course not independent and in many cases they are interleaved. However, here they are presented separately to illustrate the emphasis of the decision-making models map to the activities in a RE process.

4.1 Macro Decisions in Requirements Engineering Process

Anthony's model is organization-oriented and demonstrates macro decisions. Each phase in the model has components that may have structured-to-unstructured decisions. More specifically, we believe that in the RE process 'strategic decisions' are primarily an organizational issue, 'management control decisions' involves a project management view, whereas 'operational control' decisions are about implementation of requirements. The following details are identified from Table 1.

Table 1. Mapping Requirements Engineering Process Model on Classical Decision making Models

Model	**Classification**						
Anthony's Model	Strategic Planning		Management Control (Tactical)		Operational Control		
Mintzberg et al.'s Model	Problem Identification		Development Phase		Selection Phase		
	Recognition Rt.	Diagnosis Rt.	Search	Design	Screen	Evaluat. Choice	Authorization
Macaulay's Model	Concept (Problem Recognition)		Problem Analysis		Feasiblit &Choice of Options	Detailed Analysis & Model.	Req. Doc.

- ***Strategic Decisions:*** The activities involved in the first phase of RE, known as "concept", include components of the strategic decisions and the decision-making is generally unstructured. It is important to align the RE process with the business and technical goals of the organization [5]. At this stage, as part of initial preparations, information is gathered from the stakeholders to better understand the problem and to draw the system boundaries. It is important to seek information about potentially important aspects of the problem. This leads to a way of relating pieces of information to each other in order to better understand the product in a business context. In return, team members have a better understanding of the company business as well as business opportunities.
- ***Management Control:*** The second phase, known as "problem analysis" also involves many uncertainties. The objective is to clarify an initial set of fuzzy requirements and to generate some possible solutions. Thus, understanding and developing solutions requires the identification of alternatives, and assessment of relative costs and benefits of each alternative. The existence of sufficient organizational resources are

crucial for software developers during RE activities. The decision maker is constrained by the availability of key resources, *i.e*. human and non-human resources. Examples of decisions may involve the following questions: What kind of development and implementation strategy will be taken? What sort of plans exists for the project management? What are the planned benefits? What are the resource reductions? What are the product enhancements? What priorities are placed upon the achievement of these benefits?

- ***Operational Control:*** The activities involved here are mainly routine and more structured decisions, which are concerned with the implementation of requirements. The information involved in this stage is quite detailed and arises from sources of organization. Decision makers may consider several tools and decision aids when making decisions.

4.2 Micro Decisions in Requirements Engineering Process

Mintzberg's model is a descriptive model and identifies micro decisions made in a managerial context. The following points are identified from Table-1.

- ***Problem Identification:*** It can be easily seen that there is almost one-to-one relationship between the activities of the first phase of the RE process model, '*concept*' and the first phase of Mintzberg's model, '*problem identification*'. The information is collected and aggregated mainly from stakeholders. This information heavily involves the stakeholders' point of view, goals, objectives, constraints and agendas. Identifying and integrating different stakeholders' points of view is a critical process and affects the success of subsequent activities of the RE process. If one perspective is neglected then the system may be viewed as a failure by the stakeholders. Thus, there are many decisions made about the physical characteristics of the system.
- ***Development Phase:*** To better understand the problem, developers analyze the problem and generate potential solutions. There are several tools available for software developers to analyze and model the existing system. These tools quantitavely analyze decisions with uncertainty, for example, by using the expected utility theory. Once an appropriate set of alternatives has been generated, developers typically examine the possible consequences of each option and the likelihood of each occurring. A cost-benefit assessment of the requirements is made.
- ***Selection Phase:*** The ability to make effective decisions under uncertainty is a critical aspect of management. During the phase of feasibility and choice of options, decisions on requirements entail challenging questions concerning the description of alternatives and the estimation of outcomes, both of which require inference and prediction. An example may include the following question: What are the costs and benefits of collecting additional information? During detailed analysis and modeling, decisions are concerned with individual values and preferences as well as the process

of choice. There is no simple model that describes how preferences of individuals are determined, but there are few decision aid tools.

5 A Study: RE Decisions

To better understand the RE decisions two brainstorming sessions were carried out. The first session was carried out immediately after a two-day RE workshop attended by four experienced software developers, including the authors of this article. These developers participated in a half hour face-to-face brainstorming session to identify decisions relating to RE activities. A list of 37 RE decisions was created at the end of this session. The intention was to develop a list that was as extensive as possible given the time and resource constraints. The details of the outcome of this work can be found in Regnell *et al.* (2001). In the second session, the authors of this article studied the list of 37 decisions in further detail, identifying three types of decision categories: (1) Product Scoping Decisions, (2) Activity Release Decisions, (3) In-Process Decisions. Product scoping is concerned with decisions on whether to include certain functionality in a given product. Activity release decisions are concerned with deciding what to include in a specific release of a given product. Finally, the in-process decisions are the decisions made within a project to ensure that the requirements for that project are fulfilled or handled. In order to examine the role of stakeholders in the RE decisions, a 'Stakeholder versus RE Decisions' matrix was created. Then, each decision from the list was assigned to the matrix. In other words the decisions from the list were categorized based on the decision types and type of the stakeholders.

Our findings showed that during the first brainstorming session, participants were mainly concerned with the decisions made by Customers, Requirements Engineers, Product Managers and Project Managers. Table-2 illustrates the RE decision types from the stakeholders' point of view using Macaulay's RE process model. The asterisks in the table illustrate the number of decisions identified. The number of decisions is of interest from the point of view of understanding when different stakeholders are involved in the decision-making process. However, the exact number is of less interest at this point, because the main objective here is to look at the mapping between RE and decision-making models.

5.1 Analysis-1

There is a relationship between the stakeholders' involvement and the RE activities as seen in Table-2. The following points have been concluded from Table-2.

Table-2: Stakeholders versus Decision Type Matrix

RE Process Model	**RE Processes**				
Macaulay's Model	Concept	Problem Analysis	Feasiblity & Choice of Options	Detailed Analysis & Modeling	Req. Document.

Stakeholders	**Product Scoping Decisions**	**Activity Release Decisions**	**In-Process Decisions**
Customer	**	*	
Product Manager	***	*	*
Requirements Engineer	****	******	********
Project Mng		****	**

Stakeholders' Decisions on Product Scope. Decisions in the early stages of RE activities are related to product itself. From Table-2 we see that these decisions are heavily made by the Customer, the Product Manager and the Requirements Engineer. It is important to note that Table-2 does not illustrate which stakeholders provide the information; instead, who participates in the decision-making process. Although the Project Manager is responsible for running the project and for supplying sufficient data to the Product Manager and Requirements Engineer, the Project Manager is not the main decision-maker at this stage.

Stakeholders' Decisions on Activity Release. During activity release, from Table-2 we see that the Project Manager and the Requirements Engineer are deeply involved in the decision-making process, whereas the Product Manager and the Customer participate significantly less in the decision-making process.

Stakeholders' Decisions on In-Process. Table-2 shows that at this stage the main decision-makers are the Requirements Engineer and the Project Manager. The Requirements Engineer is responsible for monitoring and supporting the implementation process. The Project Manager focuses on completing the project on time. On the other hand, the Customer's and the Product Manager's involvement in decision-making is significantly less than the other stakeholders.

Decision-Making Models and RE Models. It can be concluded that the RE model proposed by Macaulay (1996) rather easily can be mapped onto the decision-making

models available from the management literature. This means that the decisions-making models may be used in RE to obtain a common vocabulary and description of the process related to decision-making in RE for software systems. One might argued that whether we would be able to obtain the same results with another model. Although there are many available process models, their fundamental activities are fairly similar, so the choice of process model is viewed as not affecting the mapping process.

Table-3: Mapping Stakeholders Decisions on Decision-making Models

Model	**Classification**						
Anthony's Model	Strategic Planning		Management Control		Operational Control		
Mintzberg et al.'s Model	Problem Identification		Development Phase		Selection Phase		
	Recognition Routine	Diagnosis Routine	Search	Design	Screen	Evaluation Choice	Auth.
Stakeholders	**Product Scoping Decisions**		**Activity Release Decisions**		**In-Process Decisions**		
Customer	**		*				
Product Manager	***		*		*		
Requirements Engineer	****		******		********		
Project Manager			****		**		

5.2 Analysis-2

To better understand RE decisions from the stakeholders' point of view, the elements of both micro and macro decisions are projected onto the RE process as illustrated in Table3.

Macro and Micro Decisions on Product Scope. At a macro level, decisions related to product scoping are strategic decisions. The Product Manager is responsible for the product road map and strategic direction of the product from an upper management perspective. They do not foster new requirements, rather they make decisions on the ones that are already elicited. At a micro level, the information is elicited from stakeholders to better understand the requirements of the product. Thus, the Customer is one of the main decision-makers at this stage. Since the Requirements Engineer is responsible for collection, organization and management of requirements between stakeholders, they are heavily involved in the decision-making process in all activities of the RE process from

the start to the end. Examples of such decisions include: Should this requirement be accepted as a candidate or sent back to the source? Is the requirement valid for the product? How does the requirement fit with the business goals?

Macro and Micro Decisions on Activity Release. Decisions related to activity release are tactical decisions. At a micro level, decisions are mainly made by the Requirements Engineer whose task is to analyze the problem and develop alternative solutions. At a macro level, decisions are mainly made by the Project Manager whose task is to allocate the resources. Examples of decisions include: How important is the requirement? Who is interested in the requirement? How does the requirement depend on other requirements? How do we solve conflicts between different requirements?

Macro and Micro Decisions on In-Process. Although there might be some elements of unstructured decisions, In-Process decisions are generally more structured than strategic decisions made in the RE process. The Customer's involvement at this stage is significantly less than at other stages. The product manager may still try to make decisions such as: How to make trade-off between "technology push" and "market pull"? The Project Manager, whose responsibility lies both in the areas of project deadlines for release scheduling and the resource needs associated with completion of the project on time and on budget, is one of the main decision-makers. The other main decision- maker is, of course, the Requirements Engineer. Examples of decisions include: Could the requirement be discarded? Is the requirement valid for the product? How do we trace the requirements? Are individual requirements (or the whole RE-document) fit for a specific purpose, e.g. testable, & designable?

Decision-Making Models and Stakeholders' Decision. In this section, we have presented a decision taxonomy that projects micro and macro decisions in RE activities; namely product scooping, activity release and in-process decisions. It is clear from the analysis that these three categories of decisions are easily mapped onto the decision-making models. Thus, it emphasizes the usefulness of these models for RE. The decision taxonomy, while not complete or detailed, provides a good foundation for discussing RE decisions from stakeholders point of view.

6 Conclusion

The manageability of the requirements process is important as the quality of the process affects the quality of the product. By studying the decision-making process in RE activities in more detail, it is possible to conduct an analysis of the RE process and its underlying decision-making processes. By focusing on improving the decision-making in the RE process, software developers are more likely to achieve success in the

development process. In other words, if software developers' understanding of the decisions they make is improved, and if these decisions are well made, the developers can proceed with confidence, and efficiently design a quality product that will meet stakeholders' requirements.

The paper has explored the issues in the previous paragraph. The main contribution of this paper was being able to map a requirements process model to classical decision making model or vice versa. In addition to this the following points are illustrated:

(a) It presents an approach to understanding RE decisions by using classical decision-making models.

(b) It emphasizes the importance of several aspects of decision making in the RE process.

(c) It illustrates how to integrate decision-making models with RE process models to improve the manageability of the RE process.

(d) It demonstrates, based on preliminary analysis, a simple decision taxonomy that is capable of explaining the stakeholders' involvement in the RE process.

While the decision taxonomy may seem intuitive, much more research remains to be carried out. The results have limited generalizability as a small sample was used for the taxonomy. We need a better understanding of what it takes to generate adequate management support and stakeholders' participation in the RE process. Further research using larger samples is required to refine the taxonomy and render it more readily usable.

A question that arises from the new understanding of RE decisions is how to best manage the RE activities as a decision-making process? The complexity of the activities involved in the RE process call for a need for organizations to coordinate the decision-making process and make the decisions and the roles played with respect to decision-making in requirements engineering more visible. By mapping the RE process model to the decision-making models, we are able to pinpoint the different roles and responsibilities and hence support an organization in structuring their decisions in the RE process. Once an organization has identified the relevant RE activities, the suggested 'mapping' acts as a guideline for deciding what sorts of decisions need to be made. This mapping also indicated the key areas on which the different stakeholders involved in the RE process should focus. It is also important to document the discussions and decisions related to both the organizational and project levels. Finally, there is a need for a continual tracking of RE decisions to ensure that they are conducted in a way that supports the business goals. The further research will study the decision making process for customer based, market-driven and Internet enabled complex systems.

Acknowledgements

We would like to thank Dr. Barbara Paech at Fraunhofer IESE, Germany, and Dr. Björn Regnell at the Dep. of Comm. Systems, Lund University in Sweden for many fruitful discussions on the decision-making issues and in particular for contributing in the first

brainstorming session. We also like to thank Dr. Meliha Handzic, Adrian Gardiner and Irem Sevinç at the School of Information Syst., Tech. and Mang., University of New South Wales, Australia, for reviewing this paper and providing very useful comments.

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