ELEMENT OF A SYSTEMS DYNAMICS SIMULATION MODEL FOR REQUIREMENTS ENGINEERING

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ABSTRACT

The main aim of technology development and innovation is to deliver a new or improved product or service that will allow a company to maintain or increase its market share. This improvement in market share will only occur if the companies truly understand the customers' needs. This need is expressed as requirements that will form the basis of the product or service development and improvement specification. Care must also be taken not to over-specify the product or service since each of the selected requirements represents a cost to the company and eventually to the customer. The selection of the correct set of requirements are the first steps on the road to delivering a successful product or service. The elicitation of the requirements or specifications for a new or improved product or service forms part of the domain of requirements engineering. The requirements engineering domain is a complex, socio-technical system that is the result of the human element interacting with the technical element in the design and operation of the system of interest. This complexity could lead to the incorrect set of requirements being elicited if it is not understood and treated correctly. One of the methods for performing research within a complex, socio-technical system is by following a design science research approach to increase understanding of the problem domain.

Previous research has identified elements that describes the problem domain within the context of the design science research approach. This paper proceeds to present a system dynamics model that can act as the investigating artefact, simulating the interaction between the identified elements with the aim of reducing requirements volatility.

Keywords: Technology and innovation management; Complex Socio-technical systems; Requirements Engineering, Design Science Research; System Dynamics Modelling

INTRODUCTION AND RESEARCH METHODOLOGY

Introduction

Technology development can result from radical innovations that create entirely new products, or services. Technology improvement on the other hand results from incremental innovation in the form of adaptations, refinement and enhancement of existing products or services (Burgelman and Maidique, 1988; Hamid, Chew and Halim, 2012). Irrespective of the form of innovation, the purpose of these activities within an organisation is to gain or maintain a market advantage (Rouse, 1991). This viewpoint is supported by Burgelman and Maidique (1988) in analysing the results of a survey that they conducted of 158 products in the electronics industry, in which they identified eight principal factors of likely product success. The first and statistically most significant of these principles that they identified, emphasises the importance of an in-depth understanding of the customer needs and an understanding of the marketplace.

One of the measures of success of a new or improved product or service is the market's response to the product (Burgelman and Maidique, 1988; Shane, 2008). The success of such product or service can be determined by the size of the market's that have been created over a period, as well as the sustainability of the market. It is an accepted fact that a company can only gain a competitive advantage if it does something better than its competitors. This competitive advantage can only be sustained if the product or service it is something that the customer's value and other firms cannot easily reproduce (White and Bruton, 2011). Only by truly understanding the customer's needs, can companies innovate products and services that are desirable, feasible as well saleable in the target market. While these may be intuitive concepts when innovating new or improved products, these concepts should be as applicable to innovation within the service industries such as the insurance industry, banking sectors, information management services and healthcare.

It is also essential to select the optimal set of requirements for each requirement, or set of requirements comes at a cost to the company. It is thus of vital importance to identify the correct set of requirements at the beginning of the project. Later changes in requirements (additional requirements, deleted requirements or changed requirements) can have a cost impact that may negatively influence the viability of a new or enhanced product (INCOSE, 2015).

Research methodology

One of the recommended methods for performing research in a complex socio-technical environment is by employing a design science research methodology (Wieringa, 2014). This paper presents such a research approach where an investigative artefact is constructed to interact with the problem domain. This research approach aims to gain a new understanding of the requirements engineering domain. The elements of both the problem domain as well as the investigative artefact are based on the results of exploratory research methods including a literature survey and action research interviews.

Paper layout

This paper is organised in the following way. In the next section, the requirements engineering environment is described. In the following section, a description of the design science research approach, including a description of the problem domain and the investigative artefact. Some initial results of the system dynamic simulation models are presented and discussed. The final section of the paper is the conclusion followed by future research areas.

THE REQUIREMENTS ENGINEERING ENVIRONMENT

Requirements engineering forms part of the systems engineering process and is focused on the elicitation or discovering, documenting and managing of requirements. Various techniques can be used to elicit requirements from the different sources including documentation, stakeholders and existing or legacy systems (Anwar and Razali, 2012). These elicited requirements form the starting point for a project, whether it is an internal development process or a contracted-out project.

The requirements engineering process consists of the following iterative steps: Discovery and elicitation, analysis, validation and negotiation and triage. The documentation & specification, as well as the management activities, are ongoing activities that occur in parallel to the iterative steps (Wiegers, 2000; Hickey and Davis, 2004; Sommerville, 2011).

Requirements engineering is one of the most complex and critical phases in the life-cycle of the project. It is estimated that around 60% of the life-cycle cost of a project has already been committed by the end of the conceptual design stages (Blanchard and Fabrycky, 1990). The typically committed life-cycle cost over time is shown in Figure 1.

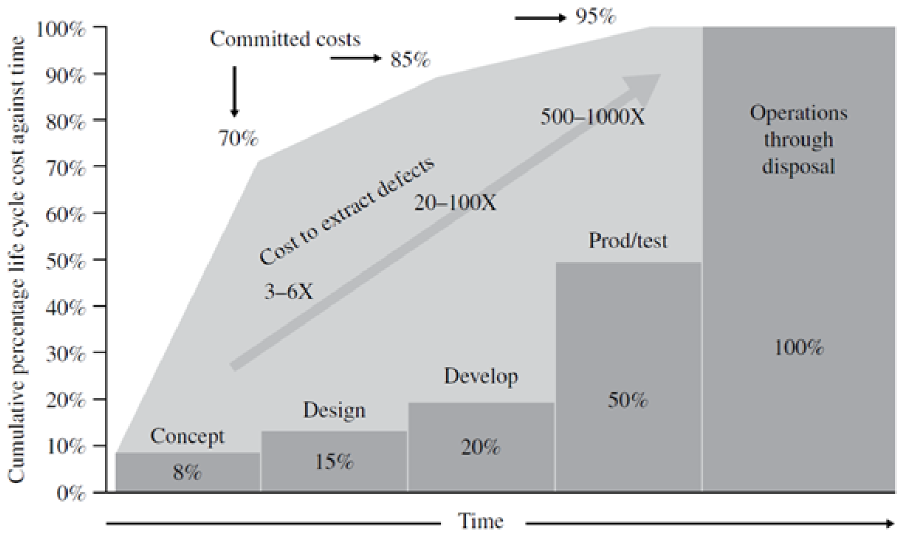

Figure 1: Committed life-cycle cost versus time (INCOSE, 2015)

Complexity in the requirements engineering process

The complexity associated with the requirements elicitation process can arise from some different causes including the maturity of the organisation, the number and type of stakeholders, as well as the required quality (Sheard, 2013). Research published suggests that there may as many as 32 complexity types spread over twelve disciplines and domains (Young, Farr and Valerdi, 2010).

The effect of the complexity encountered within the requirements elicitation process could result in an incorrect set of requirements being elicited that will then be carried forward in subsequent project phases (Scribante, Pretorius and Benade, 2016c).

An intuitive approach to dealing with complex problems is to break them into smaller, more manageable parts. This method is referred to as “reductionism” and will likely to lead to problems when applied to complex systems as complex problems contain interconnected parts, with the relationships between the parts being more significant than the parts itself (Jackson, 2002).

To deal with complex problems, one has to apply systems thinking principles to identify the parts, the relationships between the parts and the emergent properties (Jackson, 2002). Systems thinking is the result of discovering, learning, diagnosis and talking that results in sensing, modelling and discussing the real world to understand better, define and work with systems (INCOSE, 2015).

The requirements engineering process as a socio-technical system

One of the lesser recognised areas of complexity is the result of the organisation that is in need of the solution, the organisation creating the solution as well as the created solutions all being socio-technical systems. A socio-technical system is created where two jointly independent systems, the social and the technical, interact in a correlative manner to produce a single outcome (Bostrom and Heinen, 1977a). In such a socio-technical system the technical system is involved with the various processes, different tasks and technologies required. The social system relates to the different attributes of the people, the relationship between the various stakeholders as well as the reward systems that are present in such an organisation and the reporting and authority structure present (Bostrom and Heinen, 1977b). Such a socio-technical system has a high level of dynamic complexity. This dynamic complexity is a result of the interactions of the stakeholders over time, including time delays between making a decision and implementing it, or making an observation correcting it. The effect of this complexity is that the learning loop is slowed down, thus reducing the amount of improvement that can be achieved within a given period (Sterman, 2000).

PERFORMING RESEARCH IN A COMPLEX SOCIO-TECHNICAL SYSTEM

The standard approach to research from the viewpoint of the natural sciences is to follow a theory development and testing approach based on positivist methods. In the case of the social sciences, a similar approach to theory development and testing is followed, but using methods ranging from positivism to interpretivist. The use of these different methods occurs as a result of the subjective and complex nature of the social sciences. The primary product of both the natural as well as the social sciences is a theory, arising from empirical testing (Venable, 2006).

This type of research approach does not always yield the desired results when performing research in a socio-technical system environment where the aim is to improve a situation or to provide a solution to a specific problem. An alternative research methodology is to approach the problem from a design science research point of view. A design science approach focuses on not only understanding the problem but also generating a solution to the problem (Wieringa, 2014). A design science approach is an inventive or creative approach to solving problems that contain technology as one of its primary products (Simon, 1996).

Under the design science research approach, an artefact is designed that interacts in some way with the problem context. The design science research process considers both design and empirical research as the problem-solving tools. The primary focus within the design science research environment is not the artefact that has been designed neither the context in which it is being used, but rather the interaction between the artefact and the problem context that contribute to solving the problem (Wieringa, 2014).

The interaction between the artefact and the context is shown schematically in Figure 2. The format of the artefact can range from software components and systems, hardware components and systems through to business processes and conceptual structures. The context can include people, organisations through to services, methods and techniques (Wieringa, 2014). An essential aspect of design science research is that it is not the artefact or the context that provides any new insight or results but rather the interaction between the artefact and the problem context (Wieringa, 2014).

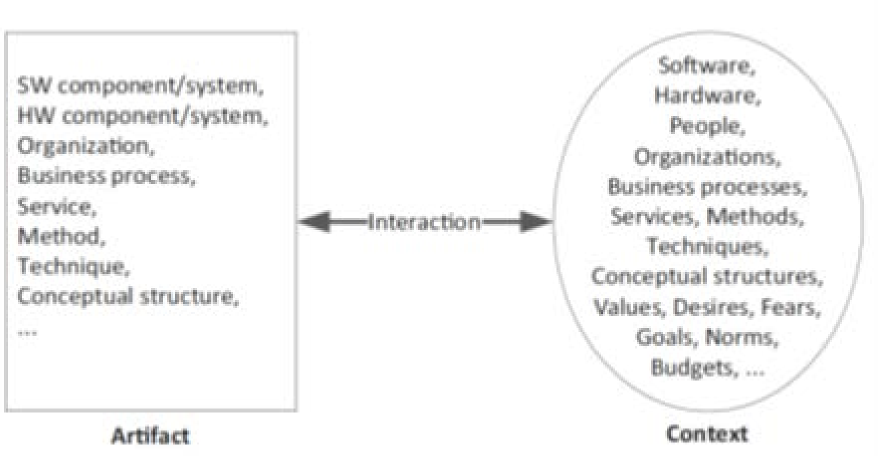

Figure 2: Depiction of the artefact interacting with the context (Wieringa, 2014)

DESIGN SCIENCE RESEARCH APPROACH

We can visualise the design science research environment in the current research context of requirements engineering as is shown in Figure 3. This environment comprises the requirements engineering problem context and the investigative artefact. The requirements engineering problem context consists of the requirements engineering process as well as the environment that it exists within.

The investigative artefact consists of the system dynamics simulation model that is used to investigate the requirements engineering process in context and within a defined boundary.

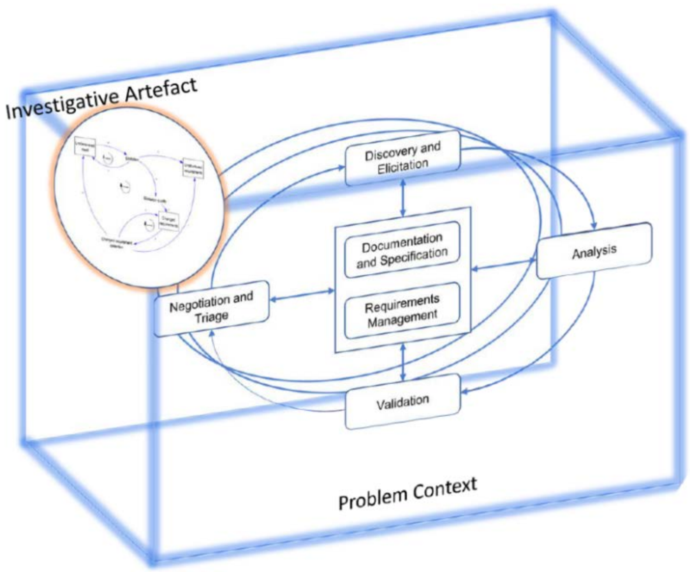

Figure 3: Requirements engineering design science research problem illustration

Requirements engineering problem context

Requirements and the Requirements engineering process

Requirements engineering is defined in the ISO/IEC/IEEE 29148 standard, (2011) as "… an interdisciplinary function that mediates between the domains of the acquirer and supplier to establish and maintain the requirements to be met by the system, software or service of interest." The ISO/IEC/IEEE 29148 specification further states that requirements engineering is concerned with "discovering, eliciting, developing, analysing, determining verification methods, validating, communicating, documenting, and managing requirements." (ISO/IEC/IEEE, 2011)

A requirement can be defined as "... a statement which translates or expresses a need and its associated constraints and conditions." (ISO/IEC/IEEE, 2011) A common understanding within the engineering industry is that the focus of a requirement should rather be on the "what" that needs to be solved rather than on the "how" it should be solved (Faulk, 1997). A requirement defines the attributes regarding capability, characteristics or quality of the system, product or service to have value for a customer (Young, 2004).

The definition provided above distinguishes between a need and a requirement. In this context, a need is considered to be an expectation stated by the stakeholders at the business management level or the business operations level. A requirement is a formal statement that is structured in a specific way to be able to be verified within the design of the artefact being created as well as verified back to the original need and expectation from which the requirements were developed (INCOSE, 2017).

The requirements engineering process

The requirements engineering literature provides various views regarding the activities that form part of the process.

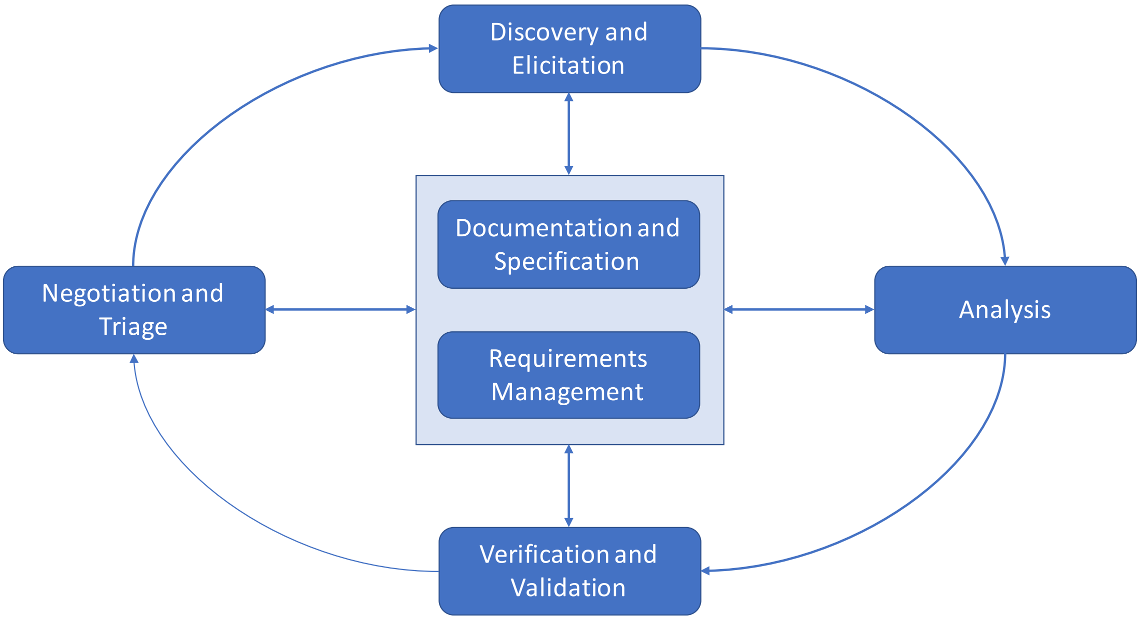

Figure 4: Requirements engineering process model (Adapted from Sommerville (2011))

Elements of the requirements engineering process

The following elements of the requirements engineering process, related to the process depicted in Figure 4, are identified from the literature (Wiegers, 2000; Hickey and Davis, 2004; Sommerville, 2011):

- **Discovery and elicitation**
  The requirements discovery and elicitation process are about the learning, uncovering, extracting, surfacing, or the needs of customers, users and other potential stakeholders.
- **Analysis**
  The analysis sub-process within the requirements engineering process is involved with analysing the information elicited from the different stakeholders. The purpose of this analysis process is to increase understanding as well as to search for incompleteness and errors in the requirement set.
- **Verification and validation**
  The outcome of the verification and validation process is a reasonable, consistent, complete, suitable, free of defects set of requirements.
- **Negotiation and triage**
  The requirements elicitation process will often identify a broad set of requirements. During the negotiation and triage sub-process, the requirements that will form part of the different release baselines will be identified.
- **Management**
  Requirements management is a formal process to maintain a set of requirements including change management.
- **Documentation**
  The capturing of the requirements in a format that will be usable to the different stakeholders, such as systems requirement specification or in a requirements database.

Types of requirements

Different types of requirements are identified in the literature (Faulk, 1997; Wiegers, 2000; Sommerville, 2011):

- **Functional requirements**
  Functional requirements define what the product or service should be able to do or how it should behave. In specific instances, functional requirements can even explicitly state what the product or service should not do.
- **Non-functional requirements**
  Non-functional requirements place constraints on the product or service be designed. The constraints include on aspects such as the development process as well as constraints imposed by applicable standards. Non-functional requirements can further be grouped into product or service requirements, organisation requirements, and external requirements.
- **Business requirements**
  The business requirements define the business case that is driving the product or service development including the benefits for both the end user or customer as well as the business or organisation.

Sources of requirements

Requirements can be elicited from three primary sources. These sources are typically used concurrently. They are documents, existing systems and legacy systems as well as stakeholders.

Documents that can be used a source of requirements include items such as manuals, specifications, job descriptions, forms, and standards that are mandatory.

Existing systems that can be considered as a source of requirements may include legacy or competing systems (Anwar and Razali, 2012).

Requirements volatility

In an ideal project, the goal for the requirements engineering process should be to elicit a stable set of requirements. In reality, requirements will change over the course of a project due to some factors including advances in technology, errors in the original requirements, and changes in the business needs. Requirements elicitation should instead be viewed as a learning exercise rather than just a gathering process (Reifer, 2000).

Ferreira *et al.* (2009) define requirements volatility as the growth or change in requirements during a projects development lifecycle. Alternative terms for requirements volatility include requirements evolution, and requirements creep. Requirements volatility is measured regarding the number requirement additions, deletions or modifications over a specific period (Ferreira *et al.*, 2009). Requirements volatility is also sometimes referred to as requirements churn or requirements creep in the literature.

Challenges in the requirements engineering process that may contribute to requirements volatility

The challenges that the requirements engineer face have been presented and discussed in previous research papers that were published (Scribante, Pretorius and Benade, 2015, 2016b, 2016c). The factors that contribute to these challenges are summarised in Table 1.

Table 1: Summary of challenges in the requirements engineering process that may contribute to requirements volatility

Stakeholder and requirements engineer characteristics	**Stakeholder and requirements engineer interaction**
• Domain knowledge • Technical knowledge • Stakeholder or customer introduced misinformation • Requirements engineer introduced misinformation • Requirements engineer personality • Requirements engineer experience • Resistance to change • Use of external specialists or consultants in the elicitation process	• Communication between stakeholder and requirements engineer • Conflict • Cultural differences • Social nature of requirements elicitation **Project environment** • Legacy requirements • Project size, type and complexity • Quality and quantity of documentation sources • Attainability of the requirements • Changes in technology • Implementation independence • Time pressure to complete the project

INTERACTION BETWEEN THE ELEMENTS OF THE PROBLEM DOMAIN

The previous paragraphs described the different elements of the problem domain. It can be challenging to understand the interaction of the different elements to create the complex situation that is found in real life. One of the methods that can be used to increase understanding in this process is by constructing a causal loop model that shows the interaction by the different elements as well as indicating if this effect is increasing or decreasing the impacted element.

A causal loop model exploring the impact of the various elements on requirements volatility was previously presented and discussed by Scribante, Pretorius and Benade, (2016c), is shown in Figure 5.

INVESTIGATIVE ARTEFACT

The second element of the design science research approach is the investigative artefact. The purpose of the investigative artefact is to perform research on the problem domain within the context that it is being used in. The goal of this investigative artefact is not to provide a concrete answer but to instead improve the understanding of the problem domain in greater detail. A system dynamics model was selected to act as the investigative artefact to interact with the problem domain.

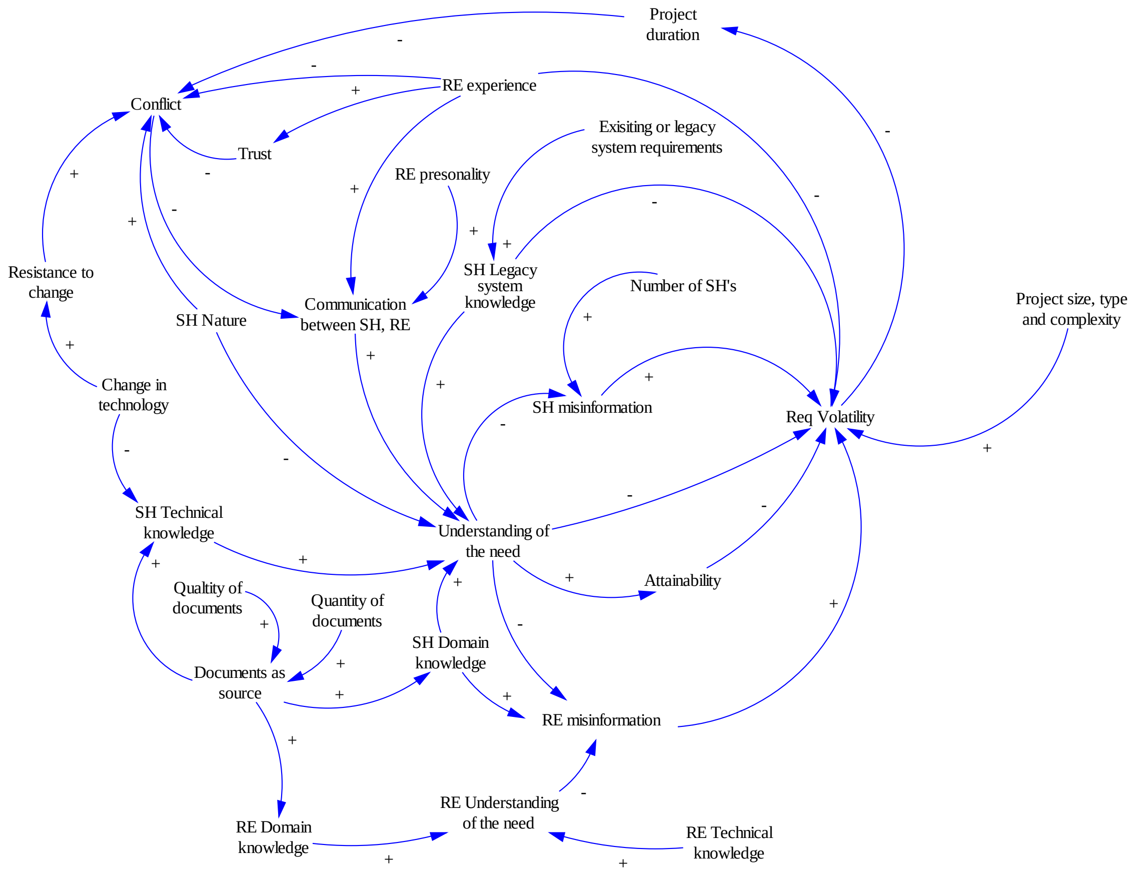

Figure 5: Causal loop model of the elements impacting on requirements volatility (Scribante, Pretorius and Benade, 2016c)

System dynamics

System dynamics is a methodology for studying complex feedback systems, such as one finds in business and other social systems. Feedback in the context of the system dynamics methodology refers to the where a situation consisting of X affecting Y and then in turn Y affecting X through a chain of causes and effects. Of importance is that one cannot only study the link between X and Y independently, as the link between Y and X also influence the behaviour of the system. Only a study of the complete system including any feedback loops will lead to correct results and interpretations (System Dynamics Society quoted by Khan, McLucas, and Drive 2008).

The purpose of a system dynamics model is to create a better understanding by improving understanding of the relationships between feedback structure and dynamic behaviour within a system (Richardson, G.P. (1991) quoted by Khan, McLucas, and Drive 2008).

A typical systems dynamics model consists of one or more elements that may include cause and effect (Causal loop) diagrams, stocks or levels (quantities that accumulate / de-accumulate over time), flows (the rate of change of stocks), feedback, delays and nonlinearity (Sterman, 2001; Pretorius, Pretorius and Benade, 2015; Scribante, Pretorius and Benade, 2016a)

Problem statement

During the requirements engineering process, the undiscovered needs of the stakeholders are converted into unstructured requirements via the requirements elicitation process. The requirements engineering process should ideally be a linear process where the undiscovered needs are converted into unstructured requirements over a period at a fixed elicitation rate. The actual situation is that the elicitation process is not perfect. Many different errors including the factors identified in Table 1 can result in requirements being incorrectly discovered and elicited, which will, in turn, require correction at a later stage in the requirements engineering process that will have an impact on the cost, schedule and performance constraints of the project.

Dynamic hypotheses

A dynamic hypothesis is a viewpoint of the modeller about what structures and interactions exist that can generate the expected behaviour (Keloharju, 1981). The dynamic hypothesis for the requirements discovery and elicitation process is shown in Figure 6. The <u>undiscovered need</u> that exists is transformed into <u>unstructured requirements</u> via the requirements elicitation process. During the elicitation, process errors are created resulting in incorrect <u>unstructured requirements</u> being captured erroneously. These errors (<u>changed requirements</u>) will only become known errors after they have been detected. After detection, the incorrectly elicited <u>unstructured requirements</u> will be removed and added back to the <u>undiscovered need</u> to be processed via the discovery and elicitation process again.

System dynamics simulation model

A system dynamics simulation model can now be constructed based on elements of the dynamic hypothesis as is shown in Figure 6. The purpose of this simulation model is to demonstrate the use of such a tool that can be used as an investigative artefact within a design science research environment. This simulation model also plays a role the model validation process that is used to gradually build up confidence in the results and boundaries of the simulation model. This process starts at the model conceptualisation stage and continues even after the implementation of the results (Barlas, 1994).

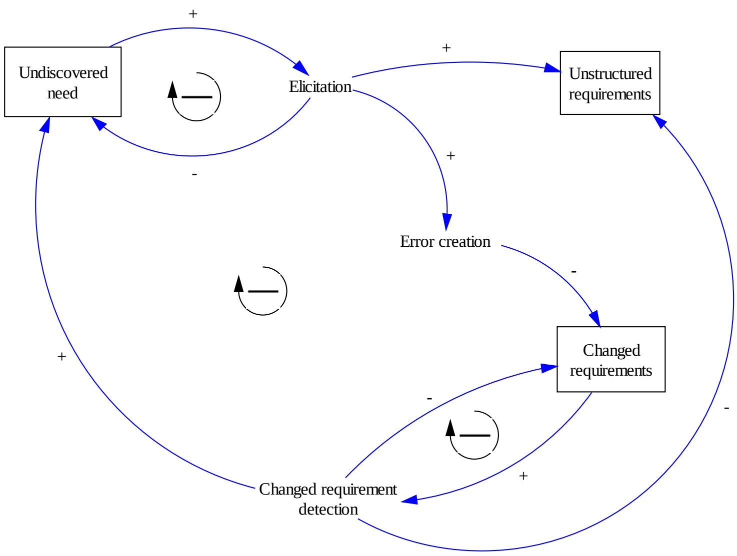

Figure 6: Dynamic hypothesis model for a single stage requirements engineering model (Scribante, Pretorius and Benade, 2017)

Model description

The stock and flow diagram for this simulation model is shown in Figure 6. The endogenous variables for this simulation model are the undiscovered needs, unstructured requirements, and changed requirements, elicitation, and changed requirements detection. The parameters "*initial undiscovered requirements", "elicitation rate", "detection rate", "elicitation behaviour lookup", "error creation lookup" and "error detection lookup"* are all determined via an action research process using subject matter experts from various industry segments.

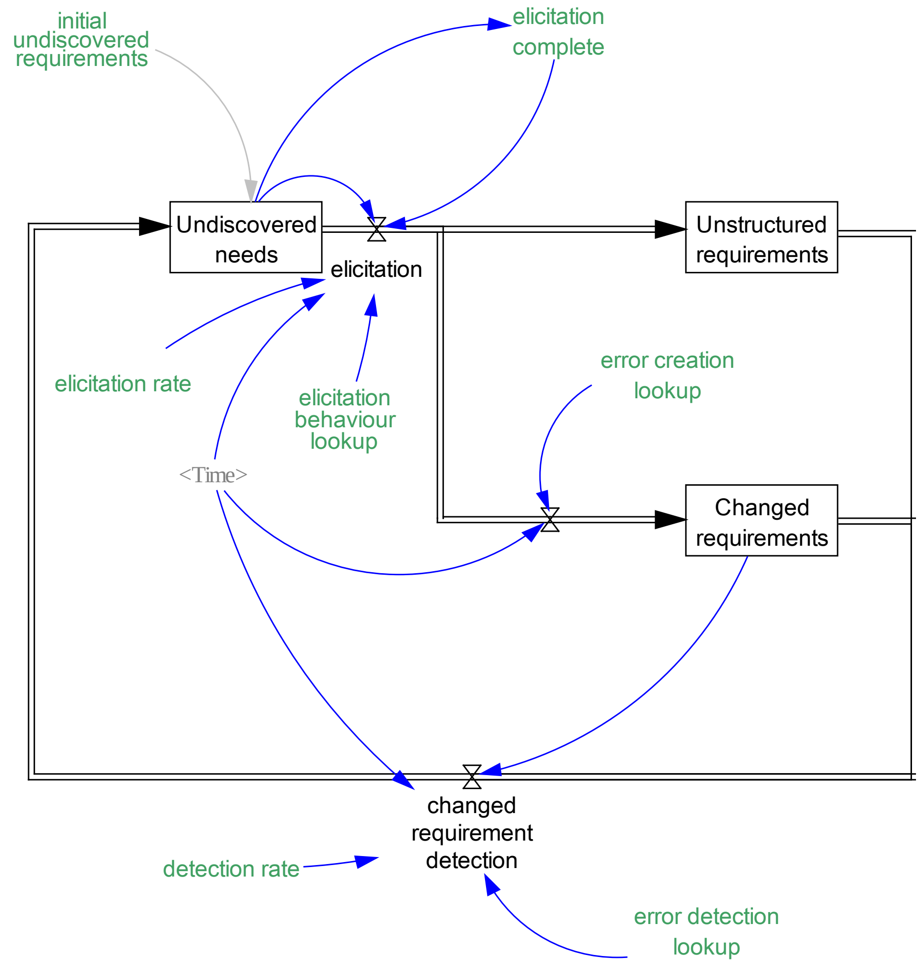

Figure 7: System dynamics simulation model

The algorithms for the endogenous variables are presented in Table 2.

Table 2: Endogenous variable algorithms

Variable	Basic algorithm
Undiscovered needs	$\int (changed\ requirement\ detection - elicitation)$

elicitation	*elicitation behaviour lookup(Time)*elicitation rate*
Unstructured requirements	$\int(elicitation - changed\ requirement\ detection)$
Changed requirements	$\int((elicitation * error\ creation\ lookup(Time)) - changed\ requirement\ detection)$
changed requirement detection	*detection rate*error detection lookup(Time)*

The base variables for the simulation model were determined from action research interviews with subject matter experts. The following variables were determined typically for the banking sector as the first illustration of simulation results that can be obtained:

Table 3: Base simulation parameters for the banking sector

Variable	Value
Small project duration	3 months
Project definition duration	1 month
Typical number of requirements	250
Calculated elicitation rate	12.5 requirements/day
Estimated error detection rate	4 requirements/day
Simulation time	50 days

Control scenario

The purpose of the control scenario is to provide a systematic verification of the simulation model. This verification is done in this simulation research, by using constant variable lookup tables as is shown in Figure 8.

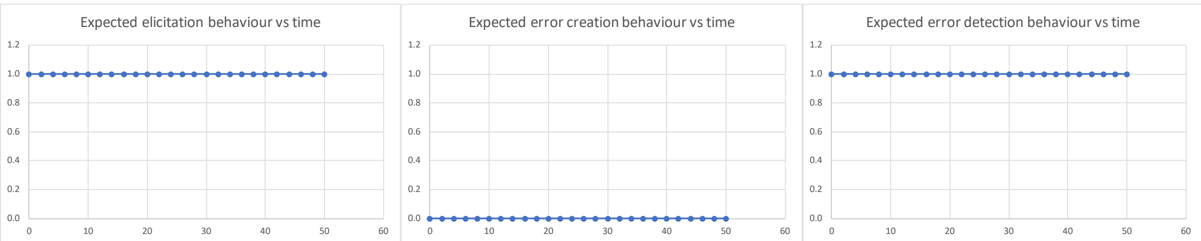

Figure 8: Control variable behaviour vs time

The simulation results using the control variables are shown in Figure 9. Since the <u>expected elicitation behaviour</u> is constant at a value of 1 (perfect) and the <u>expected error creation behaviour</u> is constant at 0, all the requirements discovered and elicited are directly transferred from the <u>undiscovered need</u> stock to the <u>unstructured requirements</u> stock without any errors. The elicitation process as simulated based on the control variables shown in Figure 8, is completed shortly after twenty days.

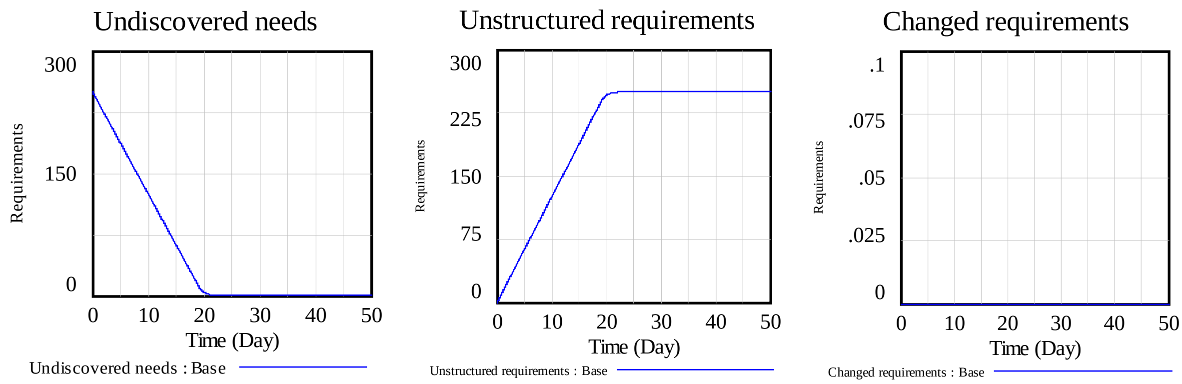

Figure 9: Control variable results

Discussion

The behaviour and results for control scenario are as expected for the dynamic hypothesis created. As the elicitation is perfect, the undiscovered needs are all converted into unstructured requirements at a rate of 12.5 requirements per day, being completed after twenty days. The model is designed so as not to be able to elicit more requirements that are available, resulting in the gradual rounding of the graph as the undiscovered needs approach zero and the unstructured requirements approach 250.

Expert vs uninformed domain knowledge

One of the factors that were identified in a previous section that can influence the requirements elicitation process is that of the stakeholder or requirements engineer level of domain knowledge. The following system dynamic simulation scenario investigates the potential effect of domain knowledge in the elicitation process by comparing the results of expert domain knowledge vs uninformed domain knowledge. The control variable for the expert domain knowledge case is shown in Figure 10 and for the uninformed case is shown in Figure 11.

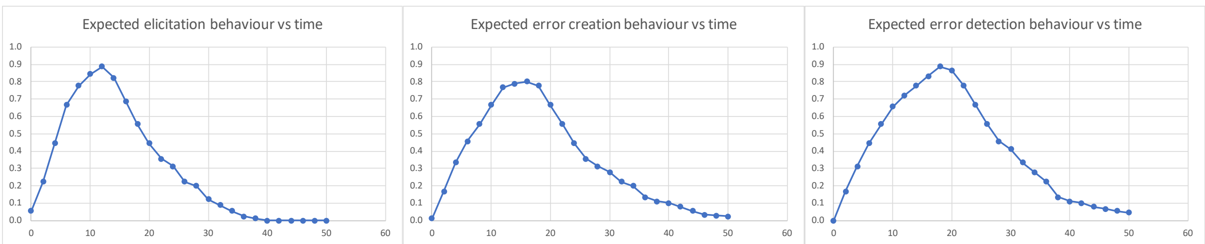

Figure 10: Expert domain knowledge variable behaviour vs time

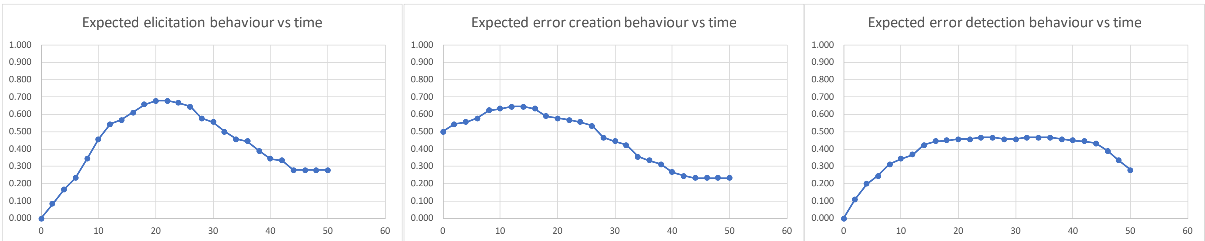

Figure 11: Uninformed domain knowledge variable behaviour vs time

The results of the expert domain knowledge simulation case vs the uninformed domain simulation case are shown in Figure 12.

Discussion

The undiscovered needs simulation results shown in Figure 12 present a counter-intuitive picture. One would assume that the expert domain knowledge case would in all cases present the most optimal results. The picture that is presented however seems to indicate that the uninformed domain knowledge simulation case has resulted in more undiscovered needs being converted into unstructured requirements. The actual picture only becomes evident when one examines the changed requirements results. Here it becomes clear that the requirements that were incorrectly elicited, but still has to be discovered are worse in the case of the uninformed domain knowledge case. The result of this will typically be that the project team will work under the assumption that most of the requirements were elicited while in fact, a large number of requirements can still potentially change.

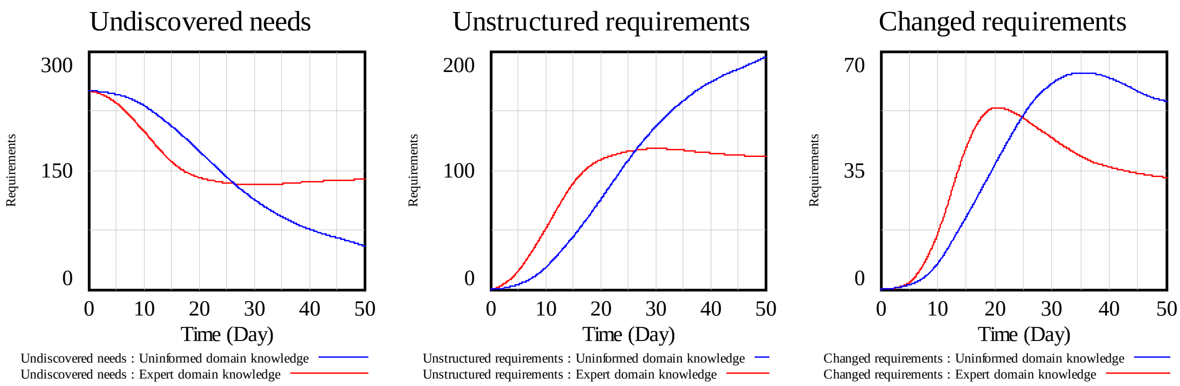

Figure 12: Simulation results for the expert domain knowledge case

SUMMARY AND CONCLUSION

This paper proposes a design science research approach that is used to investigate the complex, socio-technical system inherent in the requirements engineering process. An investigative artefact in the form of a system dynamics simulation model is proposed. Initial simulation results using parameter behaviour as determined from action research interview shows promising results that can be used to increase the understanding of the requirements engineering process.

FURTHER RESEARCH

Future areas of research will focus on the evaluation of the effect of the other factors that can influence the stability of requirements as well as combinations of the factors to determine if specific instances can be identified where the requirements volatility will be increased or decreased. The eventual aim is to determine if there are a generic combination of parameters that are known to increase the volatility and in that way decrease the probability of project success.

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