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Towards A System Dynamics Theory of Requirements Engineering Process

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Abstract:

This paper presents initial results of the research towards the development of a system dynamics theory of 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 process by incorporating improvements aimed at better understanding, improved communication and more effective process modelling and analysis. The need for developing such a theory as a basis for understanding and a fulcrum for debate have highlighted a strong case for integrating research approaches. In developing such a theory the paper fills an important gap in the Systems (software) requirements engineering process modelling and analysis literature. Research in systems (software) on requirements engineering process modelling and analysis is vital if requirements managers, researchers and software development organisations are to cope with the pace of software evolution, retain competitive advantages 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-based theory provides both a foundation for theory building requirements engineering process and a basis for improving requirements engineering process modelling and analysis.

1. Introduction

Requirements Engineering (RE) process modelling 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 Finkelstein, 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 RE process and its effectiveness. 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 the 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.

Although there is a considerable body of literature on requirements engineering, little research has been published on the modelling and analysis of the requirements engineering process. Research on the latter has tended to examine formal specification of requirements, rather than focus specifically on process modelling and analysis (Williams, Hall and Kennedy, 2000). 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. To place the discussion in context, the section below defines what is meant by the terms 'requirements engineering' and 'requirements engineering process' and 'process 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.

The final term *requirements engineering process 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.

This paper attempts to develop such an understanding by proposing a framework that identifies the factors that influence effective process modelling and analysis. Since there is no empirical research on decision-making in RE, the rest of the paper is organised in nine sections. In section 2 a review of RE engineering process modelling literature, is given to provide a context of which process performance effectiveness is achieved. The background to the requirements engineering process modelling and analysis is discussed in section 3. In section 4 a problem statement for RE process modelling effectiveness is presented. Section 5 discusses the advantages of using system dynamics /system thinking in visualising, (through a model of the RE process. Section 7 presents overall model structure and the resulting behaviour, while section 8 highlights initial observations and insights from this research. Section 9 presents an initial system dynamics model-based theory of the RE process, while section 10 considers some future directions to further improve the RE process and conclusions.

2. The Requirements Engineering Process Modelling

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 modelling and analysis.

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 cannot 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 modelling. 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 applied 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.

RE process modelling and analysis, 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 static RE process-based approaches to requirements engineering (Pohl, 1993), but very little has been done utilising dynamic process-model based tools. Neither has any dynamic theory of requirements engineering process has been proposed to facilitate debate and understanding of the problems in this important phase of software systems development life cycle. This paper contributes to developing such an understanding by proposing a system dynamics theory that may facilitate the understanding of the RE process modelling and improvement amongst RE 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 the relationship between different activities or their entities. Main coverage of this domain tends to pay more attention to specification language issues or form part of a wider systems development method. The requirements engineering process as a social aspect 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 process modelling practice, there is no consensus on what the deficiencies are. However, systems failures continue to be 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 in the modelling process. Further more, maybe more important poor understanding of the critical success factors that contribute to the effectiveness of the RE process. Even 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 customers' 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 elicite and analyse requirements.

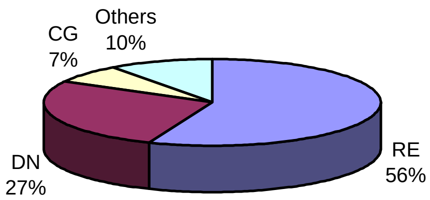

Figure 1. Distribution of Error Sources (Finklelstein, 1989)

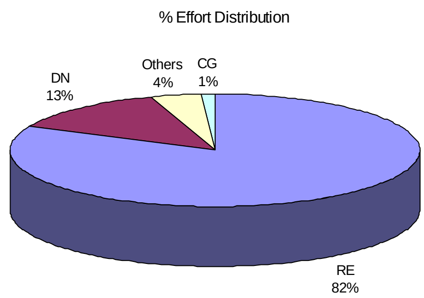

Figure2. Distribution of Effort to Error Sources (Zahedi, 1995)

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 process measurement environment

3. Requirements Engineering Process Performance Measurement

Controlled RE process are stable processes, and these in turn should enable Software Development Organisations (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: Aspirations of 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!

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).

By organizing captured RE process data, generating timely focused reports and projecting process trends, the RE process mode provides problem-specific information. RE process model-based simulations, optimisations, and sensitivity analyses transforms the knowledge into satisfyicing solution. Jani's (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 RE process support tool developed can be used to systematically examine the discovered problem or opportunity. This model may 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.

4. Problem Statement

A Requirements Engineering Prescriptive framework is described as a theory and associated experimental evidence and field studies concerned with helping RE process stakeholders improve their performance in problem-finding and problem-solving given the complexity and constraints often presented in real life RE processes. As started earlier, current approaches to RE process modelling are too informal or too formal to support useful understanding of the RE process modelling and analysis (Bubenko, 188; Davis et al 1993) or to provide useful theories to facilitate understanding (Williams and Kennedy, 1997; Williams, Hall and Kennedy, 2000). Discussions presented in earlier sections raise important question for this paper:

How does the RE process modelling and analysis impact on process effectiveness? Can modelling and analysis of the RE process from a feedback control viewpoint and the resulting system dynamics theory be a useful tool to provide a fulcrum for debate and enhanced understandability of the RE process?

The above question implies that a good model should show a tendency toward fluctuation in both customer requirements, quality of specification product, cost of resources and customer satisfaction. When the productivity per requirements engineer decreases, the observed quality decreases. After some delay, additional requirements may be acquired, the increase in training, however initially reduces the productivity of analysts. This increased training effort further reduces quality. However, after training is completed, the productivity ration per requirements engineer increases and observed quality increases. In order to answer and operationalise the above problem statement, this section seeks to develop a dynamic requirements engineering process and improvement model capable of capturing both formal and informal aspects and to facilitate better understanding of the RE process and its effectiveness in terms of feedback loops, delays and non-linear relationships between key processes' products and resource variables.

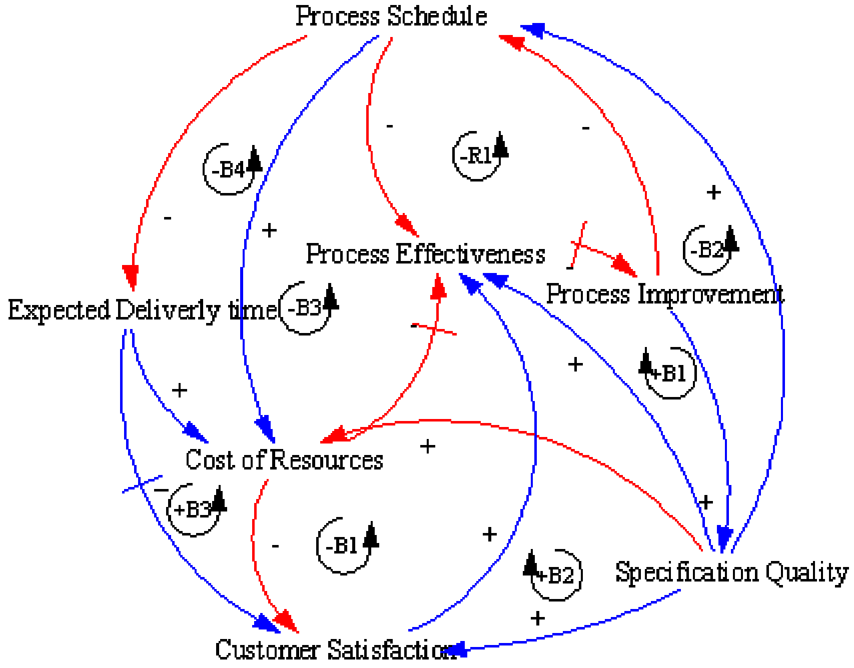

Figure 5. Dynamic Hypothesis of requirements engineering process effectiveness

Process effectiveness as defined the measure of the overall accuracy and completeness of goals achieved in RE process model. The dynamic hypothesis described in Figure 3, can be used to explain the cause of the problem. As illustrated in Figure 3, the effectiveness of the RE process must be related to the quality of the product, the cost of resources and the time the product is developed. For the above statement approach to be correct we assume to have a valid model that incorporates the RE process structure, quality assurances, budgets and RE process planning and control procedures. A RE process system can be used as a decision support system for RE stakeholders to explore the likely impact of their various polices, before actually implementing them. Systems thinking/systems dynamics offers a vehicle for conceptualising the dynamic theory of RE engineering process (Senge, 1990; Morecroft, 1988; Sterman, 1994).

5. Use of System Dynamics To Model The RE 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). I have urged 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. The model provides a systemic and holistic view of the RE engineering process that influence decision-making effectiveness in RE process. Williams, Hall and Kennedy (2000) have argued that that such an approach is crucial to understanding the dynamics of requirements engineering process modelling and improvement.

6. Feedback Structure in RE Process Modelling and Analysis

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. These concepts of feedback structure, delays and non-linearity have a significant impact on a RE process depending on assumptions embedded in the system.

6.1 RE Process Modelling Scope and Assumptions

Classification of phases of system (software) development life cycle (SDLC) may vary from one system (software) development organisation (SDO) to another (Boehm, 1981). To put this research into perspective, the requirements engineering process is the initial phase of the SLDC (Williams and Kennedy, 1997). Figures 4 and 5 positions the RE in SDLC, which starts when a SDO receives a Request for proposal from a customer or request for change from a user and ends with the delivery of a requirements documents just before preliminary design begins. Main process areas form the basis for management control of software projects and establish the context in which technical methods are applied and how work products (models, documents, data, report forms, etc.) are produced (Pressman, 1997). Software engineering methods provide the technical 'how' for building products.

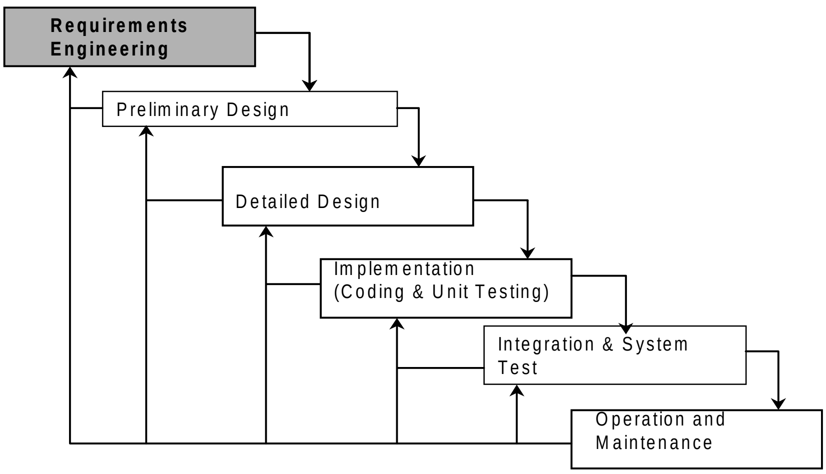

Figure 4: Positioning the RE process in relation to the Classical Waterfall Model of SDLC

These methods encompass a broad range of processing including requirements engineering, design, programming, testing and maintenance. RE tools like in software engineering tools, provide automated or semi-automated support for the process and the methods. To put this research into context, figure 4 identifies the position of requirements engineering process in the context of traditional software development (SDLC) 'waterfall model' based on Boehm (1981).

The RE process starts with elicitation of customers/users requirements that are informal and incomplete and ends with a specification document that is formal and complete. For the purpose of this research, the software development lifecycle has been divided into six phases (Figure 5) that are consistent with the NASA's IV &V (NASA, 1984), the GPL (1985) on cost effectiveness and Boehm's (1981) waterfall model. A RE prescriptive theory represents a generic system dynamics model of the RE process modelling and analysis that focuses on the first phase of the SDLC. A RE process can be thought of as a Use Case (Jacobson, Booch and Rambaugh, 1999) and as having a start state, a request of proposal (the leftmost rounded rectangle), intermediary states (the subsequent rounded rectangles), end states as delivery of specification document (the rightmost rounded rectangle), and transitions from one state to another as illustrated in Figure 5.

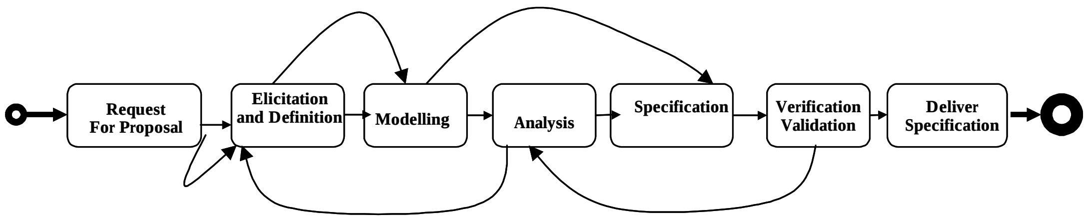

Figure 5: Description of the RE process Transitional State Chart

In Figure 5 straight arrows illustrate the basic path, and curved arrows represents key feedback or feed forward likely to take place in the Requirements Engineering. Feedbacks are one of the fundamental features not supported in the Unified Modelling Process provided by Jacobson, Booch and Rumbaugh (1999) as a de facto standard for software process modelling. This paper adopts the above set of activities as a generic RE process. Since these activities are flexible, can easily be customised to different domain application or different SDO providing such services. The problem is to select the process model that is appropriate for a large-scale system to be engineered by a RE process team. Metrics defined in this paper provide key process performance measures that can be used in the management and improvement of the model depending on the assumptions made for the system. The majority of the structure in the model is endogenous. Schedule, quality and cost are tightly coupled to one another. The requirements change request (or request of proposal) is exogenous. The use of exogenous variables serves feedback loops, which may have important policy implications. The requirements change requests normally arrive at the process manager's desk in a non-steady-state build-up from different stakeholders. On the other hand active requirements over the RE process life cycle are in a steady state, after which a review process decides to implement them, freeze them or reject them completely. In the Draper model, Smith and Lavery (1991) reports that a moderate scenario of 15 percent requirements change with a group of 50 experienced managers only a few finished the project on time and within budget. Aranda et al (1993) postulate, "no matter how good your requirements process is, there are still some requirements for a system you could not have known about until the system was built". Boehm (1981), in another IBM study estimated that requirements changes averaged 25 percent for a typical project. In this paper an average Error Rework of errors is set to vary between 15-25 percent.

The model can be divided into a number of subsystems with relatively sparse interactions with the remainder of the model. Given the above observations in the software process modelling literature, the following assumptions have been considered in the development of RE process modelling and analysis prescriptive model:

- the inter-arrival times for requirements change requests are exponentially distributed,

- the review times are exponentially distributed,
- the number of active (implemented) requirements is typical of large scale complex systems i.e. > 10000, therefore finite change requests queuing formulation must be used,
- minimum quality possible is set at 0.25 (dimensionless),
- the inter-arrival times for change requests are statistically independent of the review and specification times,
- the review and requirements specification activities are parallel and each is capable to review or to specify requirements,
- the mean time between reviews (MTBR) and mean time to specify (MTTS) values vary for each requirements age groups and represent the expected value for those variables for that age group,
- rework of requirements errors will be distributed between 15 and 25 percent for a typical project.

The average completion time for a requirements process varies between three months to two years for business systems and command-and control defence systems respectively. Other assumptions used in this paper will be stated in the appropriate sections. The above model assumptions have guided this research to state explicitly the purposes of the model implemented in this paper. The focus of this research is on resources, processes and product variables in the RE process modelling and analysis. The success of such a process is determined by the effectiveness of the size of documentation, quality of specification, cost of resources, and project schedule. (Williams, Hall and Kennedy, 2000).

6.2 Time Horizon

RE process vary in duration depending on domain application and the size of the product specification. Based on Boehm (1981, 1989) requirements analysis takes 6 to 8 percent of time schedule of the whole software development life cycle. The whole SDLC varies from 7 to 12 years of systems to critical business applications respectively. Requirements engineering process takes between 3 and 24 calendar months for business application and critical defence systems respectively (Smiths et al, 1993). The mean value is 10 calendar months, however this paper adopts 15 calendar months, as a nominal simulation time frame used for generic RE process model. There are five working days in a week. Therefore a calendar month (4*5) will have 20 days. Converting 15 calendar months give us 300 days. The final simulation time in the model is therefore set at 300 days. While it was not the purpose of this study to estimate model parameters from the data, the comparative longer simulation time period provides useful test of reference model behaviour.

This section presents a feedback structure of the RE process modelling and analysis. SD modelling approach takes a philosophical position that feedback structures are responsible for the changing patterns of behaviour we experience in complex problems (Richardson and Pugh, 1981). Robert et al, (1983) suggest that there are three important aspects of the SD approach to developing computer simulation models: establishing cause-and-effect relationships, determining feedback linkages among components of the system**,** and setting appropriate boundaries for defining what is to be included within a system. Conceptualising system structure and communicating model-based insights about feedback structure and dynamic behaviour can be achieved through causal-loop diagrams or influence diagrams (IDs), Stock and Flow Diagrams (SFDs) techniques supported by SD. To improve our understanding of the RE process dynamics, the paper explores the feedback concepts by explaining the model structure using influence diagram and the net effect on *RE Process Effectiveness.* An increase in *Changes in Requirements* increases the number of process activities, which in turn increases the number of requirements to be specified. An increase in the number of requirements increases the total requirements, which in turn increase the number of requirements processed as a result of the review process. At the same time an increase in *No of Requirements* to be specified increases the *Error Generation Rate*, which in turn increases Error *Detection Rate* there by increasing *Error Rework*. The feedback structure presented in figure 6 contains some of the validated theories of software development dynamics published in public domain. This paper makes a contribution by adding features and variables that only are pertinent to requirements engineering, which have not been modelled by other researchers before.

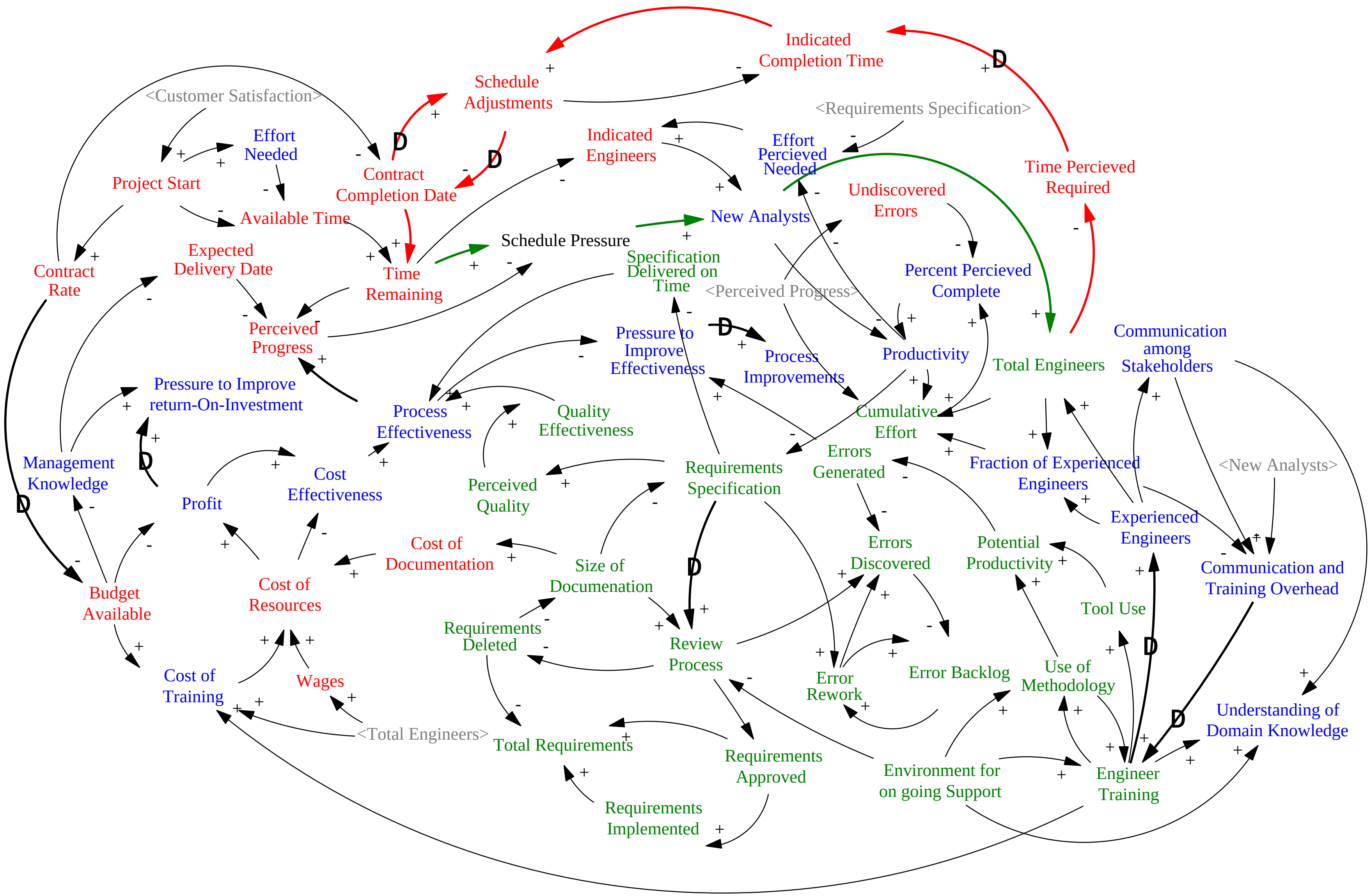

Figure 6: Feedback Structure of the Requirements Engineering Processes Performance

The model (figure 6) is useful insofar as it depicts the main factors that influence the effectiveness of RE process and indicates some of the possible interrelationships between them. However, it does not depict the process, delays, complexity or dynamic nature of RE process. If effectiveness in RE process is to be improved it is necessary to go beyond merely listing factors and activities that influence process effectiveness and develop a model-based process support system for the RE modelling and improvement.

6.3 Audiences and Purpose of the Model

The beneficiaries of the model developed in this paper are requirements process stakeholders including requirements managers and researchers, customers and management of SDO. The stakeholders are responsible for the management of the RE process and would require some guidance on how to improve RE process effectiveness through controlling the schedule, cost and quality of the specification product. The resulting model will be used as a tool that allows requirements stakeholders to experiment with decision choices for improving Requirements Engineering process modelling In addition to the aims and objectives of this paper and the model requirements. The RE process prescriptive model implemented in this paper will be used for the following purposes:

- to create a discussion environment for better understanding of RE process management,
- to clarify policy implications and problems of the requirements engineering process management and improvement;
- to create an efficient way to expand the mental models of stakeholders about the RE process modelling and analysis.
- to form a basis for data collection in a framework for Requirement Engineering process
- to create a platform for experimentation research tool as part of planning and prediction of RE process performance evaluation;
- to create an environment for testing the various hypothesis about RE process modelling and analysis and their implications for RE process stakeholders.
- to provide a platform for Reuse of RE process enactment and technology acquisition in different application domains.

The assumptions stated and purposes of the model above facilitate the scoping of the boundary.

6.4 System Boundary

The model developed in this paper focuses upon aspects of requirements engineering process dynamics that may be potentially within control by RE process stakeholders. The components define the boundary of the system dynamics model for RE process developed in this paper and will be used to generate the behaviour of interest. The assumptions and the model purposes stated earlier provide a basis for describing a generic system dynamics RE process model. Each phase is generic in structure and represents a specific stage of product development. The four project components (described as subsystems) interact within each phase and impacts project performance. The model also uses the three traditional measures of project performance (time, cost and quality) and these are reflected as cycle time, defects and cost. The requirements elicited and to be specified flow through the RE process, as described iterative activities.

To help identify divisions among development activities and specification requirements, it is assumed that requirements within an activity are uniform in size and tangible, and that they are also small enough to be defective or correct but not partially defective. The model then describes development process through elicitation and definition, specification process and review process encompassing all six activities.

The interacting three subsystems and 14 sectors in Table 2 and figure 6, endogenously presents the RE process modelling problems and also in the problem statement and determine the effectiveness of the RE process modelling and analysis. Table 2 summarises the major functions of each sector.

Table 2: Major Functions of Each RE process modelling and analysis Model Sector

Sub-System	Sector	Major Functions
Process Organisation		
	Project Scope Sector	Main function is to ensure that the Organisation producing requirements specific action adheres to standard process and there is business case in the project.
	Process Integration Sector	
	Customer Services Sector	
	Project Finance	
Product Engineering		
	Process Technology Sector TE	The main function is to ensure that customer acceptance and satisfaction with the product quality.
	Development \Process Sector	
	RE Support Environment	
	Process Schedule Sector	
Project Management		
	Quality Assurance	The main function is to plan and control achievable commitments regarding cost, schedule and resources.
	Planning and Control Sector	
	RE Procurement and Contract Management	
	Document Management Sector	
	Process Performance Sector	
External	Customer/User Sector	

Table 2 summarises the major functions of each subsystem and their sectors represented in the model. The next section discusses each of the model sector subsystems in detail. The model consists of about 495 Stella Research 6 (HPS, 2000) equations with 45 level variables. The full listing of the model equations are in Appendix A1. In the model, request for proposal and inflation are assumed to be exogenous. There are eleven endogenous interacting sectors within three subsystems identified (Morecroft, 1979). The three subsystems and 14 sectors are consistent with figure 6 proposed and developed in this paper. The model subsystem discusses detailed complex relationship between variables.

7. Overall Model Structure and its Resulting Behaviour

Figure 7 shows the overall structure of the system dynamics model that considers important interacting variables in the RE process modelling and analysis based on concepts explored.

Simulation results presented in Figure 8 through 13 can help develop an understanding of the system dynamics model and the behaviour of the RE process management. As emphasised earlier, in a generic model of the RE process exact variable numeric values are not as important as understanding derived from the impacts of the model structures on its behaviour illustrated in Figures 8 through 13. The structure of the model includes some of the previously validated models of software process engineering.

Analysis of graph outputs shows the benefit obtained from using novel environment for exploring complex problems like RE process. The modes of behaviour, which are exhibited in these graphs, reflect real-world concerns of requirements engineering process stakeholders. These outputs provide the RE stakeholders with measures of how well the RE Process is being managed and therefore process bottlenecks can be identified and improved. The dynamic behaviour produced by the model is analysed with respect to the underlying structure or its influence diagram (Figure 6) upon which the model is founded (Wolsteholme et al, 1990). Analysis of the results in graphs (Figures 8 to 13) shows the benefits of IS obtained from modelling the entire Requirements engineering process. As suggested by Forrester and Coyle (1986) Wolstenholme et al (1997) analysis the change in the dynamics produced or the quantitative results is not enough. It is crucial that the interpretation takes account of how the underlying structure is changed and how the output dynamics are produced. The cross-analysis of between Z-S shaped dynamics and the living dynamics is easy to understand.

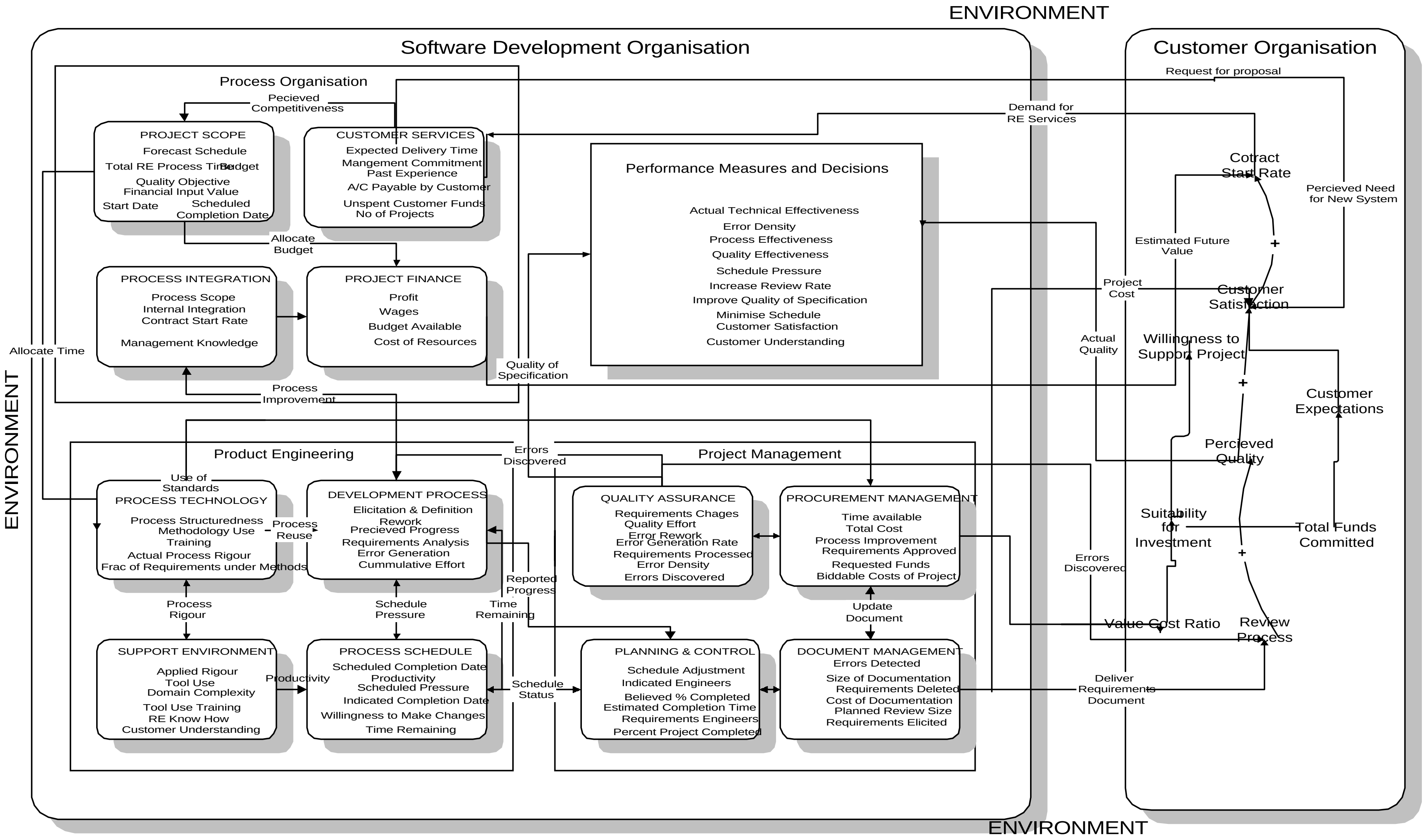

Figure 7: Overall Structure of the Requirements Engineering Process Performance

Graphs shown in Figure 8 through 13 represent some of the inferences about the requirements engineering process performance. Thinking within reference modes supported by the graphs helps to understand several effects of decision engineering and helps to improve our understanding of the system we are modelling (Richardson and Pugh, 1981).

Figure 7 illustrates difference between planned and actual effort expended.

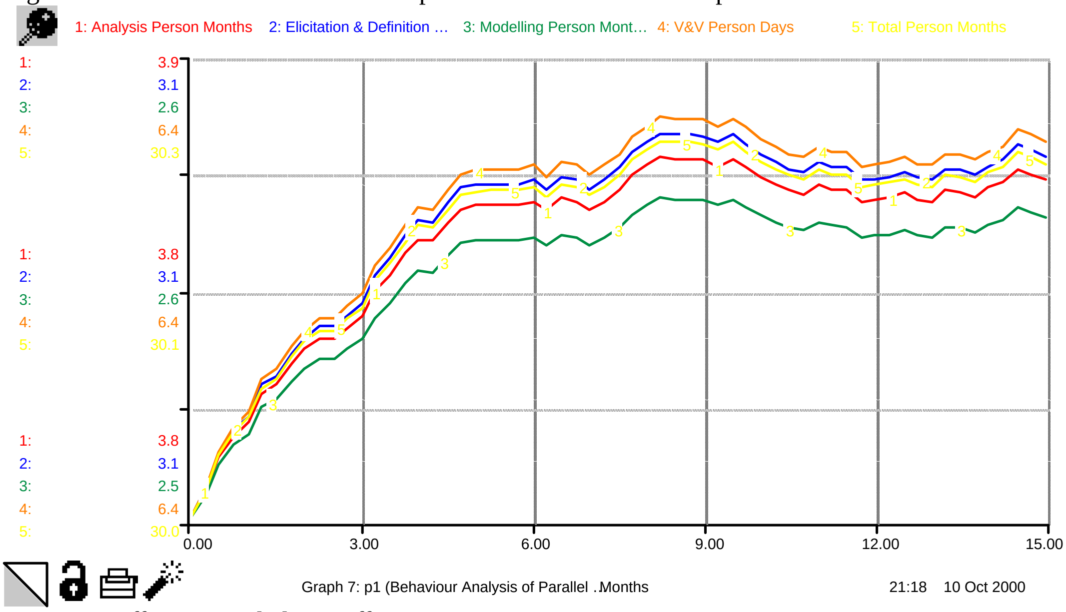

Figure 8: Effort Expended on Different Requirements Engineering Activities

Figure 8 illustrates the amount of planned time spent on the requirements engineering process as a result in time due to errors is exhibited in verification and validation (4) and this compounded in the total Person Month(s). The scenario is reflected through the policies and initial condition in the model (Wolstenholme, 1990). Figure 9 shows interesting dynamics into the effects of estimated schedule on completion time.

Figure 9 shows interesting insights. Notice the Z-shaped dynamics. This shows the rate of technology transfer (3) starts fairly high, then drops dramatically after five months. While planned reviews size (4) starts fairly low then increases as the customer identifies more errors in the specification document. These dynamics correspond to real-life behaviour of requirements engineering process.

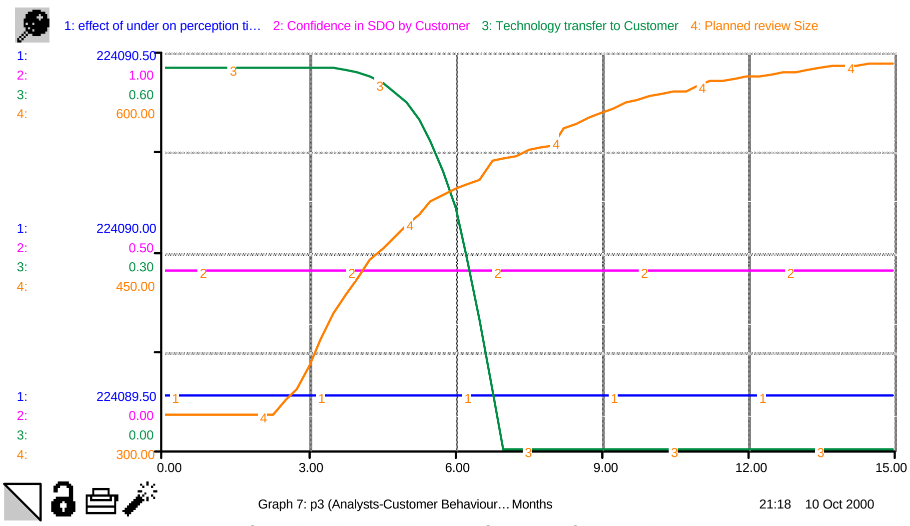

Figure 9: Behaviour of Technological Transfer, Confidence by the SDO and Perceived Review Size

Figure 10 shows dramatic effect of 'Lump' type of behaviour. The actual technical effectiveness (1) starts fairly slowly and rises sharply after nine months. This is due to the fact that it takes time to learn to use tools and new methodologies (4). Initially, requirements discovered (3) are high, but progressively reduce over time. This behaviour is correspondingly true to requirements documents size (2), which is initially large, but reduces, as understanding is refined.

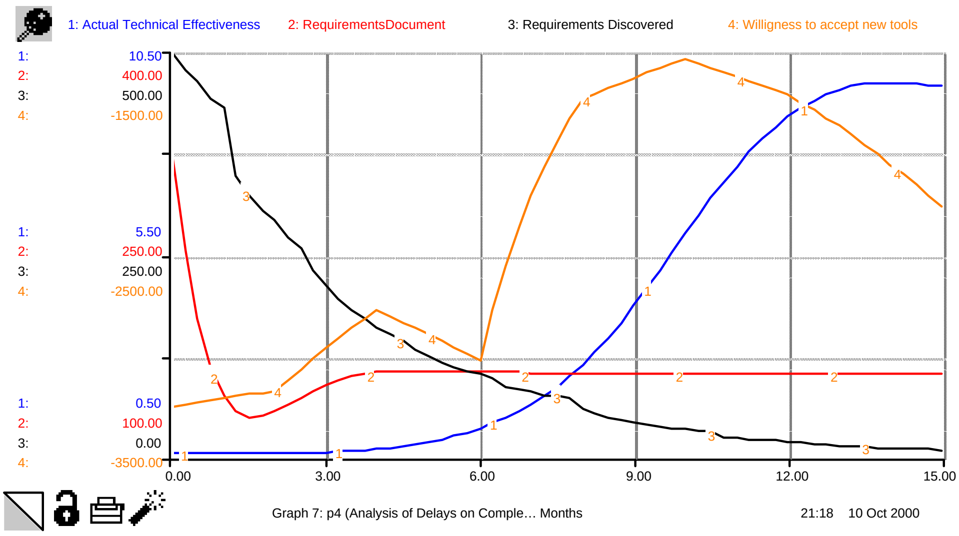

Figure 10: Technical effectiveness, Requirements Document and Requirements Discovered

A more stable behaviour showing slow increase in all variables. It is interesting to note that the behaviour of understated completion date (5) is similar to that of cumulative costs (1) and project cost effectiveness (4).

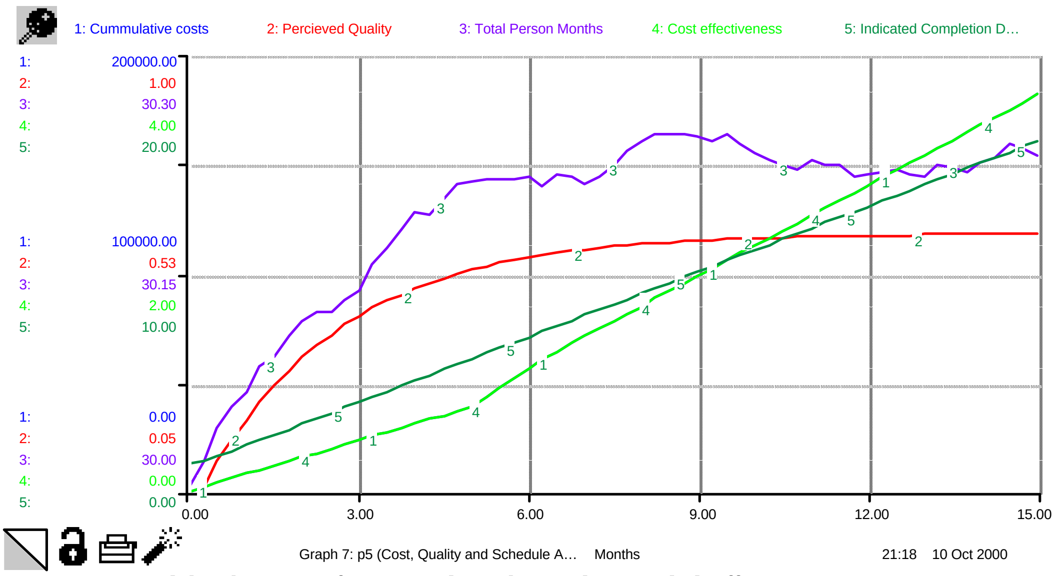

Figure 11: Model Behaviour of Perceived Quality and Expended Effort

Perceived quality (2) increases initially but stabilizes in the 7th months equally total Person-Months (3) expended on the project increases with time, but drops after 9th months, this is due to fewer errors discovered and high technical effectiveness exhibited in Figure 12. Figure 12, exhibits 'lump' and 'ground rush' and 'Z' shaped dynamics. Customer satisfaction (1) starts off fairly high but falls dramatically due to delayed use of tools and methods.

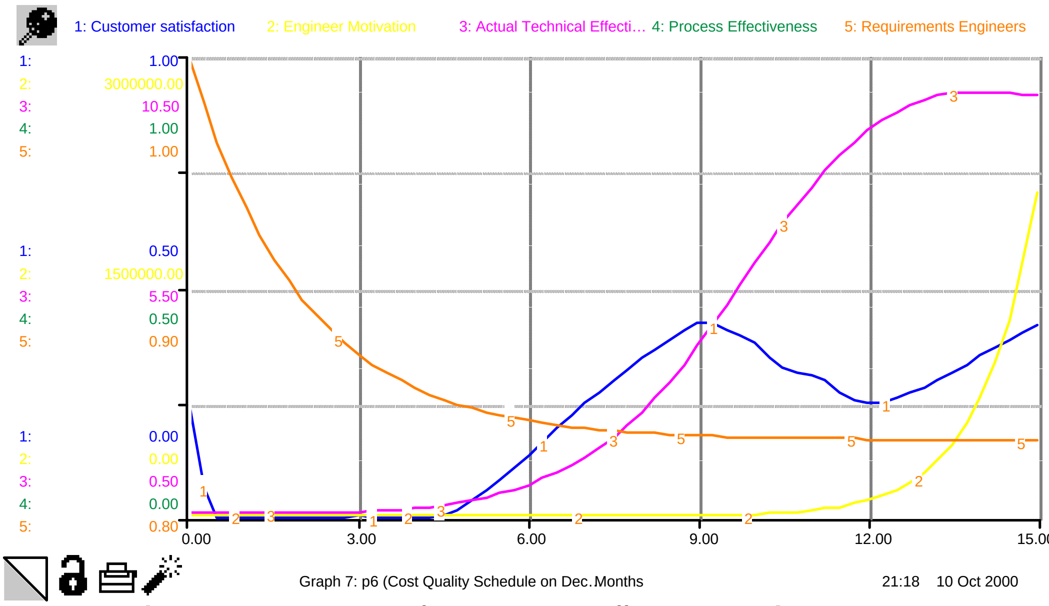

Figure 12: Changes in Customer Satisfaction, Process Effectiveness and Engineers

This makes communication between analysts and customers difficult initially but improves later in the project. Shortened and delayed requirements changes have a dramatic effect on completion time. A delayed requirements change is mainly due to delay in harnessing technical effectiveness (4) in many software development organisations. Improvements in technical effectiveness reduced the requirements volatility and the need to increase number of requirements engineers on the project. This is in line with Brooke's law (Brookes, 1978) described in Abdel-Hamid and Madick (1990).

Requirements volatility has a major impact on cost, and quality. Due to high levels of errors discovered, demand for RE services (2) continuously increases due to pressure (4) for process improvement.

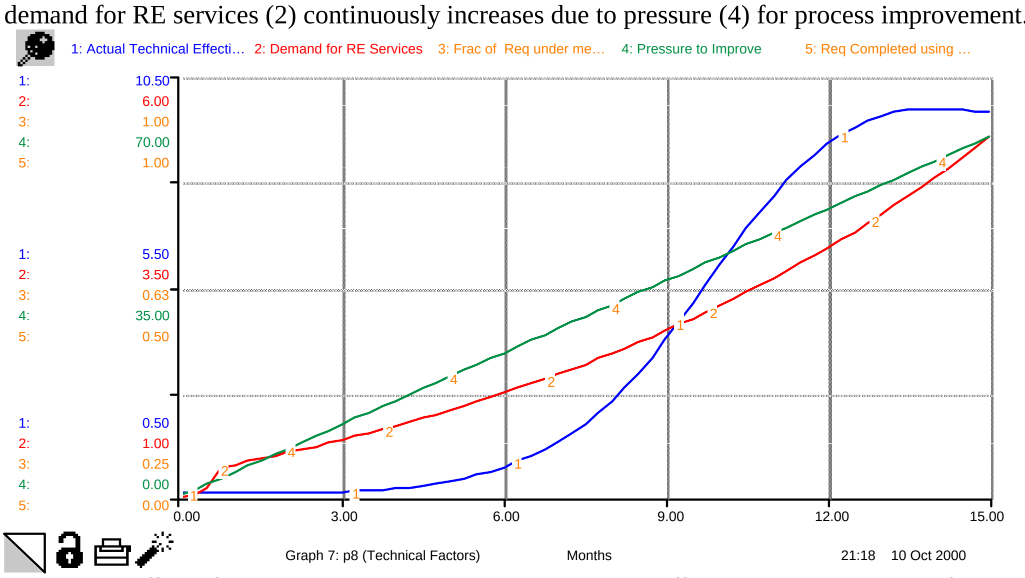

Figure 13: Effect of Fluctuating Requirements on Technical Effectiveness and Demand for RE Services

However due to non-linearity of activities in the requirements engineering process perceived specification size (4) behaves differently as initially demonstrated in the literature.

This section has modelled explicitly the effects generated by key variables explored in this paper and provides a basis for discussing general insights derived from the RE engineering process model. I would like to concur with Wolstenholme et al (1990), who conclude that it is *"the process of interpreting the results obtained by super-imposing the model which gives rise to an understanding of how the results are actually generated"*. The RE process model relationships are based on the views of requirements engineering process stakeholders, thus their insights captured into the model shed light on fundamental aspects of the real requirements engineering process.

However, it should be noted that the RE process model-based theory has not studied the performance of a RE process under a number of different scenarios. Undertaking scenario analysis will undoubtedly unfold some weaknesses in the model. This process points the model in areas of further work will be directed.

8. Insights Generated by the RE Process Model

The model accurately replicates most of actual process patterns. The model produced typical behaviour of schedule, quality and cost although it did not replicate the exact figures. In the SD study the focus is on behaviour rather than on numbers (Coyle, 1996); Forrester and Coyle, (1998); and Wolstenholme et al (1990). As already articulated, the model aims to provide a platform for debate and enhanced understanding of problems in the RE process. This paper developed prescriptive and descriptive model by applying System dynamics modelling concepts. This section identified resource, product, processes and information feedback between states. This paper explicitly modelled the requirement engineering process dynamics and simulated the process. The resulting generic model can be used as a tool by which problems in the requirements engineering process management can be explored and explained and appropriate decisions to change taken jointly by the owners of the problem. (Wolstenholme 1994, Coyle 1996). The rigour of the model and the modelling process facilitates the understanding of the RE process and will facilitate process enactment and technology development.

This section describes some of the initial insights generated by the model, which have arisen through this research programme. These insights demonstrate how system dynamic modelling approach could be applied to requirements engineer process. Further insights may be explored in the light of areas of future research discussed section 9. It is intended that such insights show how using dynamic synthesis methodology based on system dynamics modelling approach can generate ideas for extended debate in facilitating understanding of the issues rather than opinions or suggestions concerning model-based tool.

Insight 1
In a system like the model, which supports automated planning and control, problems might occur where adjusting cost, delays or effects. This aspect of target specification was highlighted through the observations of an unexpected dynamics in the model outputs. It was found that where the scheduled completion time was assigned the model-produced value, which is over the maximum allowable scheduled date. This variable (Scheduled Completion Date) was found not to have any substantial effect on expected delivery time. This is contrary to the position stated in the literature (Abdel-Hamid and Madnick, 1990; Boehm, 1981).

Insight 2
Technology and Critical Success Factors of the Software Development Organisations were found to have effect delivery times rather than on Scheduled Completion. Date as initially designed. This is very important and fundamentally very difficult question generated by the model which requirements engineers, researchers and project managers will have to deal with.

Insight 3
As suggested by Wolstenholme (1990) an interesting aspect of insight generation is that structures that give rise to them are often generic. This is illustrated in the fact that the problems of requirements error rework are associated with the allocation of manpower for rework. Use of generic structures like prescriptive theory in requirements engineering process provides a way of generating further insights, which are not always obvious to practising managers or requirements engineers. Key variables that seem to generate behaviour in the Model are summarised as:

- Project Size
- Software Development Organisation's seasonal critical factors
- Customer satisfaction
- General impact
- Technology Use

As illustrated by this case study, this paper seeks to understand problems of RE from a feedback control point of view. The model developed provides a fulcrum for debate and enhanced understanding of the RE process. The model should not be viewed as an answer to the problems, but rather as a vehicle for exploring many of the problems reported in the literature. 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 modelling. The model makes a useful starting point for developing a theory of the of RE process modelling and analysis.

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 modelling 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. This paper is a contribution to the literature on requirements engineering process modelling and model-based systems engineering debate.

This paper seeks to understand RE process problems from a feedback control point of view. The SD model developed provides a fulcrum for debate and enhanced understanding of the problems. SD has been acknowledged as an excellent medium for exploring and identifying knowledge gaps (Wolstenhome, 1991), but it has not been utilised in the requirements engineering process domain. The theory developed in this research applies SD modelling techniques to model and analyse the RE process and to be developed. The use of both qualitative (casual loop diagrams) and quantitative modelling techniques (Stock and flow Diagrams) Morecroft, 1987; Forrester, 1961; Richardson, 1990; Wolstenhome, 1991; Coyle, 1996) in SD, is of beneficial effect in communication between different stakeholders, and understanding through explanatory insights generated from complex models like those frequently identified in RE process.

The model can be used to investigate the effects of possible changes in customer perception of the progress or as a result of prioritising requirements and freeing others for future exploration. Due to the flexibility and customisable capabilities of the generic model developed, can be further improved to represent domain specific requirements engineering process. Such a domain specific model will allow for examination of different forces at play in each application domain, also for a more accurate representation of the schedule of the required complexity and associated quality and costs. Particularly, the model also extends the existing Abdel-Hamid and Madnicks' (1990) model to allow more holistic study of the software development dynamics. This extension may be achieved by adding a RE process model which was absent from the published model (Williams, 1994).

9. Towards a SD Theory of Requirements Engineering Process

Existing Software Engineering process models like CMM, Bootstrap, SPICE and ISO 9000 Standard identifies several prerequisites and technical practices that enable an organisation to consistently achieve these goals, BUT they do not prescribe specific requirements process modelling and analysis that SDO organisations must follow. As discussed in sections three and five, and verified in the feedback-based process behaviour. There are detailed interactions between RE specifications product quality, the SDO'S resources, Customer satisfaction, the schedule, and cost and activities relating to the nature of the process itself. These interactions determine the progress and completion time of the RE project. There are several activities within closed loops of the RE process dynamic theory which are sequential. However, over time these activities become iterative and continuous as depicted in Figure 14. Figure 14 depicts relationship between the dynamic theory of the RE process feedback structure and the factors of consequence in the Requirements Engineering process. The RE process starts with Request for Proposal by the customer to the SDO, and ends with Delivery of Specification. The representation of these generic activities was accomplished in the RE process several other activities occur, including:

1. Perception of the need for a new or updated systems software specification by both the customer and the software development organisation (SDO).
2. Estimation of the desired manpower effort to specify a new or upgraded systems software specification.
3. Estimation of cost, and schedule of corresponding to the desired effort.
4. Software Development Organisation investment of funds.
5. Acquisition of Project requirements engineers and other supporting resources.
6. Software Development Organisation request for funding.
7. Customer evaluation of the request of funding by SDO with respect to expected project cost – value resulting to commitment of funds.
8. Specification of the system software and validation and verification of the resulting product quality.
9. Evaluation of the progress of the project by the SDO and the customer.
10. Reformulation of the process estimates, based on (9) newly acquired experienced and domain knowledge. The customer and the SDO then present the re-evaluation for process continued investment.

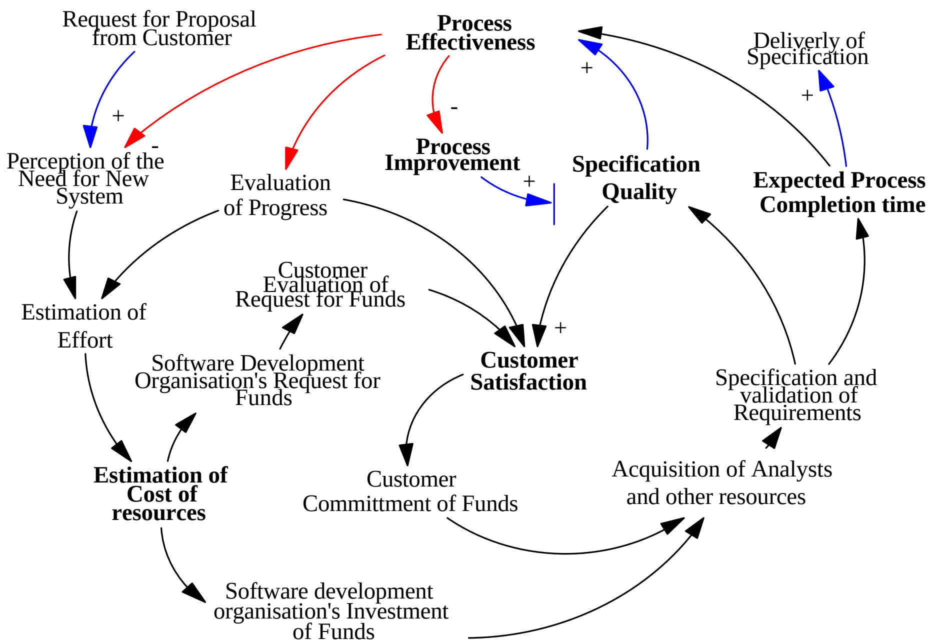

Figure 14: Dynamic Theory of the Requirements Engineering Process

As depicted in Figure 14, the activities continue to interact until the desired specification has been achieved and documented or until the process has been cancelled. Through experimental simulations the key influences upon requirements engineering process effectiveness have been isolated and studied and explicitly modelled. The factors of consequence emerging from this research as indicated by the direction and polarity of influence can be grouped in five categories:

- Size, data and complexity relating to the system software being specified;
- Critical success factors involving the SDO;
- Customer's external influences;
- Influences resulting from the very process of doing requirements engineering, particular as a social process.
- Technology availability and maturity for the SDO.

Analyses of relationships between variables indicate that they are many potentially important feedback loops. Some of these feedback loops return information about the RE process conditions that may be used in performance effectiveness.

10. Conclusions and Further Work

The requirements engineering process and other features do not happen instantaneously. Understanding the nature and the size of delays which constraint these process flows is important in relating RE process structure to behaviour. Introducing the variability in delays can be potentially effective tool for improving RE process modelling and analysis performance. Several of the relationships between process, product and resources are non-linear in nature. In particular the relationship that describes specified requirements between different activities can be described with non-linear relationships better than the linear approximation. It is these improved descriptions that expand the range of RE process, product and resource relationship, which can be modelled. This is true particularly if there is need to acquire new technology then decreasing training time on the use of new tools and methodology results in rapid process industry and technological integration. This time delay effect can also be avoided if at the start of the RE process there are more engineers.

Further work will be directed towards validating the system dynamics theory of the RE process. 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 that need to be refined. The third test – for policy implications of the impact of process effectiveness can be implemented by empirical observation.

I intend to carry out a programme of research to validate the model and test the propositions that may help explain the effectiveness of the RE process. I aim to undertake a survey that will identify characteristics of RE process and decision-making stakeholders relevant to research on RE process performance 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 understanding the RE process performance effectiveness. 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 RE process performance 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 RE processes modelling performance. 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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