Towards a Model of Decision-Making for Systems Requirements Engineering Process Management

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Abstract:

This paper presents a model of the decision-making behaviour of stakeholders in the requirements engineering (RE) process. Poorly defined requirements cause projects to fall behind schedule, go over budget and result in poor quality system specification. Many systems (software) development organisations are attempting to increase the effectiveness of the RE decision-making process by incorporating improvements aimed at better understanding, improved communication and more effective management.

Little research has been published on factors that influence the decision-making behaviour of the system's stakeholder in RE process management (REPROM). In developing such a model the paper fills an important gap in both the requirements engineering and decision-making process literature. Research in this area is vital if both requirements engineering managers and software development organisations are to cope with the rapid pace of organisational systems change and reap the benefits of an effective RE process.

The paper concludes that current management and decision-making models fail to make sufficient allowance for the complexity of requirements engineering stakeholders' business goals and aspirations in a dynamic software development environment. The paper suggests that the model provides both a foundation for theory building on decision-making in REPM and a basis for improving decision-making through the use of learning/training environments.

1. Introduction

Although there is a considerable body of literature on managerial decision-making, little research has been published on the factors that affect the decision-making behaviour of RE managers. Research on the latter has tended to examine general changes in their role and skill profile, rather than focus specifically on decision-making (Cheyney et al; 1989). As RE stakeholders are involved in making decisions about a resource that has a major impact on organisational survival and effectiveness, an understanding of the factors that affect their decision-making behaviour is vital if software development organisations (SDO) are to remain competitive.

This paper attempts to develop such an understanding by proposing a framework that identifies the factors that influence decision-making behaviour. Since there is no empirical research on decision-making in RE, the first part of the paper draws on the management literature to identify relevant factors and applies these in an RE context. An initial model of the factors that influence decision-making is then presented. The paper then takes this analysis further by focusing on the impact of requirements changes on decision-making. The final part of the paper examines how the model presented could be used to improve decision-making and proposes a programme of future research. To place the discussion in context, the section below defines what is meant by the terms 'requirements engineering' and 'decision-making' and 'requirements engineering effectiveness'.

1.1 Definition of Terms

The term *requirements engineering* is used to describe a systematic process of developing requirements through an iterative co-operative process of analysing the problem, documenting the resulting observations in a variety of representation formats, and checking the accuracy of the understanding gained (Pohl, 1993). RE is a transformation of business concerns into information system requirements (Pohl, (1993), "WHAT" the system needs in order to achieve the organisational goals.

Requirements engineering process, is the other key term used to describe the decomposition of RE into interacting non-linear activities. These proceed from informal, fuzzy individual statements of requirements to a formal specification that is understood and agreed by all stakeholders.

'Decision-making', is usually defined as the act of choosing between alternative courses of action (Flynn and Williams, 1999). Effective decision-making occurs when decision makers select the "best" course of action based on the information available at the time (Cooke and Slacke, 1984; Drummond, 1993). Since virtually every aspect of management involves some decision-making, it is important to identify the different types of decisions managers take. Anthony (1965) distinguishes between operational, tactical and strategic decisions. Tactical decisions are taken by managers at the lowest level of the organisation and concern problems that arise on a daily basis; tactical decisions are taken by requirements project and process managers and relate to the operation of the main business functions of the SDO; strategic decisions are the responsibility of senior management and concern the future direction of the SDO. The nature and complexity of decision-making varies according to the level of management. Although changes in the macro environment have increased the complexity of decision-making at all levels, managers at higher levels of the SDO are more likely to be involved in dealing with problems that are 'non-routine', i.e. require higher levels of judgement than managers at lower levels where the problems that arise can often be dealt with by evoking 'routine' procedures (Simon, 1960). As will be illustrated, requirements engineering stakeholders are more likely to deal with problems that require 'non-routine' decisions.

The final term *requirements engineering effectiveness* is used as the measure of the accuracy and completeness with which the RE process goals are achieved. The effectiveness dimension is captured in such a way that it can be translated into meaningful quantitative statements concerning quality, cost and time schedule.

The rest of the paper is organised in six sections. In section 2 a review of the management literature, is given to provide a context of which decisions are made. The background to the requirements engineering process management is discussed in section 3. In section 4 aspects of the decision-making environment for RE process stakeholders is discussed. Section 5 discussed potential knowledge creation and management in the requirements engineering process, while section 6 discusses the advantages of using system dynamics /system thinking in visualising, (through a model of the RE process), factors influencing decision making. Section 7 highlights initial observations from this research and considers some future directions to further improve the decision making process of the requirements engineering process.

2. Review of the Management Literature on Decision-Making

A review of the management literature on decision-making suggests that individual, peer, group, and organisational and external factors influence decision-making behaviour. At the individual level, studies indicate that differences in perception, attitudes, values and beliefs and in personality can lead to different approaches to decision-making (Argyris, 1966). Flynn and Williams (1999) report on the use of Jung's classification of personality types to distinguish different styles of decision-making. Managers who score highly in terms of Jung's 'thinking' and "intuitive" dimensions are likely to adopt a different approach to decision-making than those managers who score highly on the 'feeling' and 'sensation' dimensions. The former tend to be analytical and creative in their decision-making; the latter tend to emphasise social, emotional and practical issues. The importance of personality, perception and other 'subjective' factors challenge traditional models of the decision-making process, which suggest that individuals follow a logical sequence of steps in seeking a solution to a problem. Research by March and Simon (1958) indicates that, in reality, the decision-making process is much more complex and that individuals will often make decisions that 'satisfice', i.e. meet the minimum criteria for dealing with a problem rather than 'optimise', i.e. select the best and most logical course of action. Part of the reason is that they lack the information processing capacity necessary to assimilate all the relevant information and weigh the alternatives.

Janis's (1989) research on factors affecting the decision-making of leaders indicates that individuals are often influenced by the views or likely reaction of their personal network: "Most policy makers are highly motivated to take account of affiliative constraints ... they want to maintain or enhance their power, compensation or status within the organisation and to continue to obtain social support from their personal network" (Janis, 1989, p. 45). The desire for approval, and the need to exercise or maintain power, may thus influence decision-making behaviour. The work of Roethlisberger and others demonstrates that individual decisions regarding the level of output may be determined by the norms of the group (Roethlisberger and Dickson, 1939); Stoner's research suggests that groups tend to take more courageous decisions than individuals acting alone (Stoner, 1968) while Janis's research illustrates the impact of group norms and pressures to conformity on decision-making in critical situations (Janis, 1971).

In SDOs, like other organisations, decision-making is influenced by the mission of the organisation, its level of maturity, structural and cultural factors; and internally and externally generated change processes. With regard to mission, the types of decisions taken by managers obviously reflect the nature and purposes of the business. Managers who work in software development organisations for example are likely to take decisions that are similar to those in financial services or manufacturing firms both because the core business is the same and because the emphasis on profit generation is likely to lead to a same set of priorities. With regard to organisational maturity, research indicates that the longer an organisation has been established the more likely it is to have developed complex procedures for handling problems and decision-making. It has been suggested in Flynn and Williams (1999) that such procedures may become so ingrained that they handicap the manager's ability to respond to volatility of requirements or to customer's changing requirements. Williams, Hall and Kennedy (1999) suggest that as the requirements engineering process progresses, the ability to identify creeping requirements diminishes due to lack of decision support tools to manage the process. Recently established organisations will not have had the time to develop these procedures; hence managers may respond more flexibly to change. This argument may be challenged on grounds that older organisations will have had more experience of controlling and monitoring organisational processes and may have developed procedures that can transmit 'shared corporate experience' of change to managers including requirements managers. Thus, the individual's and SDO's capacity to learn may be more important in the decision-making process during times of requirements change than the software process maturity of the organisation procedures.

Structural and cultural factors also may have a significant impact on the decisions taken. The structure and culture of an organisation are influenced by its corporate and departmental strategies. These help to define the organisation's goals and guide future development. Decisions regarding the strategic direction of the organisation influence the business rules that guide decision-making at lower levels of the organisation. Thus, if senior managers change strategic direction, an act that necessitates changes in the organisation's business rules, decision-making at every level of the organisation will be affected. While this may have a significant effect on decision-making in the long-term, it is unlikely to produce significant changes in the short-term because of the length of time it takes to alter policy guidelines and software development business rules and to change established procedures for decision-making. Changes in departmental strategies may have a more immediate and direct impact on decision-making at lower levels of the organisation, as these can generally be actioned more quickly. Of course, changes in departmental strategies may influence other departments within the organisation and impact on decision-making at the corporate level. Again, it is likely to take time for changes in direction at departmental level to influence decision-making in other functional areas and at corporate level. It is these time delays that may help explain the emergent behaviour of many requirements engineering processes in different software development organisations (Williams, Hall and Kennedy, 2000).

The quality and availability of information has a major impact on the SDO's capacity to respond to requirements changes and customer satisfaction on decision-making. It seems reasonable to assume that RE managers who have access to high quality information and used systems to support decision-making are likely to make more effective RE process decision than those who do not have such systems. Another most important factors that influences decision-making in RE management is the change in external environment (Cooke and Slack, 1984). In recent years major changes in the economic and political environment in which firms operate, the introduction of new "enabling" technologies, changes in social attitudes and demographic patterns combined with the general growth of competitiveness have resulted in dramatic changes in the strategic direction of many organisations (Doherty and Nyham, 1997). Decision-stakeholders at all levels of the SDO have had to cope with an increased rate of change in requirements, volatility, and uncertainty. Research suggests that decision-making ability may decline under such conditions (Taylor, 1984).

3. The Requirements Engineering Process Management

Requirements Engineering (RE) process management and improvement has become an important field of research in requirements engineering, a subset of systems (software) engineering. From the early 1970s RE was established as a distinct field of investigation and practice. In 1977 and 1991, special issues of IEEE Transactions on Software Engineering were devoted to RE and in 1993 a bi-annual conference on RE was instituted (Ficas and Fickelstein, 1993). In 1996, the RE Journal published its first volume (Loucopoulos and Potts, 1996). By the term "engineering" we mean managing, costing, planning, modelling, analysis, implementing, testing and maintaining the systems requirements. As an engineering discipline the RE process needs paradigms, which are underpinned by models and theories.

Although substantial progress has been made in terms of analysis methods, techniques and tools used within the RE phase of systems development, little attention has been paid to understanding of the management and effectiveness of the RE process. The designers of information systems (IS) and programmers often begin designing and programming the incumbent system too early, before they actually understand the users' or stakeholders' requirements. Since designing and programming systems is very expensive (Boehm, 1981), ill-defined requirements (Bubenko, 1994) cause projects to fail behind schedule (Abdel-Hamid and Madnick, 1991; Macualay, 1996) and over budget. For the future system to be effective it has to have a balance between the technical worldview of designers and programmers, and the social worldview of users and customers (Williams and Kennedy, 1997). Current research efforts have been heavily criticised as failing, in many cases, to improve user / customer understanding of RE problems and offering poor return on investment. Improving the RE process research effectiveness, is a key issue for the understanding problems that meet the expectations of systems stakeholders, who expect these systems to be developed on time and within budget (Loucopoulos and Karakostas, 1995; Boehm, 1981) and with the "right" quality (Davis et al, 1993). There is a time-lag between the developer gaining an understanding of the systems' technical potential and the user understanding it. Curtis et al, (1988) in perhaps the most cited study of software engineering in real organisations, highlight the significant causes of problems in RE process:

- The thin spread of applications domain knowledge;
- Fluctuating and conflicting requirements;
- Communication and co-ordination breakdowns.

In addition to the above three problem areas, Williams, Hall and Kennedy (2000) demonstrated recently the need for data collection methods to support the RE process management.

Various approaches have been proposed for evaluating the success of RE process. Newman and Robey (1992) found the process modelling approach very appealing, particularly its applicability with respect to complex dynamic RE process. User/customer satisfaction has also been widely used as a measure of RE process success (El Emmam and Madhavji, 1995) The perceived utility is obtained by seeking the opinion of the customer/user during a requirements review meeting about both the requirements and the whole process. Melone (1990) has discussed the limitations of this approach, which is highly subjective; requiring users to assign numeric value on entities (such as attitudes) which cannnot be directly measured (Clark and Augustine, 1992). A clear link between user satisfaction and process effectiveness as a measure of RE process success has been difficult to establish.

In information systems studies some researchers have used a general systems approach to assess the value of information systems (Swanson, 1971). This approach has been demonstrated by Morecroft (1979) and later tested by Jones (1983). The general systems approach uses simulation modelling in an attempt to overcome the limitations of analytical techniques. This approach has also been used in software development process (Abdel-Hamid and Madnick, 1990) and in product development process (Ford and Sterman, 1996), but it has not been specifically directed at requirements engineering process. Wolstenholme et al (1990) have used simulation modelling in evaluating an information system in the Defence sector. They proposed a holistic framework that focused on the effectiveness of an entire Information Systems process. The approach we are applying in this paper is similar to the above, but differs in that we are focusing on patterns of behaviour in RE process, while they focused on information attributes and decision-making. The use of simulation modelling by Wolstenholme et al (1990) confirmed the usefulness of the system dynamics methodology in assessing value of complex information. In order for the modelling methodology to be useful in RE process performance we must identify relevant entities, variables and attributes, their interaction, relationships, and dimensions, and test the RE process performance.

Decision-making in RE process management, particularly in large-scale projects, is a complex process. As the research question become more complex and precise, the activities in each phase of RE must become correspondingly more demanding, precise and controlled. A great deal of work has been carried out on RE process-based approaches to requirements engineering (Pohl, 1993), but very little has been done in utilising dynamic process-model based tools. This paper contributes to developing such an understanding by proposing a framework that facilitates understanding of the RE process management and improvement amongst decision stakeholders.

Many requirements specification frameworks reported in the literature provide insight into the problem of specifying requirements. These frameworks cannot be regarded as methods of analysing information needs and determining their information requirements or shading light on decisions taken, due to the fact that coverage of this domain tends to pay more attention to specification language issues or form part of a wider systems development method. Social aspects have largely been ignored where organisational, strategic and human “soft” communications issues are being examined (Mumford, 1984; Jirotka and Goguen, 1994). Many authorities (Wieringa, 1995, Macaulay, 1996; Loucopulus and Karakostas, 1995) have indeed identified problems with current RE process and, while most observers will acknowledge that there are deficiencies in the current decision-making practice, there is no consensus on what the deficiencies are. Systems failure has been blamed on poor requirements engineering process (Macaulay, 1996; Zahedi, 1995; Fickelstein, 1989). This is mainly due to poor understanding of domain knowledge and poor use of methods, techniques and tools. Macaulay (1996) reports of inconsistency in positioning of requirements engineering process within the various software development life cycle models.

Both academia and practising managers are concerned with the development of software or systems that are within cost estimates, and on schedule, with a high quality product that fulfils the requirements. Boehm (1981) provides the most comprehensive empirical evidence on the importance of the requirements engineering process. In an analysis of 63 software projects performed at TRW, he demonstrated that the relative effort cost and effort spent on requirements analysis grows disproportionately as the size of the project increases. In terms of quality and cost specifications, a study of 8,380 applications development effort (Standish Group, 1986) found that cost overruns averaged about 189% of the original estimate and 31.1% of development efforts were cancelled. Of the developments that were completed:

- only 16.2% delivered initially specified functions
- the remaining 53% delivered, on average, about 61% of the initially specified functions.

In large companies, only 9% of projects come in on time and on budget while the average time overrun is 222 % of the original estimate.

Fickelstein (1989) reports that a disproportionately large proportion of errors in IS development were due to faults in requirements engineering. Figure 1 (below), shows that errors in information systems have the following distribution: Incomplete requirements (RE) 56%, Design (DN) 27%, Coding (CG) 7% and Other 10%. The high error percentage due to incomplete requirements confirms the earlier assertion on the poor methods used to elicit and analyse requirements.

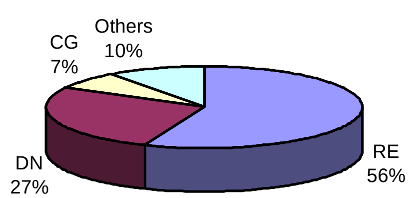

Figure 1. Distribution of Error Source (Finklelstein, 1989)

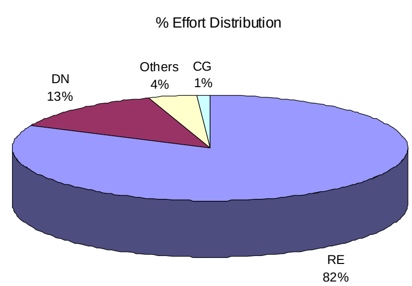

Figure2. Distribution of Effort to Error Sources (Zahedi, 1995)

Finklelstein's (1989) analysis in Figure 1 is also confirmed by Zahedi (1995). She reports that correcting errors in IS from various sources does not take proportionally the same amount of effort. Figure 2 (above) provides further evidence that errors due to incomplete requirements analysis take a disproportionate larger effort share: Incomplete requirements (RE) 82%, Design (DN) 13%, Coding (CG) 1% and Others 4%. The empirical evidence presented confirms the deficiencies with the current RE process effectiveness. The problems of RE and process management are complex and may need the use of methodological pluralism as a value-added approach, in order to facilitate communication among stakeholders and understanding of information needs. There is a lack of agreement on the definitions of requirements engineering. Macaulay (1996) and Castello and Liu (1995) argue that requirements engineering and RE process are to an extent situation dependant. For a RE process to begin a situation trigger is necessary. The RE process trigger may be changes in user information needs, incremental improvements to the existing system, change in management decision making rules, or change in legal requirements.

Whatever the reason for the RE process trigger, the complexity inherent in RE leads to the need to develop an understanding of the nature of the problem. This complex situation makes it very difficult to define the tasks and the skills needed by the requirements engineer. The different designations used by organisations for the requirements engineer means that different knowledge and skills were being applied to the requirements engineering process. This is a major source of the problems (solving a wrong problem) in RE process management. The above analysis provides a basis for the need for new approaches to RE process effectiveness problem solving. It is critical to appreciate that systems are complex socio-technical systems, largely influenced by human system and management culture. From this perspective, it is therefore necessary to use methodological pluralism or new problem solving approaches that support effective capture and synthesis of cost, schedule and quality in the RE process (Galliers, 1984; Williams and Kennedy, 1997). Traditional process modelling approaches are flawed in a number of ways and cannot facilitate an effective decision-making, let alone the understanding of the RE process. Gaining an understanding of the RE process and the factors that lead to its effective completion is the prerequisite for improving the RE practice and the decision-making process (El Emmam and Madhavji, 1995; Newman and Robey, 1992). The next section explores how concepts developed section two and three can be applied in a decision-making environment

4. Decision Making Environment in Requirements Engineering Process

Controlled RE process are stable processes, and these in turn should enable SDO to predict process performance. Predictable process performance in turn enables SDO to prepare achievable plans, meet cost and schedule commitments and deliver the RE specification with acceptable quality and consistency. In cases where of a controlled RE process is not capable of meeting customer requirements or the SDO's business objectives, the process is then improved through a decision-making process or deleted. Fenton and Pfleeger (1996) provide measurement guidelines into how to improve visibility with which the processes, products, resources, methods and technologies of software development relate to one another. Performance measurement allows managers and requirements engineers to monitor the effects of activities and the volatility of requirements on the whole RE process. Fenton and Pfleeger (1996) contend that measurement is useful for:

- Understanding,
- Establishing a base line, and
- Assessing and predicting.

Where actual measurement differs significantly from the plans based on business goals, action should be taken as early as possible to control the final cost, time and quality of the system specification. Where a process is out of control, use of statistical control methods helps identify process or attribute variability. Causes of parameter variability can then be identified and decisions taken to correct it so that stability and predictability can be achieved. RE process controllability often leads to differing measurement needs and decision-making information requirements. In the RE process many stakeholders are interested in different aspects of the process, its output products or its products as demonstrated in Table 1. These aspirations may influence the resulting product and its quality. Paradoxically, a RE process demand greater understanding of the domain knowledge, the experience of analysts and training in the use of tools aids greater understanding, this should lead to fewer errors and improved quality in system specification. Improvements in technological development has facilitated the automation of the RE tools; however this automation has focussed on documentation of requirements rather than the whole process including process management and organisation (Williams, Hall and Kennedy, 1999; Williams and Kennedy, 1999). This shortcoming has meant that requirements stakeholders do not have a whole picture of the process, its cost, schedule and quality and therefore understanding is not complete so as to facilitate effective decision-making and process improvement.

The fears and aspirations illustrated in Table 1, shape the success or failure of the RE process decision-making and process improvements.

Table 1: Stakeholders in a RE Process [Adapted from Gilles and Smith, 1994]

Stakeholder	Aspirations and Interests
Requirements Engineer	Wants a tool that makes their job easier, more statisfyicing and more productive.
Customer/User	Wants a system specification with minimum errors that will describe the system they want with lowest price and in the shortest time. Wants usable system, with fewer errors
Project/ Process Manager	Wants to deliver on time with the right specification quality and to satisfy the customer.
Quality Manager	Wants to ensure that the delivered system specification is error-free and meets the aspirations of the customer.
Senior Management	Wants to see a return on investment, increased productivity, increase in quality of products and services and fears the possible failure of the project!

4.1 Factors that Influence Decision-Making Environment of RE Stakeholders

Decision support model-based theory can be utilised in a RE process management to improve the quality of decision regarding quality, cost and schedule of the RE process output. Many empirical studies support this assertion by demonstrating that decision support systems have improved the management of various public and private enterprises (Mallach, 1994; Sprague and Watson, 1996; Turban, 1995 and Young, 1989). There is a clear link between decision-making process and decision outcomes. This theory-based model using SD can show how the process affects outcomes to the decision maker (stakeholder) and the Software Development Organisation. DSS are designed to support RE process stakeholders in their decision-making (Williams, Hall and Kennedy, 1999). This support is offered during the various steps of the decision-making process. As demonstrated in figures three and four, there are possible relationships among process steps; outcomes; and between the process and outcomes of decision-making. Several frameworks have been developed to describe the human decision making process. Simon's (1961) three-phase paradigm of intelligence, design, and choice is the most widely used in decision support effectiveness studies. As illustrated in figure 3, this paradigm has been expanded by adding an implementation phase and by incorporating steps reported in the literature within the four phases (Mallach, 1994; Turban, 1995 and Young, 1989).

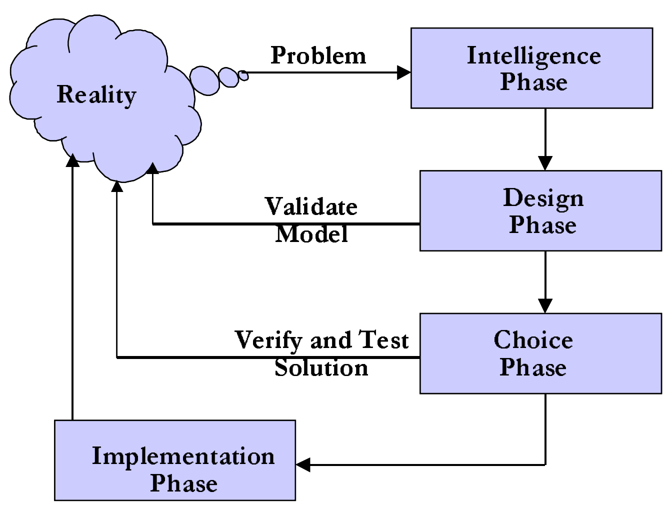

Figure 3: The Decision Making Process based on Simon (1961 and Young (1995)

During the intelligence phase the decision maker gains a fundamental understanding of, and acquires the general information needed to address, the organization's problems or opportunities. In the design phase, the decision maker develops a specific and precise model that can be used to systematically examine the discovered problem or opportunity. As illustrated in figure 3, this model will consist of decision alternatives, uncontrollable events, criteria, and the symbolic or numerical relationships between these variables. Using the explicit models to logically evaluate the specified alternatives and to generate recommended actions constitute the ensuing choice phase. During the subsequent implementation phase, the decision maker ponders the analyses and recommendations, weighs the consequences, gains sufficient confidence in the decision, and implements a final decision.

The decision making process is assumed to be continuous (Flynn and Williams, 1999). After the final choice is implemented, the decision maker should observe the new reality and, where appropriate, follow through with intelligence, design, choice, and implementation. Conceptually, the decision making process applies in the same manner to individual or group decision-making. In practice, group decision making must accommodate the communication intensive aspects of cooperative problem-solving within and between organizations, use structured techniques to support voting, ranking, rating, and other methodologies for developing a consensus, and provide group and organizational collaboration support (Jessup and Valacich, 1993).

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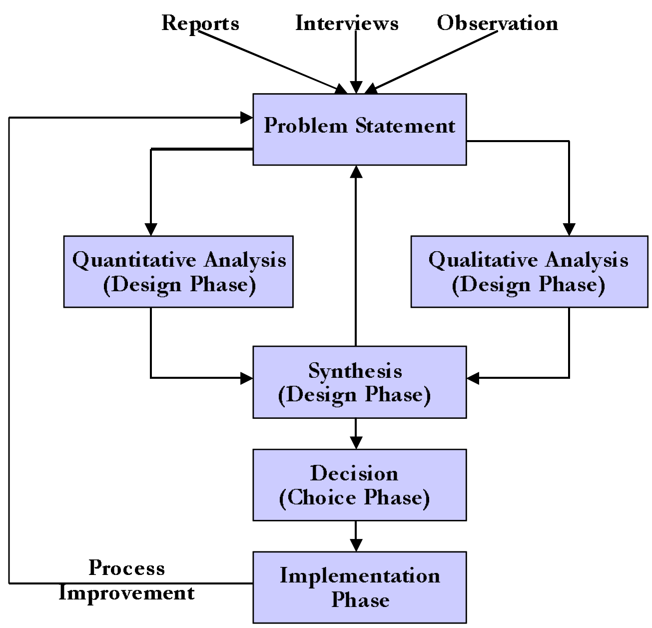

Figure 4: A Model of Decision-Making Process in Requirements Engineering Management

Intelligence

In intelligence phase the critical data that is filtered, compressed, and tracked by other information systems can be captured in a DSS database. The DSS can be used to organize this captured information, generate timely focused reports, and project trends. Such processing helps the decision maker to quickly monitor the decision environment, set objectives, and evaluates the processed information for opportunities or problems (Sprangue and Watson, 1996; Turban, 1995).

The Design Phase

Requirements engineering processes, resources, and products information constructs, and statistical methodologies can be captured in a DSS model base. The DSS, augmented by the requirements managers' (or perhaps analysts) insights and judgments, can be used to process these captured constructs and models into criteria, events, and alternatives needed to formulate a model of the decision problem (Mallach, 1994; Sprage and Watson, 1996; Williams, Hall and Kennedy, 1999). Additional processing with the statistical process control methods can estimate the parameters required to operationalize the formulated decision problem model choice (Young, 1989).

Choice

The formulated model, augmented by the managers' insights and judgments, are used to evaluate alternatives in a systematic and analytic fashion and to recommend alternatives (Fripp, 1985). In decision-making process, these evaluations typically involve: (a) simulating performance outcomes from stipulated actions and policies under specified internal and external conditions, and (b) solving specified models for the most preferable actions and policies for implementation (Turban, 1995; Young, 1989).

Implementation

A System Dynamics model-based DSS can provide the analyses in rich and varied detail with tables, graphs, and iconic animation of variables of interest. Systems thinking can facilitate the synthesis of soft and hard data identified in the problem. Such iconic animation supported by many SD simulation packages increase the decision maker's confidence in the recommendations, improves the decision maker's perception of support system effectiveness and enables the decision maker to better explain, justify, and communicate the decisions during implementation (Dean and Sharfman, 1993 and Tan and Benbasat, 1993).

Continuous Decision Support and Improvement

Feedback from the processing RE support provides additional data and models that may be useful for future decision-making. Output feedback (which can include outcomes, cognitive information, task models. and what-if, goal-seeking, and other types of sensitivity analyses) is used to extend or modify the original analyses and evaluations (Mallach, 1994; Sengupta and Abdel-Hamid, 1993; Williams, Hall and Kennedy, 1999). These interactive feedback loops make it relatively easy for management to support the decision making process in a continuous and dynamic manner. Along with the original analyses and evaluations, the feedback loops also increase the users' confidence in the recommendations and enable the decision maker to better explain, justify and communicate the decisions during implementation (Liang, 1986; Sengupta and Abdel-Hamid, 1993 and Sprangue and Watson, 1996).

5. Knowledge Creation and Management in the RE Process

By organizing captured RE process data, generating timely focused reports and projecting process trends, the DSS provides problem-specific information. Structuring the decision model with the DSS accesses virtual expertise that helps the RE process stakeholders to gain knowledge about the decision problem. DSS Model-based simulations, optimisations, and sensitivity analyses transforms the knowledge into satisfyicing solution. Janis' (1971) analysis indicates that in the RE process environment stakeholders fall into "*the individual differences approach*" paradigm described by Keen and Morton (1978). The RE process stakeholders behave very much as individuals (or group) as their aspirations and interests tend to be different (table 1). Simon's (1961) approach, "*the satisfyicing, process-oriented view*" describes the goals of a decision maker as making a good decision, but not necessarily the best decision. This description closely resembles the approach taken by RE process stakeholders, given their constraints of time, schedule, cost and uncertainty.

Gaining an understanding of the RE process facilitates stakeholders acquiring the general information needed to address the SDO's RE process problems and opportunities for product quality improvement. The model-based decision support tool developed can be used to systematically examine the discovered problem or opportunity. This model will consist of decision alternatives, uncontrollable events, criteria, and the numerical relationships between these variables. Using the explicit generic SD model of the RE process enables management to logically evaluate the specified alternatives and to generate recommended actions constitute the ensuing choice phase. During the subsequent implementation phase, the decision maker ponders the analysis and recommendations, weighs the consequences, gains sufficient confidence in the decision, and implements the chosen option.

5.1 Linkage between RE Process Decision and Product Outcome

While some phases, or some activities within RE process, may be performed concurrently decision-making fundamentally is a sequential process. Design will require intelligence. Choice should not proceed without design. Implementation follows choice as illustrated in figure 3. Since a process outcome from the RE process management can occur only after the final choice has been implemented, likewise *Decision Outcome =f (Decision Making Process)* or the decision outcome will be a function of (largely explained by) the decision making process. There can be an outcome to the SDO (for example, improved performance) or the decision maker (for example, learned skills and capabilities). That is,

RE Process Decision Outcome = {SDO, Decision Stakeholder}

or decision outcome is defined as the set of results accruing to the software development organisation and decision stakeholder. The decision making process can be defined as the set of its phase activities,

or *Decision Making Process = {Intelligence, Design, Choice, Implementation}*

while each phase can be defined as the set of its step activities. For example,

Choice = {Evaluating Alternatives, Choosing Final Alternative}

is the set of step activities defining the choice phase.

It is theorised that, given that steps in decision making phases are generally sequential, improvement in a RE process management decision making can lead to an improvement in other steps. Similarly, supporting a RE process outcome can lead to improvement among RE process product outcomes. The above theory-based model may help us to understand the relationship of decision-making process and outcomes on the effectiveness of the RE process decision support tool. Pidd (1996) contends that if organisations are to deal with the complexity of systems and decision-making within systems, there is a need for a new way of thinking about decision-making. Systems thinking/systems dynamics offers a vehicle for conceptualising the dynamics of the decision-making process (Senge, 1990; Morecroft, 1988; Sterman, 1994). The next section explains the nature of the systems thinking/systems dynamics approach and highlights its potential in understanding the decision-making behaviour of RE process decision stakeholders.

6. Use of System Dynamics To Model The RE Decision-Making Process

Systems dynamics (SD) has become an important methodology for understanding and formalising conceptual process models (Abdel-Hamid and Madnick, 1990). SD supports analysis of the system's pattern of behaviour in a way that facilitates understanding and insights into organisational structure and managerial decision-making. It can be used to provide the basis for a model of a feedback structure in decision-making, which encapsulates the complexity of decision-making behaviour generated by the iteration of many non-linear loops over time. SD has been applied to a wide range of domains, from the management of socio-economic systems to the management of eco-systems (Roberts, 1978). Recent studies have focused on modelling managerial decision-making (Senge, 1990, Sterman, 1989; Morecroft, 1987; Clark and Augustine, 1992). Clarke and Augustine have devised what is perhaps the most comprehensive model of managerial decision-making. They use SD to measure the value of information in the business organisation and describe in detail the decision-making processes involved in managing the flow of information and effective resources in pursuit of organisational objectives.

SD has developed over time as a method for modelling the behaviour of complex socio-economic systems (Forrester, 1961; Keys, 1988; Coyle, 1986, 1995). It can enhance understanding of the nature of an organisation's soft (Checkland and Scholes, 1990) and strategic issues (Senge, 1993) and can be used to improve corporate decision-making. The Stock/Flow notation used in SD can be applied to build detailed conceptual models of decision processes (Meadows, 1982; Pidd, 1992) and facilitate identification of information needs at different levels of managerial activity. The main advantage of SD, however, in terms of modelling decision-making processes is that it can handle both soft and hard aspects of decision-making. The problem with the 'hard' approach' it is that too narrowly focused to be genuinely useful in facilitating understanding of decision-making and cannot tackle adequately problems that are ill structured (Keys, 1988). Soft systems approaches are much better suited to coping with complex, ill-defined problems but they are too all-encompassing to capture the fine detail of the decision-making process The ability of SD to integrate both hard and soft approaches means that it is uniquely capable of revealing and explaining the decision-making processes (Meadows, 1982; Wolstenholme, 1992; Kuhn, 1970).

The authors argue that the advantages of the SD approach outlined above suggest that it is an appropriate vehicle for examining the decision-making process in IT. As has been demonstrated earlier in the paper, individual decision-making is influenced by hard and soft factors. SD integrates both factors but is also good at capturing the dynamics of organisational change processes. Earlier it was suggested that organisational change has a significant impact on decision-making in IT. It follows that SD may offer a way of exploring the dynamic impact of change on decision-making behaviour and competency. If SD could be applied in this way it would provide a basis for modelling decision-making, capturing the impact of change processes and exploring the potential impact of change on competency. This would be of great value in developing a theoretical framework for understanding decision-making in IT and for improving competency in a learning situation, since the Model could be used to explore what might happen to decision-making competency during periods of radical change. The next section presents an SD Model the authors have developed from examining the impact of organisational change on decision-making competency and then describes its unique characteristics. The model (shown below) provides a systemic and holistic view of the factors and attributes that influence decision-making effectiveness in RE process management. Williams, Hall and Kennedy (2000) have argued that that such an approach is crucial to understanding the dynamics of requirements engineering process management.

6.1. Decision Making Effectiveness Factors in Requirements Engineering Management

Morecroft (1977, 1983) provide a reference point for understanding the range of factors that influence decision-making in requirements engineering process management as the quality of information. At the centre of the model is the RE stakeholder. The decision(s) made by stakeholders is depicted as being influenced by the factors discussed in the management literature. Personal factors are shown to be important as are the influence of peers and the groups to which the manager belongs. Personal and peer/group factors are subject to the influence of organisational factors - the structure, culture and political ethos of the organisation, its goals, quality of information available, etc. "Business rules" are shaped by the organisational context and strategic objectives, while investment policies are influenced by technological factors and are also shown to have an impact on the RE stakeholder. The model, as illustrated in figure 5, identifies the importance of organisational learning and suggests that it may have a direct impact on the individual IT manager's ability to learn and to make effective decisions

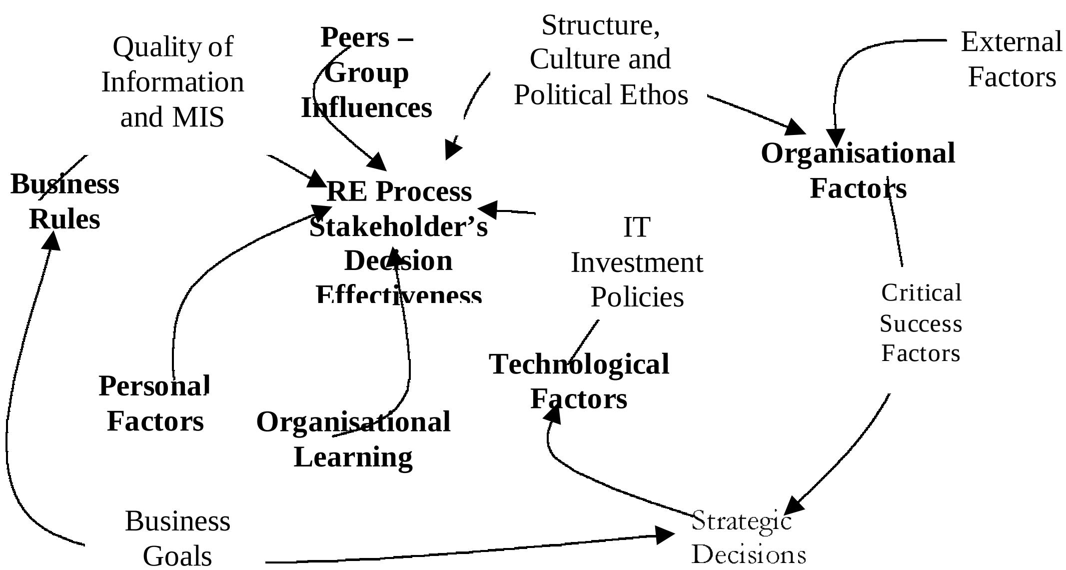

Figure 5: A Model of Main factors that Influence Decision-Making Environment of RE Process Stakeholders

The model (figure 5) is useful insofar as it depicts the main factors that influence the decision-making of RE stakeholders and indicates some of the possible interrelationships between them. However, it does not depict the process, delays, complexity or dynamic nature of decision-making RE process. If decision-making effectiveness in RE process is to be improved it is necessary to go beyond merely listing factors that influence decision-making and develop a model-based decision support system for the RE management decision-making process.

7. Summary and Future Directions

The model offers a useful basis for research on decision-making process in Requirements engineering. This section identifies a number of propositions (P1, P2, P3) that can be drawn from it and suggests how they may be tested.

P1: There is a time lag between the requirements engineer gaining understanding of the system's technical potential and the customer's understanding of their own requirements at the time of requirements volatility.

The model offers a basis for capturing the mental models of RE stakeholders and facilitating understanding of their decision-making processes during the RE process. There is no theory or research which relates directly to the mental models of RE stakeholders, or to the impact of requirements volatility on the SDO processes or RE stakeholder mental models. The model thus provides a basis for generating new knowledge about the decision-making processes of RE stakeholders through shared mental models of the decision making process. It has been stressed throughout the paper that there is little theory or research on decision-making in requirements engineering process management. The model makes a useful starting point for developing a theory of the decision-making processes of RE stakeholders.

P2: The quality and availability of information has a major impact on the SDO's capacity to respond to requirements volatility and customer satisfaction on RE process management decision-making.

P3: Requirements Reprocess stakeholders who have access to high quality information, and use those systems to support decision-making, are likely to make more effective RE process decisions than those who do not have such systems at the time of requirements volatility.

The model's most distinctive feature is that it can deal with both hard and soft aspects of decision-making. As suggested previously, the inadequacies of purely hard or soft approaches make it difficult to capture the complex relationships and feedback loops that characterise decision-making processes. As a tool the model can be used by practising managers in a learning situation to reduce the uncertainty about requirements volatility by highlighting the factors that influence decision-making during the RE process. This "fly by wire" concept of the learning process has been used in organisations to facilitate learning but it has not been used as a basis for developing RE process stakeholders' decision-making effectiveness.

In order to test the above propositions it is necessary to establish confidence in the model. Forrester and Senge (1980) propose three main tests for establishing the validity of SD models. These are: tests for model structure, tests for model behaviour and tests for policy implications. With regard to model structure, the model proposed in this paper could be tested by comparing its structure with the descriptive knowledge elicited from RE case studies in interviews. The second test applied to establish confidence, could be carried out by comparing the behaviour of the model with the observed real-life decision-making behaviour of RE process stakeholders who take those parts in a simulation of organisational change. The results of this stage of the testing process may indicate aspects of the model which need to be refined. The third test – for policy implications of the impact of change on decision-making competence can be implemented by empirical observation.

We intend to carry out a programme of research to validate the model and test the propositions that may help explain the decision-making behaviour. We aim to undertake a survey that will identify characteristics of RE process and decision-making stakeholders relevant to research on decision-making behaviour, i.e. personal factors such as age, education, background, experience of managing requirements change and characteristics of the organisation to which they belong that might influence decision-making behaviour. RE process stakeholders in the survey who indicate that their organisation is undertaking a RE process would be randomly selected for a series of interviews and group modelling exercises based on case scenarios of requirements volatility. The aim would be to capture their mental models of the decision-making processes and ascertain whether the effect of requirements change on the participants corresponds with that predicted in the model. The data gathered about the individuals and their organisations would be used to test specific propositions. The paper indicates that a great deal of work has been carried out on the nature of managerial decision-making but that very little has been undertaken on decision-making RE process management. It has been suggested that the findings of research on managerial decision-making may be relevant in RE but that research needs to be carried out on the factors that influence the decisions of RE stakeholders. The paper has drawn on the management literature to identify a range of factors that may influence decision-making of RE stakeholders and has proposed an initial model to illustrate the relationship between the factors. While this is useful as a first step, it was argued that a systems thinking/systems dynamics approach is necessary to understand the process of decision-making in RE process (Flynn and Williams, 2000). The advantage of SD is not merely that it captures the complexity of decision-making processes; it also offers a way of exploring the impact of requirements volatility on decision-making over time. The paper described the model in outline, identified initial propositions that can be derived from it and suggested how these may be tested empirically. The value of the model in both theory building and in learning/training situations was highlighted. It was suggested that it may provide a framework for building a body of knowledge on decision-making processes in RE. The final part of the paper explained how the data would be collected for empirical analysis and highlighted the potential value of the research for both theorists and practising managers.

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