UNIVERSITY OF KWAZULU - NATAL

THE NON-LINEAR EFFECT OF PROJECT CHANGE ORDERS: A SOUTH AFRICAN CASE

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"Our only responsibility is to look after the interest of, and to protect the client."

Derick Serfontein (personal conversation held 16 September 2011)

DECLARATION

I, Mhlengi Arthur Madiba, declare that

(i) The research reported in this dissertation/thesis, except where otherwise indicated, is my original research.

(ii) This dissertation/thesis has not been submitted for any degree or examination at any other university.

(iii) This dissertation/thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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Signature,

………………………………………

Mhlengi Arthur Madiba

ACKNOWLEDGEMENTS

Dedicated to God and:

- Ntokozo the love of my life;
- Akhanya and Khanya, the "meaning";
- Sithokozile, my father & mother;
- The Madibas and the Ncubes;
- To my friends for the positive influence. To Sandile for unintentionally showing me the crippling effect if indecisiveness;
- Bosch Projects for the opportunity, Guy Perrins for being such a cool boss and mentor;
- Nico Wentzel, Marie Foord, Norman Hind, Andrew Cruickshank, Brian Venkatasen, Ryno Eksteen and Nick Schutte for taking your time to participate in this research and share your knowledge with me (the muffins will come forth);
- "Spaullidas" and "Gokoolidas" the original Spartans!
- Bode for the assistance, I do not think you know how much you helped me in getting to grips with the modelling process and the use of iThink;
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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

ABSTRACT

The research focused using System Dynamics to model and simulate an engineering project with the main aim of understanding:

- Why change orders are notorious for negatively impacting on project execution;
- The root cause(s) of the behavior in order to find ways to better manage change orders in future projects;

The research was carried out at a leading KZN-based engineering consultancy using data from a recently completed project as a basis for the model. The research took the following approach and sequence:

Introduction: In this section I present the dominant school of thought, the reductionist scientific perspective and its strengths. I then highlight the weakness of the school and present systems thinking as an alternative way of viewing life issues. I then propose system dynamics as one of the better methodologies that can help us understand a dynamic and non-linear system.

Literature Survey: In this section I review literature on project management with the primary aim of highlighting that projects, regardless of size, are complex non-linear systems. I then cover literature on system dynamics with the aim of justifying my perspective, that it is suitable for application in the project management context.

Research Methodology and Results Analysis: This section presents the methodology I followed in executing the research. The research process started off with extensive data reviewing from a recently completed project. It also covered conversations with the research participants in order to help me fully understand the project that was to be modelled. The data reviewing and interviews culminated in a group model building exercise where a number of "what if" scenarios were explored and discussed with the participants. The final stage of the research was to get the participants to respond to a post-modelling questionnaire. The outcomes from these processes were then used to answer the original research questions and to draw any additional insights.

The resultant model can now be used as a learning tool for teaching clients of the unintended consequences that can result from issuing change orders.

Conclusion: I then close off the research by concluding that change orders do have a non-linear impact on project execution and they require careful management. I then suggest that the best way to manage this is by educating all the project participants, especially the client of how their well meaning requests can be detrimental to the project if not well managed.

Additionally it was surprising to all participants that for some reason, exploration of change orders that are not approved is rarely ever charged for. This "work for no pay" can negatively impact on the financial situation of the service provider which may have a knock-on effect to other areas of the project.

Value: This research eventually revealed itself to be about learning to effectively lead a group modeling exercise and what pitfalls to look out for when creating models. There is great value for people interested in finding progressive and well informed ways for model building and managing change orders in projects.

This system dynamics in project management research is grounded on the concepts of the learning organization and systems thinking as the core drivers.

TABLE OF ACRONYMS

VO	-	Variation Order
BP	-	Bosch Projects
SD	-	System Dynamics
QCP	-	Quality Control Plan
PMR	-	Project Man-hour Resources
WBS	-	Work Breakdown Structure
TCH	-	Tons Cane per Hour
EU	-	European Union
SACU	-	South African Customs Union

DEFINITION OF TERMS

The following terms and definitions are important to understanding the paradigm from which the research is being undertaken. Some definitions here are not complete but are sufficient for the purpose of meaningfully engaging this research:

System: A group of things, pieces of equipment, etc. that are connected or working together.

Change Order/ Variation Order: This is a client request in a project management environment that adds to the workload of some or all of the service providers. It may have cost or time impact on the overall project.

CONFIDENTIALITY CLAUSE

November 2011

To Whom It May Concern:

RE: CONFIDENTIALITY CLAUSE

Due to the strategic importance of this research it would be appreciated if the contents remain confidential and not be circulated for a period of five years.

Sincerely

....

Mhlengi A Madiba

CHAPTER 1

MaMntungwa

1. BACKGROUND & RATIONALE

1.1 Overview

In this chapter I will present the background of this research endeavor. I will commence by discussing my worldview, the scientific method and its shortfalls in helping humanity understand and address complex systems. I will then discuss complexity science and systems thinking, which I will argue pick up the pieces when the scientific approach begins to fail. This will be followed by a discussion on bounded rationality and how it explains human behavior when dealing with complex systems. I will show a clear link that justifies the need for this research endeavor, clearly arguing that all these concepts (the scientific approach, systems thinking and complexity science and bounded rationality) are all interconnected.

This chapter will culminate in the presentation of the research aims, questions and propositions.

1.2 My Perspective

It is important to acknowledge that I have chosen to take a systems view of the world and this will be revealed during this research.

Systems thinking is a term that has become generic and is now used and understood to loosely mean thinking about problems in a systemic way. The term covers all systems based methodologies; including Complex Adaptive Systems (CAS), Soft Systems Methodology (SSM), System Dynamics, Viable System Model (VSM) etc. and the common theme as will be shown later in this chapter; is the holistic approach to addressing issues. The use of the term has taken a fad-like form. People who do not truly know or understand what it means to be a systems thinker usually use it rhetorically, especially when positioning themselves as deep and reflective experts who have covered all the bases in addressing a problem.

All the systems methodologies are rooted on the belief that all system variables have feedback relationships. This is the reason that diagramming techniques used to enhance the analyses and understanding of a problem situation, are circular and try to capture the influence and feedback relationships. The most common tools are Causal Loop Diagrams and the related Influence Diagrams. While these tools do enhance understanding as they explicitly factor in the feedback relationships, they are not sufficient to infer the dynamic effect of the causes. In drawing the causal diagrams, we also assume that we know the causal direction between the variables which I will be arguing is not exactly true. This misallocation of cause and effect usually leads to the misdiagnosis of systems.

Obviously hand drawn sketches have a limited potential in revealing the feedback dynamics that exist within a system. System dynamics goes a step further by taking the causal relationships and exploring their dynamic interplay on the system. It does this by harnessing the power of computer simulation. From the simulation one is able to witness a system wide impact of changing the variables. Unlike static analysis tools, more than one variable can be altered if there is a need.

This distinction makes systems thinking the gateway to the advanced, more focused and more rigorous world of system dynamics. The other systems thinking tools are good for the holistic general understanding of problems but where the dynamics of the system have to be understood, system dynamics is a much more suitable method in my opinion.

I will attempt to show during this research that dynamic simulation is one of the better ways we can better understand complex systems and alter mental models.

1.3 Limitations of Mental Models

Human beings use mental models to make sense of the world. Mental models are our mental creations of how things work or how they should work. They are a selective abstraction of reality (Richmond; 2005: 4). Quite often our mental models are inaccurate, incomplete, and messy and represent a static perspective of reality (Forrester 1995: 4 and Sterman 2011: 2). The reason we are generally not aware of the incorrectness of our mental models is that we do not know that they exist. Additionally the flawed models are generally sufficient for us to keep going on with our daily activities. People unconsciously alter their mental models as they get exposed to new information and experiences (Forrester 1995: 4) and learn from them.

The danger of mental models is that people with two different mental models can engage each other and agree on issues without knowing that their perspectives differ fundamentally. This can be the source of disagreement and even litigation at a later stage as their mental models become clearer and found to be in contrast to each other. There are many methods that can assist us in exposing and questioning our mental models so that when we engage each other while aware of each other's underlying assumptions about the issue we are dealing with. The best method for altering mental models is real life experience which fosters deep learning to the participants. However, even with real life experiences sometimes the human mind refuses to learn. Next to real life experience based learning is learning by experimentation. Experimentation provides a safe controlled learning environment however some systems do not afford us the opportunity to experiment in order to facilitate learning and we have to find alternate ways to learn. The limiting factors could be things such as costs, which can be financial or otherwise.

Learning aids such as metaphors and simulation can play a major role in bridging the gap between real life learning and ones preparedness to deal with real life issues. The power of these learning methods lies in that they prepare us and allow us to see the effects of our decision without incurring real life costs. They prime us so that we know how to react when we encounter a situation in real life. Metaphors allow us to use familiar situations to make sense of unfamiliar ones. With good metaphors, system surprises do not come totally unexpected. Lyon (2000: 137) says:

> *"… definition of metaphor be that it is a figure of speech in which a word is directly applied to a thing… to which it is not literally, but imaginatively applicable."*

With metaphors new cognitive structures are developed from existing ones in order to facilitate learning (Hsu; 2005: 772).

This research will primarily focus on using simulation to create a deep learning environment aided by metaphors. The simulation and the learning will be based in a project management environment and will help the participants visualize the effects of a constantly reoccurring problem in projects.

1.4 Connecting the Dots

Quite often people have what they describe as life changing experiences. What this means is that people have mental models changing experiences which can suddenly alter ones values, priorities and behavior. Questioning and constantly challenging ones mental models is good way of engendering a culture of continuous learning and adaptability.

Adaptation is necessary in fast paced environments if you want to increase chances of long term survival. For organizations, adapting faster than your competitors increases the chances of long term survival and profitability. It can give one's organization a competitive edge over other organizations within the same industry. The ability to maintain both efficiency and flexibility are major challenges for organizations (Lant & Mazia; 1992: 47). Hsu (2005: 773) says that there is a school of thought that says there is a correlation between highly developed mental representations and sophisticated performance.

Sometimes when we go through a mental model changing event or process we find that all the things that lead us there have always been known to us but we never made a link between the processes. Gibbs et al (2004: 1190) say that sometimes metaphors do not create new mental models but they reveal pre-existing ones that are primary to our experience. This is what I call intuitive knowledge which is not always useful if the person is not aware of his thoughts and abilities. It is important to move people from intuitively knowing to consciously knowing.

Repeated learning of a skill frees the brain to focus on other aspects of a system (Billett; 2002: 461). Conscious knowledge is good in that it improves the chances that the person will act optimally most of the time. Making the link and connecting the dots is a necessary process and it is this process that allows us to think systemically and to see the bigger picture which is in line with Richmond's 10000 meter thinking (2005: 11). When one goes through the process of connecting the dots it feels like a transparent yet blinding layer has been removed from one's eyes. I call it transparent because usually it is things you always knew that suddenly give rise to a new level of awareness. Hsu (2005: 771) says metaphors highlight the rules from the source content and assist us to understand the rules of the new domain, from this process we alter or create new mental models by inference.

System dynamics modelling and simulation and the whole process of building the model is equivalent to a process of connecting the dots. This means that sometimes, even before the model is simulated, one may have already gone through the deep learning process and made a connection of variables that previously seemed unrelated.

1.5 The Nature of Issues

Amongst many things that make living engaging and worthwhile for all living beings is the ability to make decisions. Making decisions that seem meaningful reaffirms our sense of self. This sense is amplified multi-fold if others also perceive our decision choices as meaningful.

Jackson (1994: 214); under his Critical Systems Thinking meta-methodology; creates a simple problem situating diagram, as shown in *Figure 1*. By understanding where within this diagram a problem situation falls we are able to choose the most suitable systems thinking based decision support method. However this diagram not only helps us in identifying a suitable method, it also easily helps us understand the basic nature of problems that we deal with on a daily basis, even for those people who reject the systems thinking perspective.

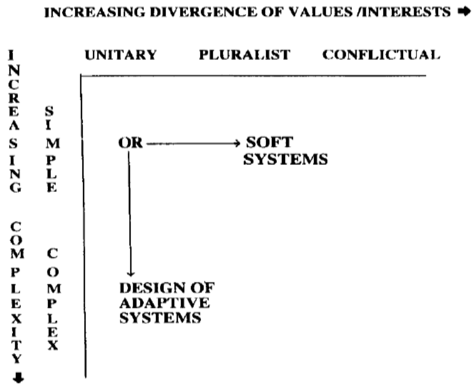


Figure 1: The Decision Situating Method
Source: Jackson (1994: 214)

The machine metaphor, so commonly used in organizations, implicitly assumes that all problems are simple and unitary. Where there is a realization that they are not so, it reduces them to this form by taking the "all things being equal" stance that is so common in many economic and engineering models. These models were developed using the scientific method, as used in contemporary language. Deterministic solutions simplify problems to the point of them being "devoid of practical interest" (Forrester; 1964: 3).

In this chapter I propose that today more than ever we are faced with problems of increasing complexity (Vertical Axis). I also propose that because of the many sub-systems; religion, race, cliques, organizations etc; we are constantly moving away from unitary goals and more towards pluralist and conflicting ones.

Past solutions and systems were designed by people assuming or adopting a simplistic and unitary worldview. Gustavsen (2008: 433) notes that:

> *"… there is a one-way process from theory to practice has been under dispute for as long as efforts to catch the salient features of the world in theoretical terms have existed."*

Even though we have had a feeling that the way of thinking about these solutions is insufficient and incomplete for the issues being dealt with, the pace of development and adoption of newer and better suited methods has been very slow. This adoption rate has been further hindered by the now realized failure of many management fads that crept up during the last two decades of the 20th century. These fads have implicitly assumed that in principle the world is the same and management theories only require tweaking to suit the limited changes. Throughout this research I will be presenting a view that systems thinking based decision methods are better suited for a world of complex and diverging views.

In the next section I will discuss the scientific method in its commonly perceived form; the positivists view.

1.6 The Scientific Way of Knowing

The scientific method, also referred to as the scientific approach is a method of enquiry used in analyses of physical systems that seeks to be objective and repeatable. It seeks to provide knowledge that is reliable and robust. Schiffer (2005: 351) describes the scientific method as:

> *"…activity of the mind investigating reality with logical rigour and objective observation."*

Scientific discoveries are peer reviewed and are only considered valid once they have passed certain tests. It then may be confidently used by others in daily life without the need to query it.

The method is based on the appreciation that human beings have biases that may sometimes cloud their judgments or may lead some to actively falsify results for specific gain or to advance a specific point of view. Maitlis and Ozcelik (2004: 375) concur that organizations (and other social systems) are emotionally charged systems. This effectively acknowledges that emotions affect daily decisions. Repeatability and full disclosure are important characteristics of the method as they allow others to interrogate claims and results thereby providing the opportunity to reinforce ones results.

The method represents a thorough act of thought in a particular field of interest. The scientific method is the primary reason for human technological advancement as we know it. It has also lead to many accidental discoveries. The method is disciplined and this has allowed scientists to observe anomalies in experiments. If the anomaly is found to be persistent in subsequent experiments, then scientists seek to find logical explanations. The anomaly then usually becomes the source of new knowledge.

Trevors (2010: 1) acknowledges that:

> *"… sometimes immense discoveries are forthcoming when one is diverted from original experiments."*

As is shown in *Figure 2*, only with a disciplined and systematic approach that is repeatable, can we repeatedly explore these anomalies that live to become discoveries and inventions. The method requires environments that are reasonably static so that one is able to observe one variable of interest without worrying about the others changing during the course of the experiment. These environments allow for repeatability. However, the method is not perfect (Trevors; 2010: 1).

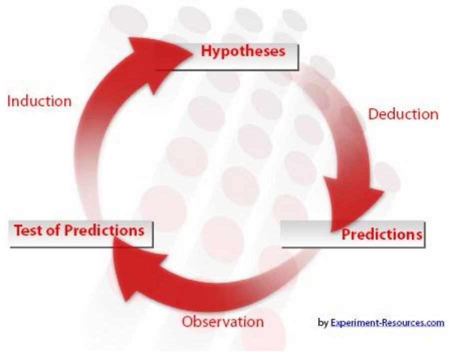


Figure 2: The Circular Nature of the Scientific Approach
Source: http://www.experiment-resources.com/what-is-the-scientific-method.html
[Accessed 18/02/2011]

Unfortunately in life, today more than any other time, a large number of systems are not static. The changes are rapid, unpredictable and ambiguous (Heylighen, 1991: 39; Henderson, 2007: 132; Hwang, 1998: 338; Feurer & Chaharbaghi, 1995:67; Panagiotou, 2008: 554); and they expose the scientific body of knowledge as insufficient and a failure in such systems.

I use the word "fail" cautiously, because this failure is actually the source of discovery of the new anomaly. The failure firstly forces us to accept that a deterministic one-size-fits-all approach is not sufficient in most complex systems and secondly we must apply our minds more when engaging complex systems. It is important to stress here that I am not saying that reductionism and determinism are invalid; I am saying they are not sufficient. Mathematical models, which are results of the scientific approach, fall short of being able to find best solutions when addressing management models (Forrester; 1964: 3).

The critics of the scientific method usually think that those who advocate the scientific method are of the opinion that all systems are static and deterministic. I would argue that this is wrong because many scholars including von Foerster (a Physicist); Forrester (an Electrical Engineer); Sterman (an Electrical Engineer) and Checkland (a Chemist); have shown a profound appreciation of the scientific approach and have used it to develop non- Newtonian and non-linear theories which form the basis of complexity sciences.

Taleb (2007: 72) says:

> *"Clearly, to a scientist, science lies in the rigor of the influence, not in random references to such grandiose concepts as general relativity or quantum indeterminacy."*

A large number of people are blind to the fact that it is people who fully subscribe to the scientific method who formalized the understanding of the non-linearity that occurs in many systems, especially social systems. At the point of discovery, the non-linearity was an anomaly. It was the analysis and observation under the scientific methods with rigor that lead to the development of complexity sciences. By the term "complexity sciences" I also mean cybernetics, systems thinking, complex adaptive systems (CAS) and chaos theory.

I acknowledge that these sciences have many differences, but in my opinion they fundamentally have more in common than they do not. The common thread of these sciences is that non-linear systems exhibit emergent behavior and are non-trivial. Another important point that we should bear in mind is that science and the scientific method are not an exclusive domain for people with science degrees.

My proposition here is that science is an auditable and rigorous way of knowing, not a body of knowledge. Taleb (2007: 72) summarizes this and asserts:

> *"Such rigor can be spelled out in plain English. Science is rigor; it can be identified in the simplest of prose writing."*

Being scientific is about being systematic, reflective, observant, questioning, creative and willing to take risks. Systematic means using "an ordered, step-by-step and methodical approach" (Stowell; 2009: 880). The scientific method only helps us to be systematic in our approach so that we are at least able to replicate accidental discoveries. By encouraging peer review and documentation, it also helps us avoid reinventing the wheel by rediscovering the same things that have already been discovered by others. Scientific papers announce the discovery (Grinnell; 1999: 487).

Walters and Williams (2003: 71) argue that we should view modernism and post-modernism as cumulative modes of organization not as oppositional and therefore take the best lessons from each perspective.

I have just argued the basic nature of the scientific method and how it led to the discovery and development of complexity sciences. The true strength of the scientific method lies in being able to take lessons from the experiments and bring them to add value in the real world. In the next section I will discuss complexity sciences; implicitly focusing on socio and techno-social systems; and show how they are helping our understanding of the real world.

1.7 The Complex Systems Anomaly

Just as I argued that science based management theories are insufficient, there has been a need for a paradigm change in management for quite some time (Espinosa; 2007: 333). In this section and throughout the research I will be taking a stance that systems thinking is the best gateway to helping us understand and make sense of the world we inhabit. Systems thinking is a perspective we adopt in order to make sense of the world (Stowell; 2009: 879). While the scientific method is systematic, the systems approach is systemic. This means it takes a holistic approach to problem solving (Stowell; 2009: 880)

Dodder and Dare (2000: 2) say:

> *"One important emphasis with CAS is on crossing of traditional disciplinary boundaries. CAS provides an alternative to the linear, reductionist thinking that has ruled scientific thought since the time of Newton. The new discipline has been distinguished by extensive use of computer simulation as a research tool."*

As I have already stated, in all complexity sciences there is common thread of systems appreciation. In this thread we acknowledge and appreciate that life is made of interconnected entities that interact to form or create unexpected results. This is commonly referred to as emergent behavior. The interaction and relationships of the entities is localized but have a system-wide impact. The overall system behavior cannot be inferred from the analysis of the entities individually. To make any sense of the system, it must be observed holistically.

Complexity describes the rich interactions of the system's entities that on superficial analysis may seem chaotic and without pattern, but in the long term reveals that there is an underlying pattern in the system and actions are not random. In these environments, the observer is part of the system.

Letiche (2000: 545) describes complexity theory as a collective of new anti mechanistic metaphors stressing process and emergence. Clemson (1988: 585) says cybernetics is:

> *"…concerned with the general patterns, laws and principles of behavior that characterize complex and dynamic systems."*

Analyses of systems, regardless of nature, reveal that there are common features present in all viable systems, these are:

- **Sensitive Dependence to Initial Conditions:** This feature highlights the fact that the system has a "memory" of previous events and these will influence how the system reacts to future inputs. The dependence is amplified for critical and life changing events and these are the ones the system and or its agents will recognize first. The system may then move to prevent them from reoccurring or catalyze their occurrence if the system thinks they will have a desirable impact. So history will decide whether we have a reinforcing or a balancing loop.

- **Interconnectedness:** System agents have localized interactions but the resultant impact of these interactions is felt by and influences distant agents in the system. The example of this is the 11 March 2011 Tsunami in Japan, whose impact is being felt by world financial markets and has triggered an international panic on nuclear power stations. Some automotive companies in the United States of America have closed some factories because they do not have parts that are normally supplied by their Japanese counterparts.

- **Multi / Inter-disciplinarity:** The agents of the system are autonomous and have varying skills, objectives and desires. As they interact their divergent goals inadvertently serve to keep the system stable. The system also faces various challenges and there must be an agent that has the ability to deal with that particular challenge for the system to remain viable. If there is none, some of the agents will alter their behavior, gaining a new focus or discipline that once gain alters the systems behavior resulting in perpetual self-organization for as long as the system keep adapting and learning. Ashby (1957: 206) refers to this as requisite variety. Heylighen (1991: 75) concurs by saying:

  "…a large variety of actions is more adaptive than a small one."

- **Emergence and Holism:** Emergence refers to the resultant behavior of the system that may not be inferred by reductionist analysis of the parts or agents. In order to understand the system it must be viewed and analyzed holistically. Only a big picture perspective will suffice in analyzing these systems. Skimming through the literature on systems thinking there is a perception that emergence cannot be predicted. I argue, however, that is an inaccurate perception because with simulation models that sufficiently factor in the dynamic relationships we can predict emergent behavior.

- **Non-linearity:** Heylighen (2008: 5) says:

  "However, while negative feedback makes a system more predictable, it also makes it less controllable: if we try to change the state of such a system, we may find that our changes are counteracted and whatever we do the system always returns to its own "preferred" equilibrium state."

  The relationship between cause and effect is not always directly proportional. A minor adjustment or action may have big unexpected and disproportional consequences and conversely big efforts may have little or no impact on the system. This characteristic links to the sensitive dependence feature.

- **Self Organizing and Learning:** Due to the constant interaction of the system' s agents and the distant effect of localized interactions, we find that agents continuously change their worldviews and behavior to make sense of the system. The system somehow stays stable even though there is no agent actively managing it. The system manages itself and self-organizes. The systems agents, and hence the system, continually learn from their environment and adjust their behavior to achieve new states of self. All self organizing systems adapt and evolve to become informed of their world (Scott; 2004: 1367).

The features themselves are interconnected as I have shown that by exhibiting the ability to do one thing leads the system to do another, which effectively represents a different feature. These features are present in any viable self-sustaining system, including organizations, families and society. As I have argued, the initial discovery of these features may have been an anomaly but because they are persistent in non-linear systems, they led to the discovery or creation of a new way of thinking called complexity sciences.

Perspective from these sciences reveals that management of organizations is not a simple application of methods developed using the old scientific method' s deterministic body of knowledge. All these sciences discussed in this section aim for beneficial control (Scott; 2004: 1176) and governance in human systems.

Old management theories, most of which are still in use today, assume a static business environment and hence are failing managers in this dynamic world we are faced with. The methods were useful for many years when the pace of change was slow and near imperceptible to management decisions. The world today is dynamic and complex and requires a different management approach. I argue that systems thinking based approaches are the ones that can deal with these dynamic systems. Maitlis and Ozcelik (2004: 375) lament that most research places organizational emotions and decision processes in individuals and ignores "the collective, systemic, and dynamic properties of emotions".

Considering how powerful the system based methods can be, it is shocking how the world has resisted adopting them. Stowell (2009: 880) references Checkland and says that this resistance stems from two things:

- The strong grip of reductionist thinking on western civilization and the omnipotence of the scientific paradigm on us;

- The refusal of the systems sciences to give one-size-fits-all solutions

In the next section I will discuss the concept of bounded rationality; a way of explaining our sub-optimal thought processes in complex systems; and will also show how it is directly linked to the complexity sciences.

1.8 Human Cognitive Limitations

Doyle (1997: 1) describes bounded rationality as:

"…rationality as exhibited by decision makers of limited abilities."

People intuitively know that they have limited cognitive abilities; it is just the limits that they are not aware of. This intuitive knowledge however seems to elude people who position themselves as experts. Somehow, we then lose this intuitive knowledge (about limited cognitive abilities) when we deal with these experts. We tend to believe that they are not inflicted with this human limitation in their areas of expertise. People make their decisions, and no matter how flawed their decision process, they find a way to justify to themselves. They effectively rationalize their decisions after the fact.

It has been argued (Doyle; 1997, and Jones; 1999) that humans have limited cognitive ability and decisions are usually made with incomplete and insufficient information. This is so because the systems within which we operate are dynamic and non-linear and therefore variables do not hold still while we try to make sense of the system in order to arrive at some decision. Jones (1999: 308) makes the following logical assertions:

> *"Proponents of limited rationality suggest that the environment is fundamentally more uncertain than is understood in prevailing choice models… In limited-rationality models, uncertainty also involves lack of knowledge of the attributes that characterize the problem (these are termed ill-structured problems). It can also involve ambiguity, which itself has two connotations… People never make decisions in isolation. They interact with others, who themselves have decision strategies. They must modify their goals in light of the social milieu in which they find themselves. Indeed, some analysts have argued that preferences should be viewed as fluid, not fixed, because of the necessity to be flexible in the face of changing circumstances"*

Managers rely on gut-feel to make decisions especially when they have a large number of options to choose from (McKenzie & James; 2004: 32). Bounded rationality does not inflict some people, it affects all of us. This therefore exposes experts to be delusional beings or unwitting con-artists.

It is important to revisit previous decisions that have already been made in order to ensure that they are still valid especially with knowledge of new information that may have been missing at the time of the decision. This is difficult to achieve especially for people who do not take time to reflect on issues that impact on their lives. Jones (1999: 307) reaffirms my argument that in certain situations people do not update their choices. Therefore continuous reflection and after-thought are crucial in management of complex systems and they are the real source of deep learning that results in altered worldviews. In complex environments, Jones (1999: 319) concludes that:

> *"In this far more complex situation, problem-space representations may interact nonlinearly with goals and processing limits."*

These human cognitive limitations cause us to filter out what seems like background noise that is not crucial for the task at hand. This is an important characteristic that helps us avoid getting bogged down by useless information.

Almost all the time, during the filtering process, important information gets lost but the impact of the loss may not be immediately appreciated. Heylighen (1991: 39) says:

> *"In the same way, we, as human beings, have inherited a number of mechanisms for distinguishing important phenomena, while ignoring or filtering out irrelevant details. This selective attention allows us to make sense of the very complex, ill-structured information we receive continously through our sensory organs. Yet we are completely unaware of this process of perceptual structuring and filtering, which is continuously taking place in our nervous system."*

As I will show in the literature review chapter, and prove during the simulation phase, people have severely limited abilities to grasp and or identify issues that accumulate over time. I will also show that these issues are the ones that result in long term system behaviors that consistently confound us.

As a way to understand complex systems Heylighen (2008: 2) suggests that:

> *"At best, we can find certain statistical regularities in their quantitative features, or understand their qualitative behavior through metaphors, models, and computer simulations."*

In this section I will also argue that computer modelling is one of the better ways to minimize the filtering of information so as to obtain a high fidelity picture of the system. Simulations help us lay bare all the assumptions and mental models that accompany our perspectives. Computer simulations are able to reveal the accumulation that most of us are unable to see.

Recognition of our cognitive limitations steers us towards rules of thumb and heuristics (Doyle 1997: 3). Sheridan (2001: 90) proposes that decision making tends to be recognition primed and situational. This statement highlights the inherent, but subconscious desire, to make decisions that we are familiar with. The statement also reaffirms the power and importance of management flight simulators (Sterman; 1998: 2) in preparing people to make difficult decisions under controlled and safe conditions. Simulators allow us to experiment with risky business decisions that we would not want to try out in the real world system.

Robust dynamic systems modelling and simulation unintentionally exposes the pseudo-science of experts. It also helps us reduce complexity and manage it on a higher more abstract level (Heylighen; 1991: 40).

In summary, I am arguing that in order to counter limitations of the scientific approach in dynamic systems we must embrace complexity sciences as they help us understand complex systems and minimize the anxiety that comes with being part of such systems. I am also arguing that because the systems within which we are embedded are so complex, it is difficult or near impossible to make fully rational decisions as the variables are non-static, non-linear, non-deterministic and therefore unpredictable.

So if the systems are so complex and dynamic don't we then need tools that can help us deal with these systems? My argument is that computer simulations are good at this, and I propose system dynamics as the preferred methodology for this research.

In the next section I will present the research problem to which I will apply the system dynamics methodology in a project management system. These models and simulation will expose the financial effects of bounded rationality in the systems modelled.

1.9 Problem Statement

The ability of theory to reflect reality can only be tested by doing and seeing what happens (Gustavsen; 2008: 433). To test my assertions as laid out in the preceding sections I will use a case study approach to test the validity of my claims in the real world context. The primary reason for undertaking a project, in any system, is to achieve a specific goal, within a specific period and within specific cost parameters. Therefore it is concerning that Fisher (2005: 6) quotes a conversation with Forrester where he said:

> *"One of the consistent findings was particularly disturbing at first glance: the problems of most companies were not brought on by competition or market trends, but were the direct result of their own policies".*

Even though Forrester was not specifically talking about projects, this statement effectively says that most problems that will be experienced in a project system will come from within. Projects are guided by policies that are meant to effectively and efficiently manage the three major parameters on which projects are measured. These policies are further governed by other rules that are meant to manage additional work and additional costs that arise in projects. The project management fraternity has created generally accepted methods such as scope change requests in a quest to try and manage unplanned work request and associated cost and time impacts on the overall project.

The problem is that current thinking and approaches to project management, even though systematic, are non-systemic and recent innovations present minimal incremental improvements. Project management tools and techniques have challenges and while useful for planning do not represent reality and its built-in complexity (Whitty & Maylor; 2009: 306 and Sterman; 1992: 7). The tools reduce the problem into smaller and hopefully manageable tasks. Contemporary literature on project management states that far too many projects do not meet their targets. Sterman (2006: 505) says:

> *"Complexity hinders our ability to discover the delayed and distal impacts of interventions, generating unintended "side effects". Yet learning often fails even when strong evidence is available: common mental models lead to erroneous but self confirming inferences, allowing harmful beliefs and behaviors to persist and undermining implementation of beneficial policies"*

Service providers and clients alike fail to appreciate this point about complexity until one of them faces financial ruin and then institutes legal action against the other. In order to achieve any new meaningful improvements, a paradigm shift would be required and the only way to initiate this shift would be by questioning the way things are done with the primary aim of gaining new insights. I expect that there will be resistance to a drastic shift as people struggle to accept evidence that invalidates all their beliefs. Meadows (1989: 70) says that:

> *"A paradigm is not only an assumption about how things are, it is a commitment. There is an emotional investment in a paradigm, because it defines one's world and oneself. A paradigm is a set of deep concepts about the nature of reality that shapes language, thought, and perceptions – and systems structures."*

The Global Community (May 18, 2004) quotes Meadows as having said:

> *"For those who stake their identity on the role of omniscient conqueror, the uncertainty exposed by systems thinking is hard to take. If you can't understand, predict, and control, what is there to do?"*

At this stage I must acknowledge that I consciously accept the paradigm of managing changes by filling out forms in a project. I do not seek to invalidate this paradigm, what I seek to do is to reveal that policies guiding it are flawed and the resulting cost estimates are inaccurate and risky to the client, the project and the service provider.

1.10 Research Goals

Contemporary thinking and teaching is informed by mechanistic and scientific thinking which has reinforced some unspoken assumptions about change being foreseeable and predictable. This approach has prevented people from questioning the assumption that outcomes are more important than process. In the project management fraternity nobody is actively challenging the norm and saying that there could be a better way, if not totally different way, of doing things. Sterman (2006: 505) reinforces my thinking and says:

> *"We have been trained to view our situation as the result of forces outside ourselves, forces largely unpredictable and uncontrollable."*

In this research I will model previously completed projects using system dynamics in order to fully understand and gain some insights to the cost and time dynamics that were at play but were most probably never fully understood. I aim to develop a systems archetype for a typical engineering project which will model the change order processes. I expect that at the end the resulting system model will be made available to interested parties to use as a tool to improve their internal systems.

The most important benefit of this model will be that people will know that they are not victims of some outside random acts of nature, but they are part of the system that leads to that random act of nature and most importantly they can minimize the negative effects of the random act.

1.11 Research Propositions

My research propositions were that:

1. Proposition 1: All parties in the project chain either gain or lose revenue when a change order is requested by the client;

2. Proposition 2: Clients and service providers are oblivious to the true impact of change orders on time and cost;

3. Proposition 3: Revealing the true nature of change orders will discourage clients from requesting non-essential changes in projects;

4. Proposition 4: Revealing the true nature of change orders will make it easier for service providers to justify seemingly disproportionate costs and time claims even post project completion;

By undertaking this research I aimed to:

1. Model project management change order systems, on whose analyses I will reveal the weaknesses of the current generally accepted approaches;

2. Gain insights on the system structure and behavior of the systems modelled;

3. Review the robustness of current methods which are believed to be best practices;

4. Use the model to inform the generation, assessment and approval of change orders;

Additional to these aims I plan to answer the following questions:

1. What are the cost implications of adopting the system dynamics methodology?

2. How does system dynamics modelling compare to other modelling techniques?

Meadows (1989: 76) advises that when challenging a paradigm you have to take an incremental approach or else people will shut-off and not engage the perspective being presented. My primary aim in this research is not to change people's minds but to reveal that there is a different paradigm. Thereby letting people change their own minds and worldviews. So in essence the model purpose will be to act as a "management flight simulator". With the simulator model the research participants can test different hypotheses and alter their worldviews. It is noted that it is important to test hypotheses, not randomly play around with variables, in order to arrive at meaningful insights. If this is not done, the whole simulation becomes just a fun filled game with no meaningful after effects or insights on the participants. The overall aim is to arrive at a state where the participants can intuitively foresee change order related problems before they even occur. With that ability they can then convincingly argue their point of views with the client.

1.12 Summary

Honkela (2005: 45) says:

> *"A trivial machine is characterized by one-to-one correspondence between its 'input' (stimulus, cause) and its 'output' … Non-trivial machines, however are quite different creatures. Their input-output relationship is not invariant, but is determined by the machines reaction."*

In essence trivial entities are those whose behavior are deterministic and will not change. They are predictable, given a similar set of circumstances. While non-trivial entities are the ones whose behavior is unpredictable and will react differently almost every time, even if faced with similar circumstances. The systems that will be studied are non-deterministic and dynamic. To validate this point I will show that a set of relatively small change requests and delays in a project can interact to lead to a rapid unbalanced situation (Forrester; 1991: 11) resulting in major delays and cost increases either for the service provider or the client. The research will show that change orders are non-trivial entities and therefore should not be treated indifferently because they have a direct impact on the financial outcome of the project.

In this chapter I have shown that the scientific method has helped the human race achieve greatness and gain control over many difficult yet simple and linear physical systems. I have shown that the method is structured and systematic and is replicable and reducible. I have shown that as great as the method is, it falls short in satisfying our desires to understand complex dynamic systems. I proceeded to provide the characteristics that make it hard to control and grasp complex systems by presenting the perspective of systems thinking and complexity sciences. I went further and linked the complexity of dynamic systems and showed how they confound us by presenting the premise of bounded rationality. I then proceeded to show that computer simulation has the ability to address the shortfall of each of these concepts. This is because:

- computer simulation takes over when we become rationally bounded;
- computer simulation can reasonably represent complex systems;
- we are able to take risky decisions and see their impact without the fear of "real world" retribution.

By using complexity sciences as a signpost, limitations of both the scientific approach and the mind in complex and fast changing environments can be discovered and navigated resulting in a better understanding and appreciation of the relationships embedded in the system.

1.13 Report Structure

The rest of the report will be as follows:

- Chapter 2 will cover the literature review on system dynamics, disruption and delay and project management;
- Chapter 3 will present a detailed research approach;
- Chapter 4 will present a detailed case to be studied to test and affirm my propositions as made in this chapter;
- Chapter 5 will discuss the major project stages (engineering, fabrication and installation). These stages are discussed with the aid of conceptual stock and flow and causal loop diagrams;
- Chapter 6 will present the model building process, presented as fragments. The dynamic understanding experiment and results are also discussed. Lastly simulations are ran and discussed in order to answer the research questions;
- Chapter 7 will be synthesized from the reflection chapter (6); this chapter will cover issues that I believe will require further research. I will also extract new knowledge; learning and value as assimilated during the research process.

CHAPTER 2

Akhanya

2. LITERATURE REVIEW

2.1 Introduction

In the previous chapter I provided the background on the scientific method. I further discussed complexity theory and explained how it is helping us understand complex and dynamic systems. This discussion was followed up by a discussion of bounded rationality and how it explains how we behave and make decisions in complex systems. I further showed that we tend to rationalize decisions that we have already made, even when we know they had been sub-optimal.

In the same chapter I made a proposition that in complex systems, where we are rationally bounded by our cognitive limitations, it is advantageous to use complex simulation methods to help us see the big picture”. In these situations, simulations and computers act as extensions of our brains’ capacity to analyze.

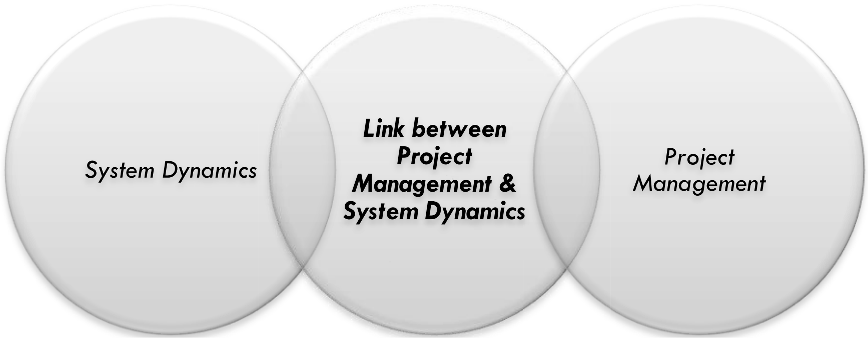
I then proposed that the system dynamics methodology is a good way of countering cognitive limitations.

2.2 Overview

In this chapter I will review the literature relevant for this research. I will discuss project management with the view of showing that it is complex and dynamic. I will then concisely discuss the system dynamics methodology and why I propose it as a way of helping me understand the systems that will be analyzed in this research. The three main aims of this literature review chapter are to show that system dynamics:

- Counters cognitive limitations and increases the boundaries of our rationality;
- Is built on complexity theory, the science that I have argued is helping us understand non-linear complex systems;
- Explicitly embodies the scientific body of knowledge and the scientific method and yet addresses issues that do not abide to deterministic scientific knowledge.

Further aims of the chapter are to:


System Dynamics
Link between Project Management & System Dynamics
Project Management

a number of people are ignorant to the existence of stock and flow in every system and therefore don't even know that they don't understand the systems within which they are embedded.

There is a general perception that a project manager is the one person responsible for what happens within the project. The perception creates an expectation that the project manager should be able to command and control what happens in the project. As with any social system, projects exhibit emergent behavior resulting from the interaction of the individuals embedded within, and therefore no one person can honestly claim to have full control of the project.

From the client and Engineer's team perspectives there are usually three major systems in a project, that of the client organization, the client representative consultancy known as the Engineer in the International Federation of Consulting Engineers (FIDIC conditions of contract) and the contractor. General design guidelines come from the client organization and clarified and documented by the Engineer in order to be detailed, manufactured and installed by the contractor.

Figure 4 represents the project system as seen by the client and the engineer in the Engineering, Procurement, Construction and Management (EPCM) concept. While the Engineer may claim to know that there are more factors impacting on the contractor's team, they ignore it. This is evidenced by the reality that the contractor is almost always held responsible for what happens on his side of the system.

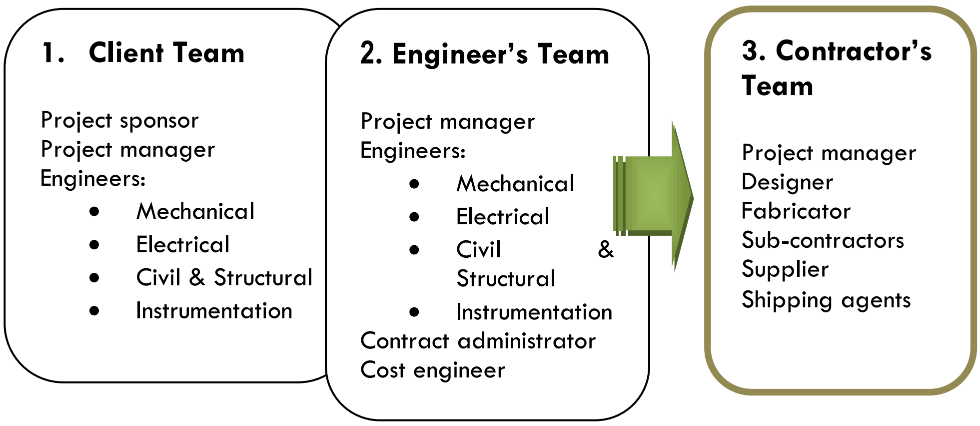


Figure 4: Project System from the Client Perspective

Figure 5 represents a further breakdown of the contractor's system and shows the detail that is ignored by the other stakeholders. It shows that additional to the client and Engineer system, the contractor also has the design team system and the sub-vendor systems embedded within his system. This layout assumes that the design component is outsourced, as is usually the case with most fabrication companies.

This clearly reveals the exposure faced by the contractors in projects and therefore the risk element coming from seemingly simple and generally innocent actions of others which may have cost and time implications on the contracting company.

The core dynamics of the project system arise from the interaction of the three systems (client, engineer and contractor). Personal experience shows that the client is usually blind to the true nature of endogenous and exogenous elements of the system but they tend to believe that they are not. The Engineer while not blind to these endogenous elements, under-evaluate their true nature. The contractor is the one party that is directly exposed to these exogenous elements and the pressures and complications they bring to the system and he too is clueless of their dynamic impact.

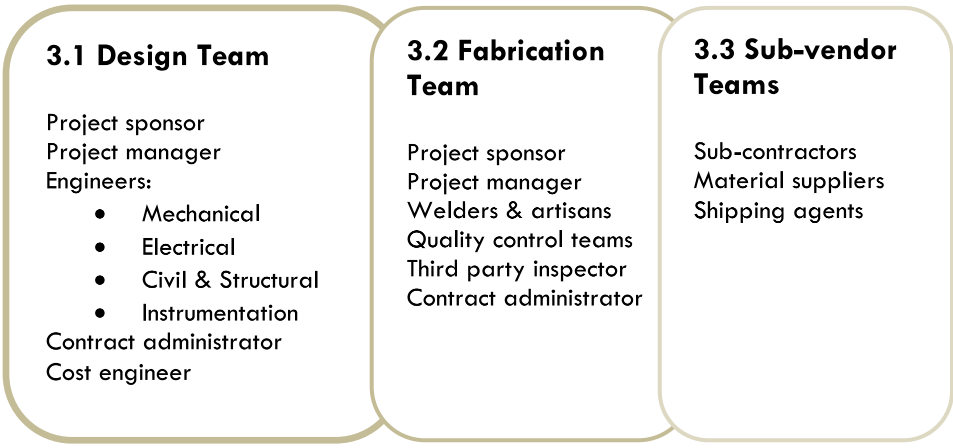


Figure 5: The Contractor System which the Client is unable to see

While being dynamic, the system is reasonably perceived to be stable especially with enough pre-planning. The problem arises with subsequent requests presented as change orders which clients usually want delivered within the original times frames at a minimal cost. Pricing a change order request takes time because there are a large number of participants in this system. The effect of this is that change requests received in the middle of the contract will affect more areas than the contractor can accurately predict and in most cases, where the contactor has vast experience in the field, the costs will be inflated to cover these unseen risks.

2.4 Project Management

Project management is the process of putting together resources, including human beings, in order to achieve a specific measurable goal. Projects usually occur within fast paced, high pressure and stressful environments as they generally stem from a need to achieve a specific goal. A project will usually be a means to an end, not the end itself and hence the pressure to complete it as quickly and as cheaply as possible.

Steyn et al (2003: 3) define a project as:

> *"…any planned, temporary endeavour undertaken to create a unique product, service or other complete and definite outcome (deliverable) within a limited time scale and budget. Projects normally require the mobilisation of resources from a number of different disciplines."*

Their definition, like many others, stresses the three main indicators of a successful project which are time, cost and quality. The following diagram emphasizes the "golden triangle" principle, which advocates for the management of costs, quality and time. I propose that there should be a fourth element, the people working on the project. Out of these components, the most unpredictable and problematic is the human factor, which is explicitly ignored in contemporary project management literature.

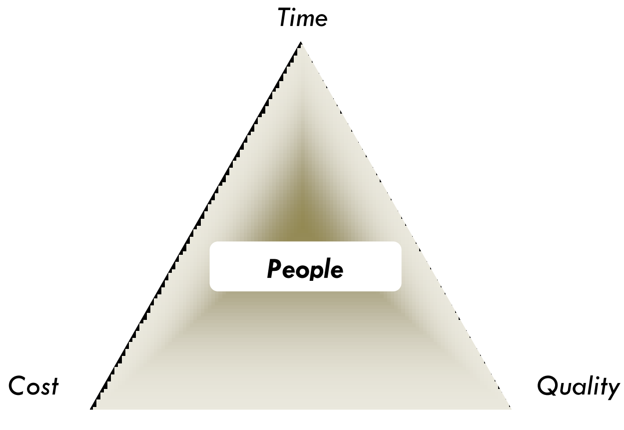


Figure 6: The "Golden Triangle" Perspective of Project Management

It is a dereliction of duty and naïve to assume that human beings are the stable component in a project, when in fact experience and objective observation has proven that they are the source of the uncertainty. Uncertainty is an inherent characteristic of all projects, regardless of size (Whitty & Maylor; 2009: 306).

The Complexity of Project Management

In a consulting engineering context, projects and project management are typically complex multi-disciplinary endeavors, as they exhibit interrelatedness (Sterman; 1992: 5) and involve more than one discipline and stakeholder. A good project manager will have a solid grasp of financial management and people management over and above engineering skills. The involvement and management of the client and other stakeholders add to the interrelatedness and interdependencies.

At a superficial level, interdependencies can be seen from drawing a project programme with linked tasks. A slippage in one task usually has a negative impact on a number of other subsequent tasks, unless they have float. Even with a float, slippages are still negative as they result in the project taking slightly longer than planned for and hence any savings that could have accrued to the service provider are lost. These tools that cater for interrelationships do not sufficiently capture the environment within the projects unfold. To try and capture any non-linearity the project members must try to capture the downstream effect of upstream activities.

Project activities also suffer from contamination (Taylor et al; 2005: 39). Contamination means that a reworked activity will cause another interlinked activity to be reworked. The reworks are rarely concurrent as one design may depend on another being completed first before commencing. If one tries to concurrently reengineer the activities, a new layer of risk and errors is added onto the project as some activities require input from preceding ones. The true extent of reworks is hard to predict on fast paced projects.

This statement leads one to conclude that there are challenges with the tools and techniques of project management (Whitty & Maylor; 2009: 306). While discussing the Critical Path Method, Whitty & Maylor (2009: 306) admit that:

> *"…it does not model the reality or the uncertainty of the project environment…"*

As stated at the beginning of this section project management is a multi-disciplinary endeavor as it is rare to find a project where only one discipline is required to achieve project objectives. The multi-disciplinarity creates possible problem areas as the different disciplines fight for the shared but limited resources such as time and money. A project manager is required to have a holistic view and create balance between the competing resources guided by the overall objectives of the project. Pinto et al (1993: 1281) stress that non-routine projects require cooperation. They further acknowledge that there will be competing needs for resources in such project environments.

As I have just hinted, an important but often ignored reality in projects is that projects share resources as it is too costly to have resources exclusively allocated to one project when it is not necessary. This sharing of resources creates tension that must be managed by both the project manager and the resource involved, and possibly another project manager leading a different project. This point is critical when clients request additional work without expecting delays and costs in order to address the request.

Pinto et al (1993: 1281) highlight that additional to the traditional measures of projects, there is an unacknowledged psycho-social measure which refers to:

> *"…how the departments or individuals involved in an implementation effort feel about working with other project team members, the extent to which they feel the time devoted to the project was worthwhile…"*

The psycho-social measure may have a positive or negative impact on a project. It is the essence of human nature to want to be validated and be perceived to be adding value. Team members who do not see how they are adding value or maybe feel that their time is being wasted are likely to under-apply themselves in projects thereby negatively impacting on the productivity. As already stated projects usually occur in high speed, high pressure and stressful environments and those who do not feel validated are prone to being the weakest link in the project chain.

It is important to have a structured way of dealing with unplanned issues in the project in order to try and meet the project objectives. It is important to draw and agree on the ground rules during inception of the project in order to know what we do and do not do in the project (Cardinal & Marle; 2006: 228).

> *"… a transformation process, from an initial to an expected final situation, evolving in an often complex and changing environment."*
>
> Cardinal & Marle (2006: 227)

This definition expands on the generic project management definition but more importantly it explicitly highlights that projects are complex because of how and where they unfold in the real world. Cardinal & Marle (2006: 226) stress that decisions made earlier in the project planning phase will have a big impact during the implementation phase. It is therefore important to take time and be thorough during the planning of a project.

While we require a human being to identify and decompose the project activities for analyses, the human brain is incapable of extracting the true nature of the relationships amongst the activities. Computer software plays a vital role in helping us understand these relationships, at least at a basic but almost static level. Popular planning tools can show the basic relationships but they lack the ability to represent the cumulative effect of time delayed responses to actions (Taylor; 2005: 3). They cannot differentiate between flow of information and that of physical entities. Even human beings have difficulty with this seemingly simple effort. Cardinal & Marle (2006: 231) say that:

> *"The problem with standard decomposition is that it does not take into account the additional interactions, it is not evaluated, and it does not allow the team members to be creative in the construction of their own decomposition."*

System dynamics modelling has its strengths in being able to simulate behavior over time which is what is required to fully understand and appreciate how project unfolds in the real world. Richmond (1991: 2) says simulating a system provides an opportunity to close the loop as the modeler is able to test his beliefs about the behavior and see "what causes what".

> *"In short, interdependency demands Systems Thinking"*
>
> Richmond (1991: 3)

Uncertainty is an undesirable built-in feature of projects (Whitty & Maylor; 2009: 306). These assertions conclusively highlight the high level of complexity in project environments, even for seemingly simple projects and the need to have a high fidelity tool, such as system dynamics, to analyze these complex environments.

2.5 Disruption and Delay

Change requests are by far the major cause of disruptions and delays. Disruption and delay describes the events that are a result of client interference, usually with a start and stop impact, and lead to additional costs for the service provider. They are a frequent occurrence in projects and usually result in scope creep where the client keeps demanding additional features but without incurring additional costs. There are means to try and manage this situation, the most common being to allow the client only a limited number of passes to minimally change the design before incurring costs. The changes must be incremental and not an outright override of a previously agreed design. This number is best agreed upfront with the client. Once the final pass is done, any further changes may only be requested through a formal change order process.

This method is meant to prevent the client from having after-thoughts and requesting non-essential changes in the project once it is going. This is best managed by making him sign general arrangement drawings as decisions are incorporated into the design. This type of disruption is manageable; the problems arise with further disruptions such as:

- Client indecision on critical items, such as approval of designs, which may lead to a claim for extension of time and additional costs. Clients are usually willing to engage in the discussion for additional time but tend to resist having to pay additional costs. This immediately starts to negatively impact on the services provider's finances and is the starting point of strained relationship between stakeholders;

- Non-responsiveness on extension of time and cost claims. This always adds to the service provider's anxiety, as he works at risk not knowing whether his claims will be approved or not. Service providers are usually non-combative on this issue as they are concerned with maintaining good relations with the client, in order to be considered for future contracts.

In a well managed project, progress meetings and site inspections should be planned upfront at the kick-off meeting in order to allow the service provider to plan his work and better manage his time. Clients tend to sometime randomly call progress meetings, some of which have no immediate value on the project. While the service provider can quantify these explicit costs, it is usually difficult to quantify the opportunity costs attributable to these unplanned excursions.

Eden et al (2000: 293) say that the client's level of knowledge, too much or too little, may contribute to delays and disruptions. Those who know too much may interfere excessively when they suspect the service provider is making a mistake and those who know too little may hinder important progress because they have no appreciation of how long things take to get done. Service providers are usually willing to accommodate the client because usually at the end of the project they come out on the positive side, financially and with their reputation intact or in a better state, but it is undeniable that these costs do add up over time, which will usually be a considerable number of months.

Clients in these cases are usually in denial of or are ignorant to the quantum of the negative impact their additional involvement has on the service provider. Even when they understand that there is some impact, they discount the impact on cost and time. Even service providers themselves fail to understand the real cost of taking on additional work.

> *"However, change orders, when they impact an already complex project, have now become difficult to properly cost and can increase complexity out of proportion to the directly attributable work involved... These costs can only be included to the extent that they are identifiable at the time of estimating. However the real cost of D&D (Disruption and Delay) is unknowable at the time of estimating."*
>
> Eden et al (2000: 293)

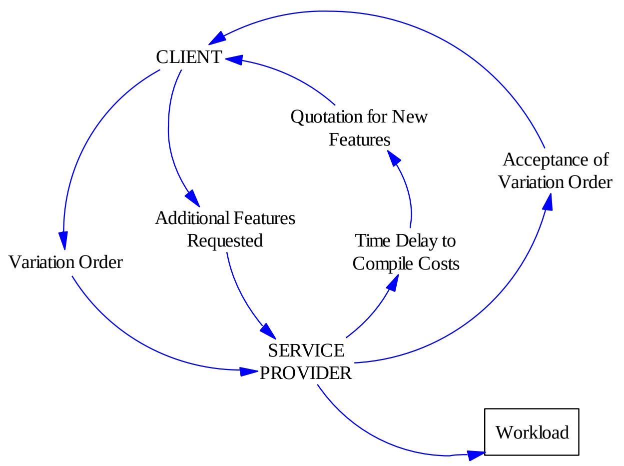


Figure 7: Basic Change Order Process

Figure 7 shows the basic client- service provider relationship without going into detail about the systems that are embedded within. It reflects the process/ information flow emanating from a single change order request. This diagram shows that there is a basic feedback relationship between the parties. It also shows that there is a time delay in providing the client with the required feedback as resources have to be committed to compile documentation (quotations) for the required item, which the client sometimes ends up not buying. In this diagram one can see that there are many seemingly simple activities but which have time delay factors as parties have to wait for feedback.

Most contracting documents; NEC, FIDIC; stipulate a specific number of days within which contractors must give notification of intending to lodge a claim (financial or time related). The original spirit of the clause is to shield the client from sudden surprise claims at the end of the project even though the contractors were always aware of them. Clients and their representatives however abuse this clause and use it to invalidate valid claims, even though they may have always known they were coming. Clients also ignore the difficulty of quantifying some costs under stressful, high pressure project systems.

Use of static non-systemic analysis and approaches incorrectly pretend to understand and reflect the intricateness of complex systems. A complex and dynamic system requires a complex and dynamic methodology. As I have already argued, it is my proposition that a very good methodology to show causation and time delayed effects, and therefore quantify damages, is the system dynamics methodology. This point is crucial in understanding that a client's request and indecision on a small issue may have a disproportionate impact on the rest of the project. This non-linearity also points to an undesirable relationship between small delays and disruptions which tend to lead to a disproportionately bigger whole. Eden et al (2000:292) stress the importance of appreciating the power of the portfolio effect. The portfolio effect is the emergent effect emanating from the interaction of small disruptions.

Disruptions and delays almost always lead to litigation if the project is cancelled or the client chooses to take a hard uncompromising stance against the service provider. In litigation, the burden of proof always lies with the service provider. The methodology called the "measured mile" is the most commonly used, internationally, in disruption and delay cases. The measured mile method focuses on an undisturbed period in the project as the basis for benchmarking contractor progress. This is then used to evaluate the costs in the disrupted and delayed component of the project.

While good in its approach it is not the most thorough as it inherently does not appreciate accumulation and therefore misses subtle costs incurred. Even though this research is not aimed at quantifying costs for litigation purposes, I believe it is important to discuss the method generally used to quantify costs in projects. I will discuss this method in more detail in the following sections.

The Association for the Advancement of Cost Engineering (AACE) (2004: 1) admits that there is no uniform agreement within the construction industry about the preferred methodology for quantifying claims from loss of productivity. They further admit that it is difficult to discern and establish causation, and therefore entitlement. Another methodology, which I have been arguing is more powerful but is less used, is the system dynamics methodology. It is able to address the cause and effect relationship which we struggle to correctly identify and we usually cloud as identified in the hindsight bias problem.

As per my argument, project environments are complex and dynamic systems. This therefore means that the relationships between the role players and activities are non-linear and result in emergent unpredictable behavior. They therefore require sophisticated tools to analyze them. Pugh- Roberts and Associates pioneered and relatively popularized the use of system dynamics in contract litigation. This is evidenced by Roberts (2007; 8) claim that system dynamics was the method of choice for the contractors in the "Chunnel Project". Extensive project modeling with the method helped them discover the effect they called "undiscovered rework". This is related to the concept of contamination which I have already described.

2.6 Priming to the Rescue?

Priming is a technique of subliminally presenting information to people so that they know without knowing how they know. Cronin et al (2009) further show that consciously priming people to the existence of accumulation marginally improves its understanding. As I have already stated, when people start feeling that a system is too complex, they start to use a correlation heuristic which is a tendency to believe that outflow should be like inflow in a complex stock flow problem (Cronin et al; 2009: 117). This is gut-feel decision making under circumstances that demand a more robust thought process from us. The correlation heuristic is a direct product of bounded rationality.

> *"Judgment and experience teach us which models to use on which occasions."*
>
> Kay (2011: 166)

Unfortunately this is only valid when dealing with situations that resemble a recognizable past experience, from which we know what to do and how the system is most likely to respond. Sweeney & Sterman (2000: 251) have shown that our inability to deal with dynamic environments is deep rooted in our nature and more difficult to deal with. Should we not then use dynamic modeling techniques in everything we do?

System dynamics modeling and simulation helps in overcoming the correlation heuristic as the computer is unlikely to feel overwhelmed as the level of complexity increases. But even if it were to be overwhelmed it would give an error message rather than taking a wild guess at the solution. As powerful as computer modeling is, computer modeling is a decision making aid. Computers cannot make decisions for us in complex and dynamic systems (Kay; 2011: 111).

Simulation can prime us to the existence of a number of system behaviors so we can make better informed decisions in the future when some of those possibilities materialize. System dynamics provides an opportunity for heuristic experimentation. Grinnell (1999: 487) describes heuristic experimentation as experiments where one learns something new, "frequently what not to do next time".

In some respects system dynamics based learning is better than real life experience learning in that it provides rapid feedback and the ability to test assumptions and mental models. Huber (1991; 102 – 103) argues that mental models will determine how people receive information. This means that the same information may be understood to mean different things to different people depending on their mental models. He, (Huber; 1991: 103), argues that for people to interpret data the same way, the medium of presentation must be rich. The strength of rich media lies in the cues it gives and the rapidity of feedback (Huber; 1991: 103).

2.7 It is Counterintuitive

The behavior of complex systems is often counterintuitive as the undesired behavior of the system usually arises from the well meaning actions of its agents Sterman (2006: 506). If in a project all agents mean to maximize production output on all components and yet the project never achieves the desired output, then the unaccounted for component of the inefficiency must be partly attributable to this counterintuitive behavior of systems. In order to audit this behavior one would have to model the system in order to gain some insights. As I have argued, almost all the problems experienced within a system are self inflicted and self-maintained over the long term. Forrester (1991: 10) asserts that unsystematic solutions tend to make the problems worse most times as agents press harder to enforce a solution that they believe is right while not knowing that it is the source of their discomfort.

Forrester (1998) argues that to understand and gain insight from a system analysis one must understand the underlying structure of the system. From this assertion he stresses that the only way to achieve deep insights is by developing models based on policies, which may be written or unwritten, and not from daily decisions. He says that system models based on decisions are sub-optimal. Extending this assertion further leads me to conclude that a model built on decisions highlights and treats symptoms while policy-built models treat the root cause of the problem. Dealing with the root cause leads to holistic long term solutions. Sterman (2006: 508) efficiently sums up the problem of complex systems, where he says:

> *"Time delays in feedback processes are common and particularly troublesome. Most obviously, delays slow the accumulation of evidence. More problematic, the short-and long- run impacts of our policies are often different... Delays also create instability and fluctuations that confound our ability to learn"*

This assertion ties up with my claim that delays are evident in change orders as the real effects only reveal themselves towards the end of projects when additional efforts to complete on time fail. Only when the service provider audits his financial position does he realize that he is worse off due to the change order when it was actually meant to bring financial prosperity.

2.8 The System Dynamics Methodology

Systems Thinking Perspective

For decades now there has been a suspicion that prevalent management approaches are incomplete and incapable of addressing problems in fast paced business environments. The weakness of prevalent methods is that they are reductionist in their approach. A problem is broken down into simpler chunks and then the chunks are analyzed independently of each other, in silos.

> *"We see the world as increasingly more complex and chaotic because we use inadequate concepts to explain it."*
>
> Gharajedaghi (2004: 1)

Many problems worth addressing are complex and dynamic. Complex means they are made up of many interacting components which have their own goals not necessarily aligned to those of the other components. The behavior resulting from this interaction is emergent and can only be achieved through the interaction of all the components. Removing one component would give rise to a different behavior.

> *"Modeling natural systems is challenging due to their complexity in terms of variables, interactions, and dynamics. Much of this complexity is rooted in the existence of multiple ways through which acting variables affect each other."*
>
> Ferrarini (2011: 55)

From around the times of World War II another perspective began to emerge where problems are analyzed holistically. The chunks are understood individually and additionally analyzed together as they tend to have emergent behavior which cannot be attributed to any of the chunks if looked at individually. This perspective is called the systems perspective. Systems thinking is a paradigm where the whole is understood to be more than the sum of its parts. There are many methods which fall under the systems thinking umbrella. Metaphorically speaking, systems thinking is similar to first-aid while system dynamics is like surgery, according to Senge in a conversation with Fisher (2005: 11). This view is shared by the System Dynamics Society (accessed 11 January 2011) as they say:

> *"A map of a causal influences and feedback is not enough to determine the dynamic behavior of a system."*

This observation and distinction is important because not everybody will have the time, skill and patience to learn system dynamics but it is important to at least have systems thinking skills in this turbulent period we are in. Human beings are unable to predict long-term or emergent behavior that they create (Whitty & Maylor; 2009: 306).

System Dynamics

The methodology proposed for this research is called System Dynamics, which was developed by Professor Jay W Forrester at the Massachusetts Institute of Technology in the 1950s. It has its history in control systems. System dynamics formally took shape when Forrester was appointed to head the newly formed Sloan School of Management at MIT. His brief was to find ways that engineering principles could be used to add value to everyday management problems (Lane; 2007b: 14). One of his first assignments was to assist General Electric (Lane; 2007b: 14) understand inventory fluctuations that negatively impacted on their business. The cycles made it difficult to develop smooth long term human resource plans, amongst other things. System dynamics is primarily aimed at presenting the behavior of the system over time. It focuses on capturing the feedback relationships between the various system components as this is where the emergent behavior arises from.

Central to system dynamics are the concepts of stocks, flows and accumulation. Stock and flow structures are present in all systems and disciplines (Sweeney & Sterman; 2000: 252). The methodology uses the metaphor of physical systems (Rego; 1999: 5). A system dynamics diagram consists of accumulating variables (stocks) and flowing variables (flows). Flows effectively are the variables that change levels of stocks. Stocks are the items that build up or deplete over time and flows are the processes that cause the building-up or the depletion. Accumulation is the building- up of a stock and while seemingly simple to explain, human beings have a very a difficult time fully understanding and appreciating it in everyday life situations. Cronin et al (2009: 117) note that people resort to guess work when they do not understand the dynamic behavior of a system.

This inability to understand dynamic behavior is baffling to human decision science researchers because even people with high levels of education, including engineering and mathematics graduates (Sweeney & Sterman; 2000: 251), have difficulty grasping problems with stock, flow and accumulation components. This failure has been shown to be present even in systems with one stock and one flow (Cronin et al; 2009: 121). Even when faced with explicit accumulation presence Cronin et al (2009: 122) note that people still fail to understand and apply the principles of accumulation.

The system dynamics methodology has been proven to be more robust then most reductionist and some econometric methods in simulating social systems. The methodology is focused and by its nature forces the modelling participants to lay bare their mental models for scrutiny. This creates a disciplined learning environment, where incomplete mental models and thought processes are tested and questioned. The end result is better mental models which are more robust and clear.

The other major advantage of system dynamics against other models and other systems thinking methodologies is that it uses the power of computer simulation to develop the model and present the results. The System Dynamics Society (accessed online on 11 January 2011) says:

> *"System dynamics is a computer-aided approach to policy analysis and design… it applies to dynamic problems characterized by interdependence, mutual interaction, information feedback and circular causality."*

This gives the methodology the ability to give point precise results if required, which are easy to explain to anyone because of the intuitive nature of the model building process and the user-biasness of the software. To help our understanding, system dynamics models are an abstract representation of reality and the underlying feedback structures (Lane; 1999: 503). The simulations are management laboratories that should not only help us explain the behavior of the system but should also help us redesign it (Lane; 1999: 503). The methodology models the interactions between system structure and policies to reveal the resulting emergent behavior that confounds us. System dynamics modeling eliminates a large number of learning impediments (Repenning & Sterman; 2001: 86). The models do not give us new skills; but they do provide us with insight and clarity of required actions (Repenning & Sterman; 2001: 86).

> *"…a body of theory and method that has been developing for forty years to enable practitioners and researchers to better understand complex, nonlinear social and environmental systems."*
>
> Senge (2000: 2)

> *"System dynamics would employ the science of feedback, harnessed to the power of the modern digital computer, to unlock the secrets of complex, multi-loop non linear systems."*
>
> Jackson (2009: 7)

Additional to these descriptions I say it is a coordinated way of creating a common language, and building a cohesive picture of seemingly unrelated entities so as to get meaningful engagement of multiple stakeholders. By understanding the sources of problems; people are able to design better policies (Ford & Sterman; 1997: 309). System dynamics shows participants how they are part of the underlying structure and this cultivates an attitude of reflection. This reflection is likely to lead into changed behavior of the system participants especially if the previous behavior was problematic.

Kay (2011:172) asserts that:

> *"Our objectives are typically imprecise and multi-faceted, and change as we work towards them, and properly so."*

This assertion shows that most of our problems are not one-dimensional (or two dimensional for that matter) or linear or deterministic. In experiments of complex systems, Moxnes (2000: 327) notes that:

> *"It seems that subjects tend to reason with rather static mental models relying on outcome feedback to correct errors."*

This observation reinforces the claim that:

> *"Forrester rejected the use of linear equilibrium analyses with the aim of optimization or prediction… His view was that feedback ideas were a solid theoretical analytical approach which would act as an integrating framework for diverse descriptions and explanations of the behavior of socials systems."*
>
> Lane (2007b: 15)

From these definitions, observations and my arguments about complexity theory in the previous chapter, I deduce that the simple but insightful premises of the system dynamics methodology are derived from understanding that:

- Human beings are unable to see the distant effect of actions;
- Reductionism is an inherent trait cultivated by society and we therefore fail to comprehend emergent behavior when we think we understand the individual components forming the system. This is more true for undesirable system behavior when none of the system's components seem faulty;
- In complex systems where there are many interactions it is easy to dismiss what seems like small actions upfront, and thereby lose their long term impact on the system behavior. This oversight also prevents us from identifying high leverage points and policies that can help us achieve our goals;
- People use simple decision heuristics even when dealing with critical issues, especially when they feel overwhelmed by information. Rahmandad et al (2009: 323) assert that:

> *"…all our learning heuristics reliably find the neighborhood of the optimum allocation and converge to it."*

People who are attracted to quantitative data and analytical methods tend to believe that this type of data is more accurate than qualitative data. The inherent risk in this tendency is that whenever data is produced and supplied by reputable people or organizations, we tend not to question its validity or its representativity. We also overlook the representativity and accuracy of the measured parameters.

We make a mistake; as observed by Kay (2011: 93); to believe that:

> *"…a number based on the flimsiest of data is better than a qualitative and necessarily subjective judgment."*

There is a prevalent worldview that we must weigh the situation before making decisions. There is nothing wrong with this perspective but the problem is that even the most quantitatively challenged people blindly trust quantitative data. People frequently use moral algebra (Kay; 2011: 89) which carries an inherent assumption that we know enough about the system being analyzed and therefore we can fully list the pros and cons. Moral algebra is the tabular listing and subsequent analysis of pros and cons of a system for the purpose of arriving at the universally best solution.

We can only know enough if we are embedded in a reducible, static and deterministic system. However in complex systems, as I have been arguing in this and the previous chapter, we rarely know enough in order to fully list the pros and cons. The list is even more deceptive if it is quantitative as we think we know the truth and we therefore end up having false confidence in our decisions. Moral algebra, whether quantitative or qualitative, is just not good enough in complex systems. It is pseudo science to give us a warm feeling that we have done the best to arrive at the best solution.

Moral algebra approximates the indeterminate real world problem by simplifying it and making it determinate (Kay; 2011: 107). It is an abstraction exercise. By losing the dynamicity and complexity of the problem, we inadvertently create unreal solutions that carry with them undesirable side effects (Sterman; 2002: 504). The side effects, the emergent phenomena with non-linear dynamics (Klein; 2004: 4) are time delayed and grow to become the new problems that require new solutions, thereby trapping us in a spiral of incomplete solutions. This is the counter-intuitiveness that system dynamics has the ability to address unlike most other analytical methods. In further reinforcing the issue of counter-intuitiveness of our daily decisions Kay (2011: 172) says:

> *"In a necessarily uncertain world, a good decision doesn't necessarily lead to a good outcome, and a good outcome doesn't necessarily imply a good decision or a capable decision maker."*

> *"…aided by computer modelling. They used these models, as any such model should be used, not to make decisions or to predict the future, but to understand better the complex systems they were dealing with."*
>
> Kay (2011: 176)

Important systems thinking skills; as summarized by Sweeney & Sterman (2000: 250); are:

- Understanding dynamic complexity;
- Discovering and representing feedback processes;
- Discerning stock and flow relationships;
- Appreciating time delayed effects and their confounding ability;
- Identifying non-linear relationships;
- Knowing that humans have cognitive limitations

As I have already said; a complex system is one composed of many interrelated components acting independently but exhibiting collective behavior that cannot be attributed to any of the independent components. The behavior tends to be dynamic, meaning it changes or accumulates with time. Systems thinking refers to a holistic view of the system of interest and when compared to the analytical reductionist approach, the systems perspective is empowering and expansive (Richmond; 1991: 2) and gives you the ability to see the underlying ongoing, reciprocal relationships.

The true aim of the systems perspective is to help us understand the environment within which we live, work and play. It gives us the ability to analyze and solve our problems from a non-reductionist view. The importance of this non-reductionist view comes from understanding that not all problems are local in space and time. By this I mean that some problems do not manifest themselves in the immediate vicinity of the triggering action; they are delayed in time.

With a localized view; as that coming from the reductionist perspective; you are unable to fully understand how and why a system may behave as it does. The reductionist view emphasizes analysis while the systemic view emphasizes synthesis. The power of the systemic view is that it empowers you to see the distant effects of actions. The distant, time delayed effects, hamper human learning if they do not match our expectations. The persistent and hard to understand problems in our lives survive because of the non-systemic approach taken to resolve them.

System Dynamics in Other Contexts

Urban Dynamics was is a book written by Forrester with a system dynamics model developed pre-1970 which looked at the long term impact of urban development in major cities. This was followed by World Dynamics which modelled the behavior of the world based on prevalent trends at that time. This model lead to the development of a model called World 3 which was used in the bestseller Limits to Growth in the 1970s. This book highlighted the plight of the world with limited resources with people' s unlimited demands for the world' s resources. The book was controversial at the time but has been proven to have been accurate as many of its insights that have lead to the drive for renewable energy sources.

The methodology has been extensively and successfully used in litigation to model the non-linear impact of project disruptions. It has also been used to improve stakeholder understanding of healthcare systems in America and in some European countries (Roberts; 2007).

Basics of the Modelling Process

As previously discussed, system dynamics is exclusively concerned with modelling the behavior of system variables over time. The aim is to see the dynamic interactions of the different system variables when put together. In a reductionist perspective, the most common analytical perspective, these variables would be analyzed individually in silos and we would lose the insights that arise from a holistic analysis of such variables. The system dynamics methodology focuses on:

- Feedback relationships with the system;
- High degree of operability. The modelling process forces a disciplined thought process;
- Generation of insights into the system behavior. It is usually less about point- precise predictions;
- The stocks and flows representation can be used in any type of system including social and business systems.

The power and the beauty of system dynamics modelling lies in the simplicity of the model building blocks used in the methodology. In this section I will discuss the building blocks of system dynamics modelling.

- Stocks

These are building blocks used to represent things that can accumulate over time. A stock may be an actual physical variable or it may be something intangible such as anger.

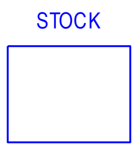


Figure 8: Stock Notation

They are nouns that exist at a point in time (Croope; 2010: 13). The reason it is a box it is to reflect a metaphor of a bathtub or a vessel.

- Flows and Rates

A flow is anything that accumulates into a stock. The valve device in the flow is called a rate and it determines the rate at which a stock is built up or depleted. Flows determine the dynamics of the system.

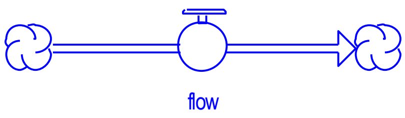


Figure 9: Flow and Rate Notation

The double lines reflect a metaphor of a pipe where the "product" flows and the valve reflect the control of the flow. The two clouds on either end of the pipe reflect that we are not too concerned with where the flow is coming from or where it ends up. They reflect an environment outside of the system boundary or area of interest for what is being modelled.

- Convertors

A convertor is a variable that directly or indirectly impacts or acts on the stock. Convertors affect the system by exerting their impact on the flows. Convertors may act on other convertors.

Figure 10: Convertor Notation

A convertor may also be used to represent stocks that we are not too concerned with managing in some system models.

- Connectors

System dynamics is a feedback-based methodology. Connectors are the "wires" that transmit the convertor output or input to a flow. They also transmit the same from a stock to a convertor or flow.

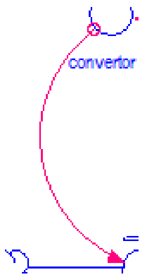


Figure 11: Connector Notation

They represent the feedback relationships amongst system components.

> *"A set of interdependent variables forms a circular relationship. Each variable co-produces the others and in turn is co-produced by the others. Which one comes first is irrelevant because none can exist without the others. They have to happen at the same time."*
>
> Gharajedaghi (2004: 4)

Due to Forrester's previous work on control systems, he was able to notice that all systems have feedback loops. In essence feedback loops are reactions to input. In machines, feedback loops are easy to perceive as they are consciously built into the system. In human systems, feedback loops are not so easy to perceive. Feedback loops reinforce or balance/ cancel the effect of the input. Observed behavior resides within the multiple feedback structures (Kirkwood; 1998: 7).

Again in social and organizational systems this means our reactions either encourage (reinforce) or discourage (balance) other's actions. From this understanding we can deduce that all situations we find ourselves in, are either of our own doing or encouraged by the way we react to them. This is called the endogenous perspective. To effect any change in the system we must look from within. The system has the power to change itself; through its agents; provided the people within the system know where to act.

Example of a Simple System

The following figure shows the building blocks put together to represent a relatively simple system. In the model we have a stock called (STOCK) whose level is raised by the flow called (flow raising the level of the stock). The stock is depleted by the flow called (flow depleting the level of the stock). There is a connector from the stock to the depleting flow. This connector denotes a relationship that the depleting flow is dependent on level of the stock.

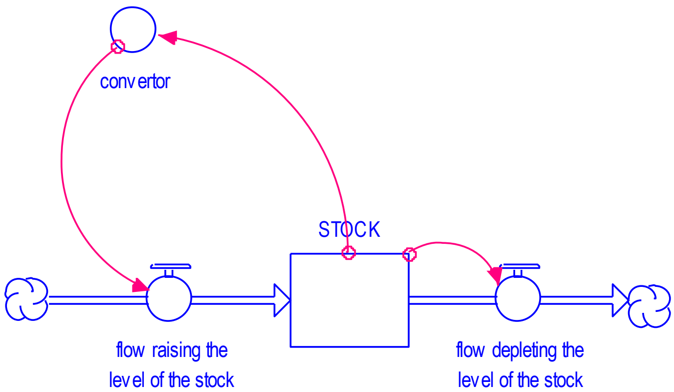


Figure 12: Generic Model Representing the Notations Put Together

We also have a convertor called (convertor) which could be a time fraction or constant for governing the inflow. This convertor is also connected to the stock, which means that the level of the stocks governs the time fraction.

Modelling Approaches

As highlighted earlier system dynamics models can be used to facilitate learning or to compute precise system variables. While a modelling exercise can be used achieve both objectives, generally they are not. The following figure represents the general directions that a modelling exercise may take.

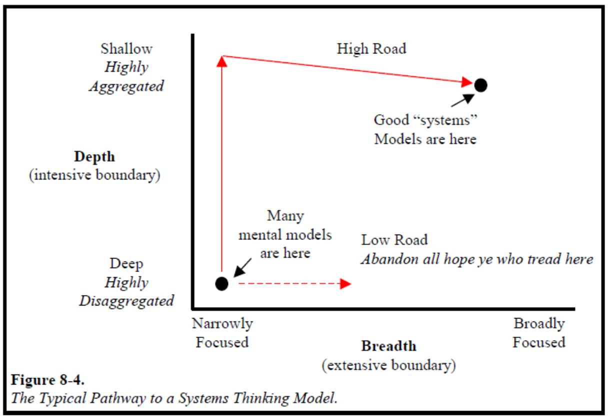


Figure 13: Typical Pathways to a Systems Thinking Model
Source: Richmond (2001: 114)

According to Richmond (2001: 114) a modelling exercise may have different levels of aggregation and focus. The best systems models are highly aggregated but with a much broader focus. This helps facilitate the deep understanding of the overall system at a higher level. It allows the modeler and group participants to see the forests while also seeing the trees. It is easy to see the power of systems thinking when contrasting this perspective against a reductionist approach which focuses almost exclusively on the trees while neglecting how they interact with other trees in the forest. There is no understanding of the ecosystem in the reductionist view.

The general perspective is that no matter how complex a system may be; it is always possible to simplify the model. There is another perspective that says that there should be a differentiation between a physical structure and the psychological one. I am however at unease about this because the mental models that inform our perspectives and opinions are the results of psychological issues. Therefore modeling a system as we see it is effectively a psychological exercise even though it may be implicit. Separating these into different models is essentially a reductionist exercise which I have argued is counterproductive for effective analysis of emergent behavior.

To commence building a model, one must first start by laying bare the variables that they consider to be critical for the system being studied. This can be achieved in many ways, but the most common are the causal loop and influence diagrams. Causal loop diagrams were developed by Helmut Weymar, who was a MIT PhD candidate at the time (Roberts; 2007: 6). Causal loop diagrams represent relationships that are difficult to verbally describe (Kirkwood; 1998: 5). These diagrams are better at telling the story of circular chains of cause and effect (Kirkwood; 1998: 5. This stage is effectively about exposing ones mental models of the system. Caution should be exercised here when using these diagramming techniques as:

- It is difficult to infer cause and effect relationships of the variables plus;
- One cannot perceive accumulation from these, which is a cornerstone of understanding complex and dynamic systems.

System dynamics recognizes that systems are path dependent as discussed in the previous chapter. This observation highlights that most system will resist policy changes regardless of how hard we try to change it. It also highlights that for thoughtful interveners, systems will implicitly present them with low-effort-high-leverage points. The key is in taking time to analyze the system in order to identify these leverage points.

The system dynamics modelling software to be used in this research is called iThink.

Benefits of using iThink

> *"A system dynamics model creates so much clarity and unity, compared to prior mental models, that the "adequacy" decision usually generates little controversy among real- world operators who are under time and budget pressures to achieve improved performance."*
>
> Forrester (1994: 5)

Some benefits (Croope; 2010: 26) for using iThink / STELLA software are:

- The language increases the accuracy and clarity of verbal descriptions, ambiguities diminish, and communication becomes much more efficient and effective;
- The software provides a check on intuition, and also provides a vehicle for building an understanding of why;
- The tools facilitate putting together in an organized and clear way the qualitative and quantitative approaches present in most systems; and
- The tool enables an easier operation, demonstration, and replication of the modelled system.

Model Building Processes

Model development is a reiterative process that is more meaningful when involving a multitude of stakeholders. Even in an adversarial context, it is more meaningful to involve the opponent in the model development process as it can change their perspective and indirectly lead to out-of-court settlements. This would have many benefits for the participants, the ultimate being the preservation of the business relationship.

A number of system archetypes have been observed over the years. These are the generic structures that regularly appear in different unrelated systems. They are combinations of positive and negative feedback loops. It is my opinion however that they should not be used from the onset of the modelling process but rather later in the modelling process to enhance the accuracy of the model. Kirkwood (1998: 3 – 4) highlights four patterns of behavior that are prevalent in different systems:

- **Exponential Growth:** The variable of interest starts off slowly but then grows dramatically over a period of time. The reinforcing loop, discussed earlier, is prevalent in this system;

- **Goal Seeking:** The variable starts off either above or below the desired parameter but moves towards it over time. I believe that Change Orders represent this type of behavior. At the beginning of the project the two contracting parties have targeted costs and time with a certain profitability attached to these. The introduction of Change Orders disturbs this target. The balancing loop is prevalent in this system;

- **S-Shaped Growth:** It starts off as exponential growth and changes to goal seeking later on;

- **Oscillation:** The variable of interest fluctuates around a certain level. It can be a combination of any of the preceding three patterns. A negative loop with substantial delay may be in action or else it may be a combination of reinforcing and balancing loops.

Modelling and Learning Processes

Croope (2010: 28) and Forrester (1994: 4) recommend the following processes, to assist the modelling and learning processes:

- Define the Issue;

- Learning Process:
    - Identify the target audience;
    - Define the objectives;
    - Define the learning strategy;
    - Implement the learning strategy;
- Model Building Process:
    - Step 1: Describe the system;
    - Step 2: Convert the description to level and rate equations;
    - Step 3: Simulate;
    - Step 4: Design alternative policies and structures;
    - Step 5: Educate and debate;
    - Step 6: Implement changes in policies and structure

It is an iterative process from the beginning to the end. The end is never real as the system is bound to change with time. Any method that purports to be an exact representation of reality is likely to be untrue and static and designed from a reductionist perspective. System dynamics modelling is about improving our mental models about the real world systems.

Model Validation

Once a model has been developed, it must be tested and validated. Model validation is a multifaceted process but the ultimate objective is to get complete buy-in from the stakeholders. The stakeholders must recognize the simulation model to represent reality as they know it. The model must serve the purpose for which it was designed (Rego; 1999: 7). The bigger the ensemble of tests used to validate the model, the more robust the decisions that will arise from it. This way, the model is better able to meet the requisite variety criterion which must be met by all viable complex systems.

Forrester & Senge (1979: 4) highlight that model validation is actually about building confidence in a model and showing it to represent reality and that it behaves plausibly. They further highlight that there is no single method of validating a model; it is a multi-test process (Forrester & Senge; 1979: 4). The aim is that if the model passes these validations tests then it should not be difficult to transfer the learning to other stakeholders. With all these objectives achieved then there should be minimal or no resistance to policy changes.

They propose seventeen tests (Forrester & Senge; 1979: 37) for building confidence in a model. These tests focus on validating three core areas; each with its own tests:

- Tests of Model Structure
    - Structure verification
    - Parameter verification
    - Boundary adequacy
    - Dimensional consistency
- Tests of Model Behavior
    - Behavior reproduction (symptom generation, frequency generation relative phasing, multiple mode, behavior characteristic)
    - Behavior prediction (pattern prediction, event prediction, shifting-mode prediction)
    - Behavior anomaly
    - Family member
    - Extreme policy
    - Boundary adequacy
    - Behavior sensitivity
- Tests of Policy Implications
    - System improvement
    - Changed-behavior prediction
    - Boundary adequacy
    - Policy sensitivity

Testing is a highly involved and demanding process. The model building participants must decide on the best tests for their modelling endeavor bearing in mind the overall aim of developing the model. Not all tests will be used in this research, only those sufficient to achieve an acceptable level of confidence in the model.

One Model - Many Audiences

As I have highlighted that the model that will be developed in this research will used to facilitate learning, altering mental models and for general clarification of thought around change order related issues, it is therefore important:

- That the system dynamics model be easy to understand and explain to all stakeholders. The participants must be able to question it and make sense of it with minimal effort. They must be able to get concise and clear answers from analyzing the model;

- That the causation logic and the relationship between the components of the model must be clear to all parties;

- To build the model, and giving the client sufficient time to test and audit it is important and will most likely reduce or eliminate disagreements around the issues being analyzed. This may lead to both parties being able to cultivate and nurture a relationship built on trust and transparency. More importantly the client learns the impact of involvement thereby minimizing interference on future projects.

Constructing clear, precise and easy to understand models will be guided by some of the validation tests as already discussed in this chapter. The ultimate aim is to keep the information minimal and the model simple as possible but without sacrificing the robustness of the model.

2.9 The Beaten Path

System dynamics has been used extensively in modelling project management systems. A large number of the models [Lyneis & Ford (2007); Lin et al (2008); Rahmandad & Hu (unpublished)] focus on modelling and improving the work already done on the rework cycle. The rework cycles are the hidden and delayed impacts on completed tasks which have to be reworked downstream in order to accommodate new changes identified later on in the project. They are highly prevalent in concurrently engineered projects as in these projects activities are started and sometimes completed with the incomplete information in a quest to get a product out to the market as quickly as possible.

Even though these models have been mostly focused on modelling rework cycles for product development projects, they are equally applicable in normal engineering projects such as the one to be modelled in this research. The major insights and impacts of rework cycles are that (Lyneis & Ford; 2007: 165 – 166):

- Haste to complete gets work out of sequence;
- Errors create more errors;
- Errors create more work;
- Hopelessness affects morale

As can be seen from the following simplified figure, the existing models focus on the reworks as discussed. These reworks occur in many areas of the project lifecycles, not only in the engineering and design stages.

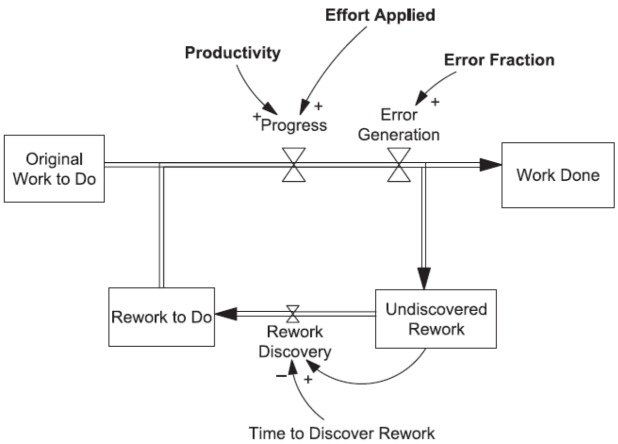


Figure 14: Rework Cycle
Source: Lyneis and Ford (2007; 165)

The fabrication stage goes through the same reworks and so does the installation stage. These are discussed in-depth in chapter four when I discuss and provide the background on the case study project.

All the work building on this has been focused on capturing more and more feedback loops. Now the general perception is that this area has been exhausted and the work should focus more on the sensitivity of the models to these loops and the secondary impact of reworks on the latter life of the product, i.e. what happens once the products is out to the market later than originally planned (Lyneis & Ford; 2007: 167).

While my model appreciates that reworks have an impact on the project, I do not explicitly capture this. My model explicitly models the change order process and its impact on the work completed and the work to be completes. I take these forward in order to quantify the costs for my organization whenever change orders are generated. An index which I call the sequencing factor reduces output due to the variation orders in order to capture hopelessness; errors induced by other errors and the negative effect of haste.

2.10 Chapter Summary

Goodman (1991: 2) stresses that the systemic perspective dispels the "us" and "them" view and teaches us that we are jointly responsible for the system problems and their solutions.

> *"…it is the system's particular configuration which is responsible for the system's history, and the cause of its dynamic."*
>
> Rego (1999: 4)

In this chapter I have discussed system dynamics and its roots. I have shown why the methodology is so powerful and suitable for analyzing project change orders. I have also shown how system dynamics models can withstand and help us answer the difficult questions that may be posed by other stakeholders. By doing this I wanted to show that if a model can clearly assign responsibility and show causation it keeps the relationship transparent and everyone knows where accountability lies.

I have also discussed the most common approach of modelling projects that almost exclusively focuses on the rework cycle. While I have analyzed the most common approach, I have not used it in my model as my aim was to facilitate learning within my organization so that the participants can engage their clients in future projects in order to avoid the persistent pitfalls in engineering projects which stem from our inherent linear perspective.

In the next chapter I will discuss the research methodology to be followed in this research.

CHAPTER 3

Khanya

3. RESEARCH METHODOLOGY

3.1 Introduction

The overall aim of this chapter is to provide the procedure I followed in executing this research. In this chapter I will give a background on the sequence of the steps I followed, provide the profile of the research participants and also attempt to place the research within a theoretical framework.

I will also briefly discuss the fuzziness and the apparent overlap of research methods.

3.2 The Fuzzy World of Research

The language of research paradigms can be very confusing and misleading. In broad terms research is generally designated as being either qualitative or quantitative. The quantitative paradigm is also said to be positivist and seen as the basis for scientific research. Within each paradigm; especially the qualitative paradigm; there are different approaches with different names but many of which are very similar in their approach. System dynamics is both qualitative and quantitative as will be shown in the research.

The data collection and modelling building stages are more qualitative, the simulation and analyses are both qualitative and quantitative.

3.3 Research Objectives

Levers et al (2008: 2) assert that qualitative research explores relationships within a particular context in order to generate hypothesis about the new knowledge. This statement is in line with my motivation for this research. I believed that there was something amiss with the management of change orders, and that is what I wanted to explore with this research.

As I have stated in the first chapter, my research arguments were as follows:

1. Argument 1: All parties in the project chain either gain or lose revenue when a change order is requested by the client;

2. Argument 2: Clients and service providers are oblivious to the true impact of change orders on time and cost;

3. Argument 3: Revealing the true nature of change orders will discourage clients from requesting non-essential changes in projects;

4. Argument 4: Revealing the true nature of change orders will make it easier for service providers to justify seemingly disproportionate costs and time claims even post project completion;

By undertaking this research I aim to:

1. Model project management change order systems, on whose analyses I will reveal the weaknesses of the current generally accepted approaches;

2. Gain insights on the system structure and behavior of the systems modelled;

3. Review the robustness of current methods which are believed to be best practices;

4. Use the model to inform the generation, assessment and approval of change orders;

Additional to these aims I plan to answer the following questions:

1. What are the cost implications of adopting the system dynamics methodology?

2. How does system dynamics modelling compare to other modelling techniques?

These aims and propositions were all overlapping and could not be addressed separately. Krauss (2005: 760) acknowledges that the social sciences researcher allows questions to emerge as they become familiar with their research systems. This assertion proved to be true the more I went through the research process.

Inherent in these propositions were my own biases for using system dynamics within the legal framework. As I got more involved in the research process I began to see how simplistic and limiting that perspective was. As I emerged towards the end of the research I was more convinced that the power of system dynamics lay more in learning, altering of mental models and creating a shared vision. Many of the problems that persist to exist are maintained by those of us who are part of the system. System dynamics has the potential to change the mental models of people who see themselves as system victims so that they know that there is something they can do about the system problems they experience.

I learnt that sometimes one does not need highly detailed models in order to facilitate deep learning; all that is required is a sufficiently detailed model. As stated in the previous chapter, breadth is sometimes better than depth when learning about a complex system.

3.4 Paradigm Wars

There is a persistent debate among some researchers about the most superior way of conducting research. Some argue for qualitative research methods while others believe quantitative methods to be superior. There is another class of researcher who choose to take the best of both worlds. I fall within the mixed methods group as I believe in using whatever tool is available to me to achieve the required outcome.

Quantitative research is considered superior by many people because it has been the basis for the growth of deterministic science and the scientific revolution. It is a hallmark of scientific knowledge as discussed in the first chapter. Management science has also developed on the basis of this paradigm. For decades the quantitative approach was sufficient but the rapid change in organizational life has deemed it insufficient for complex systems analyses as life refuses to be subjected to controlled experiments. Such systems require more than quantitative analysis but require rich descriptions and narratives from participants and the researcher. Rich descriptions form the major component of qualitative research as that is how the interactions of the system components come to be understood.

Dunning, Williams, Abanyi and Crooks (2008: 145) quote Lawson (1995) and Bryman (2001) where they assert that the division lines between qualitative and quantitative research are artificial and should be ignored.

3.5 Research Design

The research design was simple in that for the research I only needed to engage participants from only one organization. Additionally the participants were going to be people that were involved in the completed project to be modelled. This was done because I was well aware of how difficult it can be to get the participants to participate in a prolonged model building exercise which may end up feeling like a waste of time for them.

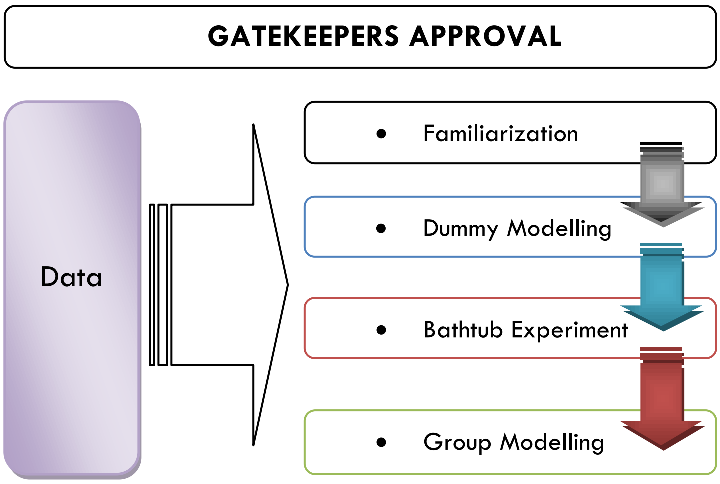
To minimize the time I had to spend with the participants in a group, I did background research on the project and focused on what I thought would be relevant information for the model I wanted to build. This information included studying the different registers, including:

- Variation Order registers,
- Monthly Cost reports,
- Manhour Budgets and Revised monthly Forecasts

I also engaged the research participants on an individual basis to get more background information on the project.

After I felt I had sufficient information I then started to build my own models to test the sufficiency of the information collected. This was also done because I wanted to be efficient in facilitating group modelling before meeting the research participants in a group setup. I went through a number of iterations of the model, regularly having to go back to people who were involved in executing the project that I was using as the basis for my model.

Before engaging the participants in the group modelling exercise, I thought it would be interesting to do an experiment to test their understanding of dynamic system behavior. The previous conclusion (Sweeney & Sterman; 2000) was that people do not do well in dynamic tests and hence my expectations were not different. This however was concerning considering that the participants were engineers who design process equipment with retention times and flows.


GATEKEEPERS APPROVAL
Data
Familiarization
Dummy Modelling
Bathtub Experiment
Group Modelling

fellow students. Each group of these was either familiar with the project or system dynamics and or iThink.

Phase 3: Bathtub Dynamics Experiment

This phase was meant to test the participants' understanding of dynamics behavior. This was done by randomly developing a model with three bathtubs. The questionnaire was sent to participants not familiar with system dynamics and they were asked to plot the graphs of the behavior of water in the three bathtubs.

Phase 4: Group Model Building

The group modelling stage was pre-planned but the participants were not aware of this. The procedure followed was to:

- Give a background on systems thinking and system dynamics;
- Develop the model in fragments as discussed in chapter six.

It is important that the participants and the end-users be part of the model building process to engender the required deep and profound learning.

The data collection process had four explicit stages. One of the stages was not part of the original research plan but was added later to add more rigor and insight into the research process. Researchers should collect multiple data using multiple strategies, approaches and methods (Johnson & Onwuegbuzie; 2004: 18). It should be a disciplined collaborative effort meant to inform and change our work practices (Ferrance; 2000: 1). The multifaceted approach is meant to link different strengths of the methodologies so they can reinforce each other and hopefully have an emergent mass effect.

Academic and practitioner literature are littered with the acknowledgment that we live in an increasingly complex, interdisciplinary and dynamic world. I therefore contend that such a world requires equally complex research methods. Again this highlights the issue of requisite variety discussed in the literature review, and I am proposing that action research and mixed methods research were suitable for meeting the needs of a complex world.

There is no reason why a qualitative researcher cannot use quantitative data collection techniques if need be (Johnson & Onwuegbuzie; 2004: 15). People do not blindly follow the tenets of paradigms as written by purists. The mixed methods stance; plus the action research approach are both inductive and deductive. Voce (2004: 4) says that through inductive thought researchers observe specific processes so as to reach wide and generalizable statements. Ideally with this research endeavor, I wanted to reach a point where I could identify consistent problems that arise with change orders so that I could make conclusions supported by rigorous research results. I am not saying that mixed methods research is perfect, but when used with due care it should provide solid and robust results.

> *"… in the strenuous journey to knowledge, researchers and scholars employ various research paradigms to guide them through the course of the knowledge seeking."*
>
> Kim (2003; 9)

Kim further claims that organizational researchers are in favor of using widely divergent research techniques (Kim; 2003: 10), which I conclude can only help in making research results more robust. As I stated in my aims section, I wanted to arrive at a point where the results of this research could assist in the generation and assessment of change orders. To achieve this I had to go through an iterative process of data analysis, theoretical analysis and hypothesis testing.

The analyses and testing processes are the main features of grounded theory (Savenye & Robinson; 2001: 1051). Grounded theory can be used in both qualitative and quantitative research.

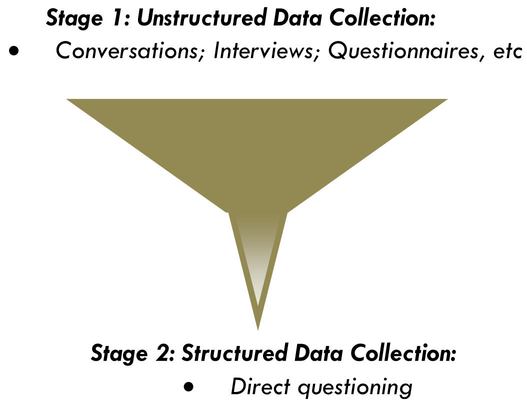


Figure 16: Data Collection "Funnel" Structure

As advocated by other action researchers, data collection was a multi-faceted process (Ferrance; 2000: 11). *Figure 16*, shows that data was initially obtained in an unstructured way from multiple sources; including monthly progress reports and other forms of written communication plus open ended interviews. The importance of the unstructured and open-ended approach was that it allowed freedom of response from the participants which could expose or reveal other unexpected data which could add value to the research project.

As is represented by the funnel, the collection method started off as being very open and unstructured and gradually moved towards being focused and direct in its questioning. Savenye & Robinson (2001: 1050) concur that when a researcher spends time within the system, the interview process may take the form of an informal conversation, loosely discussing issues with the aim of triangulating conversational data with other data already collected. At this stage the modeler begins to understand the system and identifies the variables that matter (Luna-Reyes & Andersen; 2003: 287). As I became more familiar with the project system, the data collection began to take a more structured and direct approach. At this stage I used more focused and direct questions in my collection methods.

All the data collected was the basis for developing causal loop and the stock flow diagrams which are the internal parts of the simulation model in order to investigate the variables of interest. Research results were empirically verified in order to ensure objectivity. Kim (2003: 16) summarizes that:

> *"Because research is the fundamental cornerstone on which sound theory is transformed into effective organizational practice, it is important that the methodological foundation on which the research is based be both sound and rigorous."*

Luna-Reyes & Andersen (2003: 287 – 292) argue that the use and collection of qualitative data cuts across all the stages of the modelling process. In line with the modelling process discussed in the previous chapter, they break the modelling process into the following stages:

- **Conceptualization:** This stage is aimed at identifying the variables that are important for the simulation. Oral history, interviews, hermeneutics and discourse analysis are important qualitative techniques that may be used at this stage;

- **Formulation:** At this we are more focused on defining and narrowing the parameters of the identified variables. Interviews, ethnographic decision models are important in executing this stage;

- **Testing:** This stage is aimed at exposing the model to those people embedded in the system. It is aimed at ensuring that the model is a true representation of reality. Interviews and focus groups are powerful testing techniques;

- **Policy Analysis and Implementation:** This stage is aimed at testing the impact of changing existing policies or replacing them with new ones prior to implementation. Qualitative tools such as grounded theory are useful at this stage.

Data analysis was a multistage and reiterative process as is normal with qualitative research. It commences during data collection.

- The first stage of the analysis was primarily aimed at generating stock-flow diagrams;

- The next stage of analysis was the simulation of the models with the aim of understanding the interaction of the system components;

- The last stage was a reflective analysis with the aim of synthesizing the whole research process.

Ferrance (2000: 12) suggests that during analysis, one variable at a time should be altered to gauge its effect on the system. This poses a few problems in that the claim ignores and assumes a linear deterministic and reducible system. This research takes a hindsight approach as the project analyzed was complete; just as litigation problems are likely to be when they reach the courts; this will deny me the opportunity to check the effect of variables in a real world context. As generally agreed; Gustavsen (2008: 434) states that social research addresses issues that cannot be subjected to experimentation.

Fortunately once I had collected the relevant real world data necessary for developing the system dynamics model then the process moved to the computer. This stage allowed me to take a complex social system and investigate it in a safe laboratory-like environment without it losing its complex and dynamic characteristics. As already stated, system dynamics provides us with the opportunity to hold some variables constant while focusing on others. It also provides us the opportunity to see the real impact of the portfolio effect. If we accept that system dynamics models can represent reality than it provides an opportunity to hold or vary variables in order to measure their impact on other variables. It is important to keep notes and printouts of variables analyzed and the thoughts that emerge during the analysis (Luna-Reyes & Andersen; 2003: 290).

Putting thoughts on paper forces a sharpened focus on explicitness of ideas (Zuckermann & Rajuan; 2008: 2). Sometimes initial words do not accurately represent the actual thoughts and require further refining until they are in sync with each other; therefore data analysis was a continuously reflective and iterative process.

3.7 Boundary for Data Collection

A critical issue in systems thinking is boundary definition. It helps contextualize the system being studied. At first glance it may seem a simple exercise but proves to be very difficult because as a researcher one wants to include everything that is relevant and only exclude the irrelevant. Making this decision is difficult and risky. The risk comes from the possibility of excluding one variable that seems irrelevant because it does not have an immediately perceivable impact on the system when in fact it does.

For this research endeavor my boundary will be the one project to be modelled. I am only interested in variables that impact on the financial well being of the engineer organization. Only variables from within this system will be considered. I expect that boundary refinement will occur as I get deeply immersed in the system being studied.

3.8 Sample Size and Profile

As can be expected all research is concerned with representativity as much as possible.

Item	Respondent Description	Gender	Race	Discipline	Years with BP
1	Respondent 1 (UM)	male	Indian	mechanical engineer	2
2	Respondent 2 (MG)	male	Indian	mechanical engineer	6
3	Respondent 3 (JS)	male	White	project planner	6
4	Respondent 4 (SR)	male	White	mechanical engineer	2
5	Respondent 5 (AC)	male	White	mechanical engineer	3
6	Respondent 6 (MQ)	male	White	mechanical engineer	2
7	Respondent 7 (WS)	male	White	mechanical engineer	3
8	Respondent 8 (KR)	male	Indian	electrical engineer	3
					3.1

Table 1: Profile of Research Participants

Sample size consistently comes up as a concern and one of the arbitrary measures of rigor. A large sample is seen as a good way of addressing the rigor concern.
This research involved two clusters of groups. The first cluster was the bathtub experiment participants who are employed as project and design engineers.

Table 1 shows the profile of the research participants for the bathtub experiment. There were ten participants mostly with mechanical engineering qualifications. The participants were all males. The average age of the participants was twenty nine and on average the participants have been employed by the company for three years. Three of the male participants were of Indian descent and the rest were of European descent.

These are the people that were directly involved in the Swaziland project except for the electrical engineer.

The second cluster was made up of (see appendix for the simulation attendance register):

- five project managers;
- one senior cost engineer and;
- one contract manageress/ administrator

These are the people who lead and drive the change order processes. This was a smaller group relative to the dynamic experiment group. All the project managers were males of European descent and one of Indian descent. Their age range, including the project controls manager, is thirty five to fifty five years. They have been practicing project managers for more than five years. The project controls manager was a white female of European descent and holds a law degree.

3.9 Research Approach Synthesis

Luna-Reyes & Andersen (2003: 271 – 296) highlight the indispensible value of qualitative data in system dynamics modelling.

Qualitative techniques must be used interchangeably with quantitative techniques in system dynamics model building and analysis in an attempt to ensure that the simulation mirrors reality. Qualitative data adds to the tool bag of the modeler. They are time and effort consuming to compile, however they bring richness that can never be obtained or inferred by pure analysis of qualitative data.

System dynamics literature does not impose any restrictions on how data should be collected but leaves it to the researcher to be the judge of the value of the information collected and used to develop models. Roberts (2007: 14) says that:

> *"To me, rigorous modeling, supported by empirical observation and data gathering, is and ought to remain the essence of useful System Dynamics."*

My overarching objective was to learn from my work environment. These lessons would be used to improve my work system. Lessons emanating from this engagement were found to be real, meaningful and useful. This made the lessons transferrable and value adding to other individuals interested in learning about change orders. The research approach was multifaceted and focused on making a real-world contribution.

The ultimate aim of action research is to provide insights that result in changed mental models and behavior. It is meant to handle the problem of "how to bring theory to bear on practical development in working life" (Gustavsen; 2008: 423). It represents interplay between theory and practice to identify a solid middle ground. For this to be achieved it is imperative to identify levers and gauge their resultant effect on the system behavior.

To me the action research approach is similar to the mixed methods approach which argues for the mixed use of qualitative and quantitative tools. Johnson & Onwuegbuzie (2004) argue the importance of adopting a mixed methods research approach. They propose adopting both a qualitative and quantitative stance as both have their strengths and weakness (Johnson and Onwuegbuzie; 2004: 14). The aim of research in the social sciences is to provide us with warranted assertions about human systems (Johnson & Onwuegbuzie; 2004: 15). Warranted assertions are also the defining feature of grounded theory.

Savenye & Robinson (2001: 1050) identify major characteristics of qualitative research as:

- Occurring in natural settings;
- The researcher being the main data collection instrument;
- The researcher uses intuitive knowledge and propositional knowledge;
- It does not seek to exclude quantitative knowledge.

Learning from the Real World

Even though I had asserted that I had not placed this research within some paradigm, the way I had chosen to execute it clearly fell within the Action Research paradigm. The ultimate aim was to learn and improve my system based on the lessons that emerge during the continuous engagement with the system. The three biases corresponding to emergent learning; as identified by Parry & Darling (2001: 1) are:

- Learning is about discovering and using knowledge. First-hand experience is the best source of knowledge;

- Learning should be an active part of our daily lives and not be pigeon holed into formal learning environments;

- Learning should be both an individual and a group effort. Taking time to discuss issues; even if casually; and general reflection encourage learning on a wider scale.

Learning from doing generally addresses the problem of knowing "what to do" but without knowing "why it must be done" (Parry & Darling; 2001: 2). Knowing the "what" without the "why" hinders deep learning. Without the deep learning there are no insights into the systems we are dealing with.

> *"One of the best sources to activate knowledge is that which emerges from people's own experiences."*
>
> Parry & Darling (2001: 1)

From personal experience; Hussein (2008: 392); concludes that action research stems from the practitioners curiosity.

> *"The vivid intersection between Army "doctrine" ( ) and direct battle experience allows espoused theory and actual practice to shape each other on a daily basis."*
>
> (Parry & Darling; 2001: 2)

Emergent learning taking place within a community of practice carries great potential for altering mental models to represent a more accurate picture of reality. As I have been proposing in the previous chapters, the ultimate aim of system dynamics is to foster understanding that results in emergent learning that leads to new levels of wisdom.

CHAPTER 4

Sithokozile

4. CASE STUDY DESCRIPTION

4.1 Introduction

In this chapter I will describe in detail how Bosch Projects approaches project management. I will also describe the major project to be modeled. This is important for fully and meaningfully engaging the project that will be modelled in this dissertation.

4.2 The Key Roles in the Approach

According to the FIDIC approach and as indicated in the second chapter there are three possible key roles in an engineering project environment. These are:

- **Employer:** This is the client person or institution that finances the project and will be the end-user of the project outcome. "Company A Sugar Limited" is the employer is this dissertation.

- **The Engineer:** This is the person or institution that is a specialist in engineering and project management consulting. He is employed by the client to act on his behalf and to look after his best interest for the duration of the project. The Engineer compiles the design specification, draws up the tender and contract documentation and adjudicates offers received. He recommends the suitable service providers to the client and manages the day-to-day rolling out of the project. Bosch Projects is the Engineer is this dissertation.

- **The Contractor:** This is the person or institution that bids and is awarded a contract to supply a particular service or goods. He is responsible for building and delivering the finished goods to the client's premises. In some arrangement the contractor is also responsible for installing the equipment, but in this project there was only one mechanical installation contactor. The appointment of the contractor is based on cost competitiveness, the technical competency to execute the required work within the contractual delivery times. It has become the norm that the contractor is an engineering design house that outsources the manufacturing to a fabrication specialist. The fabricator has no direct engagement with the client. Some fabrication houses have the design capability in-house but this arrangement is now an exception rather than rule.

The contractor contracts directly with the client but is managed by the engineer. On being awarded the contract, the contractor supplies a Quality Control Plan (QCP) and a manufacturing programme. The Quality Control Plans are used as a method to manage quality by providing the ability to discover non-conformances early before shipping the equipment. On receipt of the QCP the engineer and the client will identify points of interest in the manufacturing, where they can request a "hold", "witness" or "verify". On a "hold" it means the contractor is not allowed to pass that stage of manufacturing until the client or the engineer has come to site to inspect the work and signed it off to allow progress to the next stage. The manufacturing programme is a Gantt chart outlining the major fabrication activities and their duration.

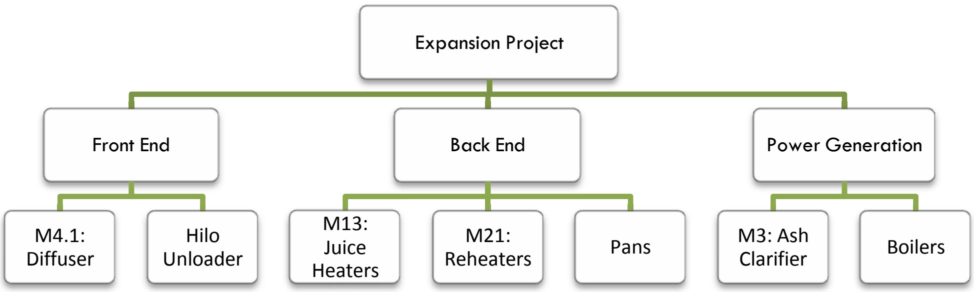
4.3 The Project Approach

For this project the client adopted a two phase approach. In the first phase the client had already decided that they wanted to increase the capacity of the mill but they did not know what needed to happen for them to achieve the expansion. They did not know where the bottlenecks would occur, what alterations had to be implemented in the mill and the cost thereof. In order to address this unknown they commissioned Bosch to do a Front End Package (FEP), which is a bankable feasibility study. In the FEP the following items were identified:

- Bottlenecks;
- Required equipment and their specifications;
- Equipment costs;
- Project duration;
- Installation costs

As is the norm in the sugar industry, a mill is divided into three major areas:

- **Front End:** This section receives the cane from the field, prepares it by shredding and separates the juice from the bagasse through the diffusion and milling processes.


Expansion Project
Front End
Back End
Power Generation
M4.1: Diffuser
Hilo Unloader
M13: Juice Heaters
M21: Reheaters
Pans
M3: Ash Clarifier
Boilers

He is ultimately responsible for the financial, engineering, quality and client management for the duration of the project.

4.5 The Budgeting Process

The engineer's costs is a sum of man-hours, sold at an hourly rate per resource allocated to the project excluding secretaries and other indirect support services such as human resources and accounts services, plus disbursements (travel, accommodation, printing etc) which are sold at cost. Bosch uses an in-house developed spreadsheet programme called the Project Man-hour Resource (PMR) schedule to estimate the time required to execute a project. In the schedule the time to engineer and manage the project plus the disbursements required are captured and added.

Figure 18 shows an extract of PMR for a previous project. The "Budget" row reflects what is sold to the client and is never altered for the duration of the project. The "Forecast" rows are only completed once the project has commenced and reflect a forecast based of the information known to the team and their assessment thereof.

	A	B	C	D	E	F	G	
1	**Bosch Projects PMR/ Quote Calc**					**MANHOUR INPUT F**		
2	**Report Month**			**Project Number**				
3	**01-Jul-11**			**1424/022**				**DE**
4							**May-11**	**Ju**
5			MONTHLY ACTUAL TOTAL DISBURSEMENTS			COST		
6						INVOICE		
7			MONTHLY ACTUAL TOTAL TRAVEL			COST		
8						INVOICE		
10	Description	Name	Group	Cost Rate	Sell Rate		**May-11**	**Ju**
11	Project Sponsor	Dave Chappelow	1	850.00	1 020.00	Budgeted		
12				850.00	1 020.00	ForeCast		
13				850.00	1 020.00	Actual		
14	Project Manager	Mhlengi Madiba	4	525.00	640.00	Budgeted	5.0	
15				525.00	640.00	ForeCast		
16				525.00	640.00	Actual		
17	Lead Engineer	Thami Mbatha	4	525.00	640.00	Budgeted	40.0	
18				525.00	640.00	ForeCast		
19				525.00	640.00	Actual		
20	Electrical Technician	Xolani Sontsele	5	410.00	490.00	Budgeted	20.0	
21				410.00	490.00	ForeCast		
22				410.00	490.00	Actual		
23	Co-ordinating Engineer	John Brandon	3	660.00	790.00	Budgeted	5.0	
24				660.00	790.00	ForeCast		
25				660.00	790.00	Actual		
26	Civil / Structural Engineer		4	525.00	640.00	Budgeted		
27				525.00	640.00	ForeCast		
28				525.00	640.00	Actual		
29	Electrical Draftsman	Tracy Broome	6	300.00	360.00	Budgeted	50.0	
30				300.00	360.00	ForeCast		
31				300.00	360.00	Actual		
53	Electrical Darftsperson	Linda Marais	5	410.00	490.00	Budgeted		
54				410.00	490.00	ForeCast		
55				410.00	490.00	Actual		
31		**NB 25 ADDITIONAL PEOPLE CAN BE ACCOMODATED IN HIDDEN ROWS**						
32								
33								
34						Budgeted	120	
35	MANHOURS					Forecast	-	
36						Actual	-	
37						Budgeted	50 125	
40	COSTS					Forecast	-	
43						Actual	-	
44						Budgeted	60 550	
47	INVOICE					Forecast	-	
50						Actual	-	
51						Budgeted	1.00	
52	Escalation					Forecast	1.00	
53						Actual	1.00	
54								

Figure 18: PMR Extract

The Actual column is completed on a monthly basis based on the time booked by the project team members. Logically in order for the project to meet or exceed profit targets the actual hours must not exceed the budgeted hours. On EPC contracts where there is no Engineer (just the client and the contractor) there is an additional cost line which Bosch calls the "Trading Account". The "Trading Account" refers to physical items bought or built and sold to the client at a marked up price. In this relationship the financial reports will report cost under three headings (Man-hours, Disbursements and Trading).

Regardless of the contracting relationship, the contract value is always fixed and only changeable through justified and accepted variation orders. In the project to be modeled there were two execution centers impacting on costs. These were:

- **Site:** These were Bosch employees based full-time in Swaziland. They were responsible for overseeing the installation and commissioning of the equipment as they arrived on site;

- **Off-site / Head Office:** This team was responsible for the engineering, fabrication quality control and site team support. These people were based in Durban. Regularly some team members would visit site to address project issues as necessary. All progress meetings with the client were held on site.

4.6 The Swaziland Project

Company A Sugar Limited and their major shareholder, British Sugar, had identified that there was an opportunity for increasing sales from Swaziland into the SACU, EU and regional markets. These markets were attractive because of the premium price that they paid for sugar produced in designated developing nations.

An irrigation project funded by the Swazi government and seven other international funding organizations had made it attractive for Ubombo mill to increase its production capacity. The irrigation encouraged the development of local farming communities to participate more on commercial farming. The two phased cane farming initiative will cover 11500 hectares on completion. The increase in cane availability necessitated an increase in the mill's average crushing capacity of 410TCH to 500TCH.

As indicated earlier in this chapter, Bosch Projects had conducted a feasibility study for the client. This was done by doing an Energy and Mass Balance (EMB) of the factory in order to troubleshoot and identify bottlenecks of the mill as it exists. The

EMB is a Bosch designed sugar mill simulation programme. The as-existing simulation was then followed by another simulation now focusing on the desired throughput of the project. The results obtained for these simulations were then used to compile the equipment specifications for the project.

The project required funding summarized as follows:

Description	ZAR
Direct Costs	
Civil	174 380 919
Structural	41 905 827
Mechanical and Piping	730 507 822
Electrical	136 761 848
Control and Instrumentation	55 377 322
	1 138 933 738
Indirect Costs	
Owners Costs	116 544 602
EPCM Fees and Disbursements	113 991 203
Other	21 963 002
	252 498 807
Escalation	120 959 384
Total Project Cost (Escalated and Rounded Off)	**1 512 400 000**

Table 2: Swazi Project Costs Summary

From the EMB and project planning, the following number of packages per discipline was envisaged for the project:

Discipline	Envisaged Number of Packages
Civil and Structural	2
Mechanical	30
Electrical	17
Control and Instrumentation	7
	56 packages in Total

Table 3: Expected WBS Packages as per FEP

The project was planned to commence on 27 May 2009 and be completed on 15 April 2011.

4.7 Sources of Uncertainty in Projects

Ford & Sterman (1999) and Cooper & Lee (2009) have shown that projects with concurrent linked activities attract rework cycles. From the perspective of this dissertation I will primarily focus on the reworks that impact on the engineer organization. A large number of variables were unknown at the commencement of the project and therefore some informed assumptions had to be made. As the design process progressed, the clearer the picture became for the team. This required that some designs already completed, and possibly in production, be revised. These are all sources of variation orders.

The fact that this was a brown-field project (expansion of an existing facility) further complicated the project. The project had to avoid any disruption of the operations of the existing factory. This meant that installation of some equipment had to be planned around the operations of the factory. To install some of the new equipment required that existing equipment be decommissioned and removed and then reinstalled. Factors such as these, impact on the project and on the client's daily production output.

As highlighted earlier, Bosch Projects had used the EMB to troubleshoot the new dynamics that would be created by the capacity and also at a high level specify the requirements of the factory. On approval of finance, they still had to do more detailed engineering in order to arrive at a much clearer picture of the equipment sizes and the most efficient and cost effective design for the mill. The timeframes to complete the project and the tasks that had to be completed resulted in the need for concurrent engineering. The rework cycle discussed earlier is an inherent feature and risk in this type of engineering work, because as the things become clearer some completed designs must be revised, sometimes even if at the construction stage.

Additionally due to resource availability constraints, not all tasks could commence at the same time. This resulted in a staggered execution approach, where long lead items get high priority and the other tasks follow afterwards.

South Africa is a country generally known to have a technical skills shortage. This means that even a competent fabrication organization may struggle to execute some work purely because it has never done it before and there are not enough people to properly plan for it. This would be aggravated by a situation where the existing competent resources are allocated to other projects and not available to the new project. This may lead contractors to underestimate the time required to execute the works and they may later allocate more resources to try and catch up. The engineer team may also shift focus from other tasks in order to rescue an underperforming contractor. Such rescue efforts are not reimbursed by the client if they are not of his own doing.

4.8 The Can Do Loop

Besides the requirement to meet contractual obligations, Bosch Projects goes an extra mile to meet and deliver on client desires. The can-do attitude helps in creating long term relationships thereby increasing the chances of becoming one of the preferred service providers. On the other side it reduces the engineer organization's profit margins thereby increasing chances of project losses beyond acceptable limits. If the losses exceed the acceptable range it can also strain the long term relationship if the client refuses to reimburse the service provider.

These desires generally tend to be more than what the client is contractually paying for. From a contractual perspective, the engineer can act rationally and require pre-approval prior to actioning of the additional requirements. However this rational thought is not conducive for long term relationship building as the clients themselves do not always act rationally and can punish you in future projects if you are seen as insensitive and too contractual in addressing their needs.

This punishment may be in the form of not being invited to bid for future work. In order to be perceived as accommodating and cooperative, Bosch Projects sometimes makes what are perceived to be calculated decisions to do work at risk with the hope of claiming at a later stage. The company is sometimes willing to moderately sacrifice short term profit targets to build long term relationships which increase the chance of future work and profitability.

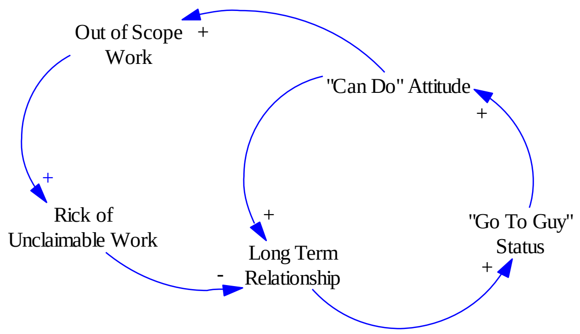


Figure 19: The Can-Do Loop

From my perspective I call this attitude the can-do loop. When operating in this loop, the engineer must try to find a balance between incurring costs and nurturing the relationship with the client. This, however, is difficult to foresee in a fast paced and dynamic project environment. This results in the costs being collated at the end and requesting the client to reimburse you based on good faith because at this stage he is no longer contractually bound to honor the payment.

From this description it is apparent that the client would only entertain a post project claim if he has been impressed by the outcome of the project and is aware of the extra mile the engineer has gone to in order to meet the project needs.

4.9 The Dibs Loop

Dibs is a colloquial English term meaning to have rights or first preference over something.

On the Swazi project as explained in the previous chapter, the head office engineers were responsible for the engineering and manufacturing quality control of equipment. Their responsibility theoretically ended when the equipment was shipped and handed over to the site team. The head office resources time was one hundred percent allocated to the project during the design stages. As some equipment went into the fabrication stage the time commitment reduced to quality control activities.

Theoretically at this stage the resources should have been available to other projects not related to the Swazi project. Extension of time and other variation orders raised by the contractors and approved by the client meant that the resources were not freed when they were meant to be and hence continued to incur costs for the engineer organization (to manage the change brought about by the variation orders) .

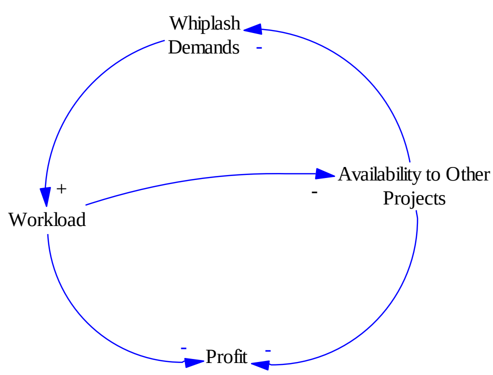


Figure 20: The Dibs Loop

If these variations occurred when the resource was already partly released to another project, it meant that the resource had to attempt to balance the new project workload with the old workload. Experience has shown that older projects get preference over new ones due to the desire to complete and close them off as quickly as possible in order to stop incurring any further costs. This means that the Swazi project had dibs over a large number of engineering resources thereby compromising the ability to reallocate resources as their workload reduced.

The "Dibs Loop" is a balancing loop where the demands increase the workload within an acceptable range. As the workload reaches or passes a certain point, the engineer becomes reluctant to release resources to the old project which effectively reduces further whiplash demands.

Taking on additional work without compensation reduces the profit.

4.10 The Design Stage

As indicated earlier in this chapter, there were a specific number of packages envisaged for the project.

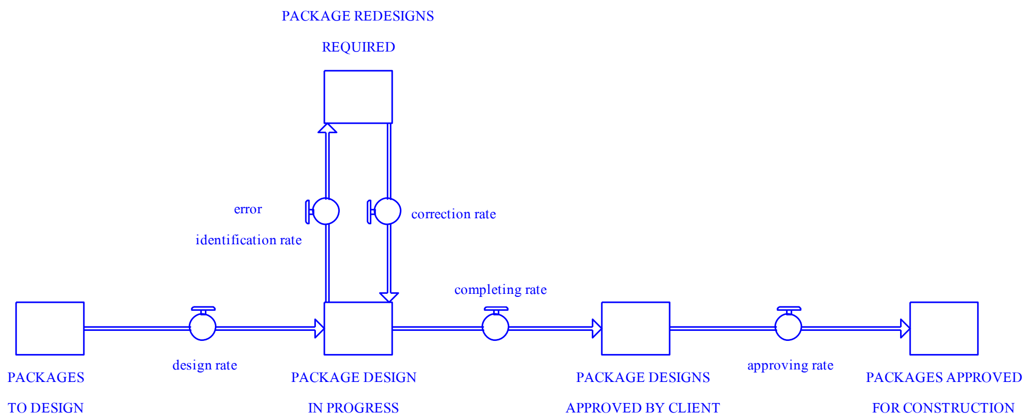


Figure 21: Design Stock Flow

Each package had engineering and design stage (executed at head office) which was followed by the fabrication stage (at the contractor's workshop) and lastly the installation stage (executed on site in Swaziland).

The packages went through four stages:

- **Design Progress:** This was the concurrent design of packages taking place at head office;

- **Redesign:** As highlighted earlier, concurrent engineering requires reworks, so some packages that would have been completed or in design progress had to be reworked to meet the engineering needs as they became clearer with each package completed;

- **Client Approval:** Each package completed had to be vetted by the client to ensure full buy-in of the end-user. The client had two teams reviewing designs. The first team was the Technical Services department based in Durban who vetted the designs and passed them on to the mill engineers for their comments. The comments were then collated and submitted to the engineer's design team for capturing and incorporating into the design;

- **Approved for Construction:** On incorporating the client comments, the design or drawings were ready for the market and were issued to the contractors stamped Approved for Construction (AFC).

4.11 The Fabrication Stage

Following on the same logic as the design stage, there were a specific number of packages to fabricate. On receiving the AFC drawings the contractors would commence fabrication work. Completed items would move to the completed line and from this line they would then be shipped to site.

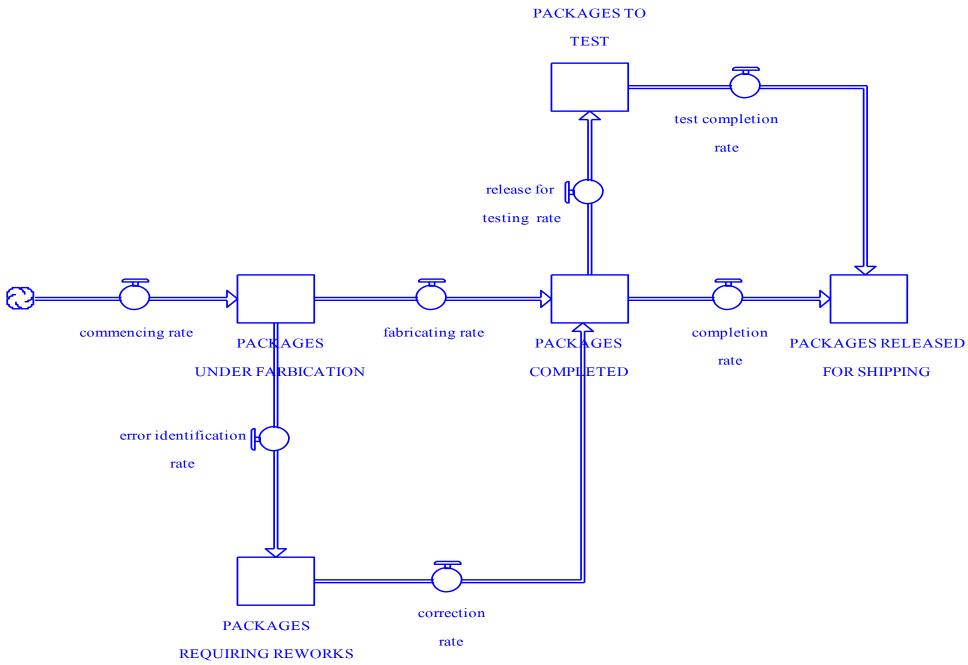


Figure 22: Fabrication Stock Flow

As a quality control measure, using the QCP, some packages under fabrication require rework and therefore have to move back into the packages in progress line. In the QCPs some items on completion had to be trial fitted in the workshop to ensure that all the parts fit together while others have to be pressure or leak tested.

Pressure testing takes about a full working day if everything goes according to plan but if there are a number of minor leaks in the vessel then corrective modifications; such as welding, tightening of bolts and changing of gaskets; have to be done which adds time demands on engineer's resources who at this stage should be available to other projects.

4.12 The Installation Stage

While all attempts are made to deliver to site equipment that is fit for purpose and ready to install, one discovers that equipment on arrival sometimes require modifications in order to fit into spaces.

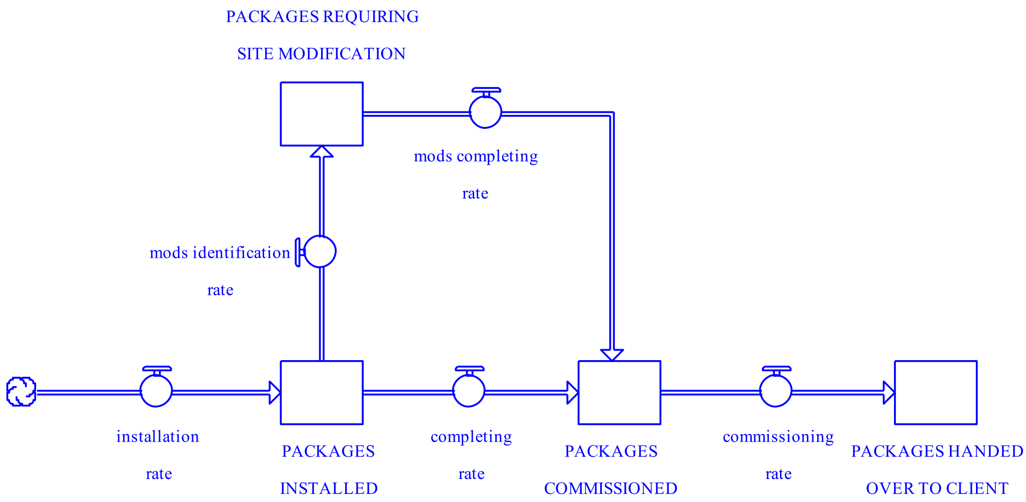


Figure 23: Site Installation Stock Flow

These modifications may also be brought on by demands of concurrent engineering as sometimes a mating piece of equipment may have been at an advanced stage of manufacturing so that the change discovered was not incorporated and left to be done on site.

On receipt of equipment and with modifications to some equipment the packages are installed, commissioned and then handed over to the client.

4.13 Chapter Summary

In this chapter I have given a description of how Bosch Projects manages projects in order to assist in engaging the project to be modeled. I also describe how the company audits its sources of costs and how it sells its services to clients. To further enhance this engagement I have given a description of the Swazi project and outlined WBS in order to understand the packages to be modeled. I have provided the overall costs summary of the project.

I further outlined the major sources of uncertainty and complexity in the way the Swazi project was executed.

I also discussed two causal loops which I believe have not been previously explored in the arena of modelling projects with system dynamics. I have also described simplified stock and flow diagrams for each project stage. I also proposed that the two causal loops are present in all the three project stages and have major cost impacts on both the engineer and the contractor organizations.

The stocks and flows presented in this section showed a high level of detail of intermediate activities. This was done in order to support the descriptive narrative about how the project is executed within my organization. On the complete model to be presented and simulated in the next chapter a large number of the intermediate activities are excluded as the overall aim of the research is to show the overall impact of change orders on a project and to use that to change mental models.
Therefore the large number of intermediate activities was not necessary for these simulations.

CHAPTER 5

Gwezula no MaMkhize

5. MODELLING AND RESULTS

5.1 Introduction

This chapter is divided into two sections. In the first section I focus on presenting the logic I used to build the model. In the second section I present the complete model and the resultant simulations.

I will start off by presenting the reference mode for the packages. This will be followed by presenting the logic behind the method followed in building the simulation model. From an inward looking perspective, the project manager is concerned with managing two areas for his organization. That is completing the project as quickly as possible but incurring as little costs as possible. The costs component may be broken down into three areas of interest:

- Change request exploration costs;
- Fabrication supervision. This assumes that the change order was approved by the client;
- Installation supervision costs. This also assumes that the change order was approved. The engineer organization must have an employee based full time on site to oversee the installation process and the subsequent handover to the client

The modelling logic is presented as fragments.

5.2 Expected Behavior of Packages

The following diagram presents the expected behavior of the work packages. It is a hand drawn sketch showing that I expected the work to complete to stay constant for a certain time period before it starts to reduce. This delay in workload reduction stems from the fact that on commencement of the project, there will be a delay attributable to the initial design work and compilation of tender and contract documentation.

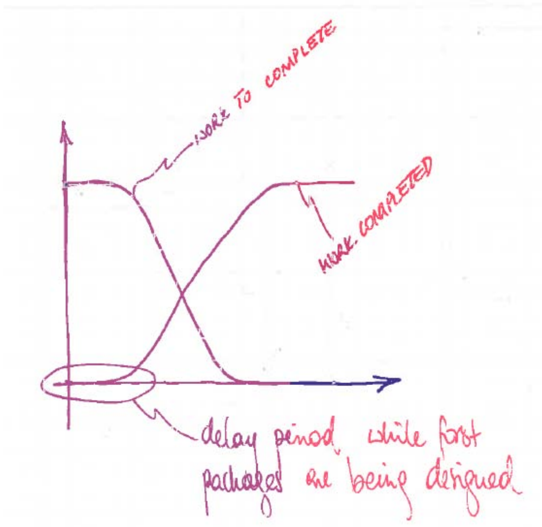


Figure 24: Expected Behavior of Packages – Reference Mode

Expanding from the logic just discussed, the work completed will initially stay at zero while the initial work to complete is in design, tender, award and fabrication stages. Only once the work starts being delivered on site and gets installed will there be real work completed.

This sketch does not show the behavior of the work in progress.

Initial models and simulations were very linear and did not factor in these delays. In retrospect, my modelling approach had been linear and it brought forward a point that I had ignored that using system dynamics does not automatically make all models developed non-linear.

5.3 The Project Implementation Story

There are three major systems in this research project. The client organization system, which finances the project and is also responsible for deciding whether new work is approved or rejected. The client issues the instruction to the engineer system to explore the impact of new work requested. The engineer then engages the contractor system to assess the costs of implementing the client request.

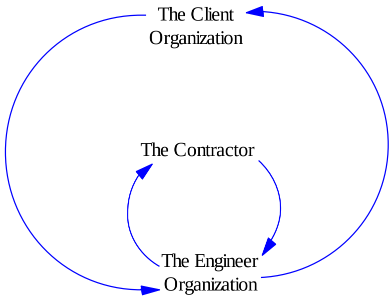


Figure 25: Influence Diagram for Project Implementation

The engineer then collates the information received from the contractor with the one they have collated internally. The engineer than presents the information to the client so that he can make an informed decision.

The following causal relationship diagram shows that when a variation order is requested it increases the workload for the engineer.

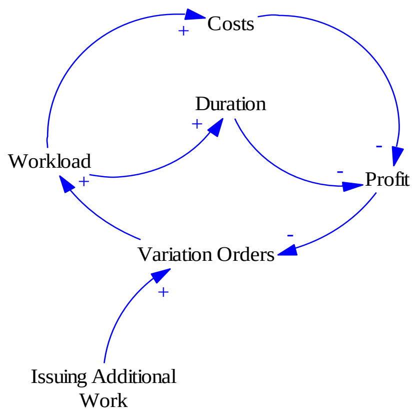


Figure 26: Cause and Effect Diagram for Variation Orders

This increase in workload increases the costs which negatively impact on the profit for the engineer. The workload also increases the duration of the project which again negatively impacts on the profitability of the engineer.

As highlighted in the previous chapter, at the beginning of the project there is a specific number of work packages that must be completed. In this case there are (18) packages which have to be completed within a (33) month period. These work packages are contained in the *WORK TO COMPLETE* stock. This number of packages can only be increased by issuing of change orders by the client through the flow called *vo gen rate.*

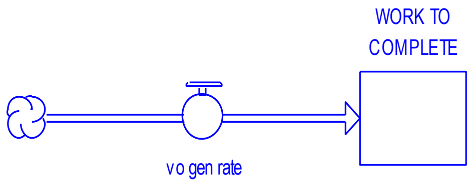


Figure 27: Fragment 1 Flow of Work Packages

WORK_TO_COMPLETE(t) = WORK_TO_COMPLETE(t - dt) + (vo_gen_rate) * dt

Packages = packages + (packages/months)*months

INIT WORK_TO_COMPLETE = 18packages

INFLOWS:
vo_gen_rate = see next fragment for discussion of the components for this rate

The *vo gen rate* flow is made up of two convertors i.e. *variation orders* in units of packages divided by the *time to issue a variation order* in units of months.

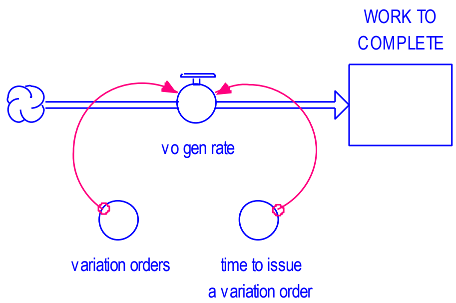


Figure 28: Fragment 2 Flow of Work Packages

INFLOWS:
vo_gen_rate = (variation_orders)*package_unit_conversion_factor/time_to_issue_a_variation_order

packages/months = unitless*packages/months

In the next fragment I add two convertors which serve the following purposes:

- *variation orders approved*: this is the convertor that allows for inputting the number of variation orders generated

- *package unit conversion factor:* this convertor is used to convert the variation orders approved to a unitless number.

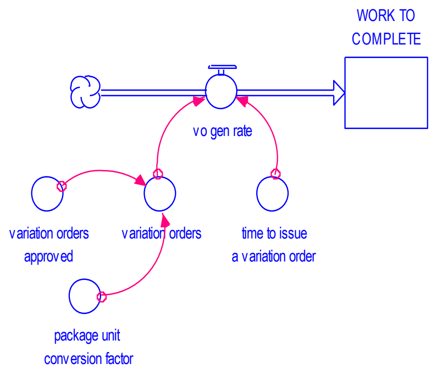


Figure 29: Fragment 3 Flow of Work Packages

variation_orders = PULSE(variation_orders__approved,15,0)/package_unit_conversion_factor

unitless = packages/packages

variation_orders__approved = 0unitless

The *variation orders* convertor carries a PULSE function to represent the issuing of the number of variation orders (*variation orders approved*) which are issued at time (15)months with zero recurrence. The pulse function is not entirely representative of reality as it assumes no reoccurrence. The truth is that change orders come up randomly during the lifecycle of a project.

In the next fragment I introduce a flow called *procurement* that depletes the *WORK TO COMPLETE* stock. The rate of this flow is the relationship between the convertor called *time to complete* and *WORK TO COMPLETE*. This equation for this flow is *WORK TO COMPLETE* divided by *time to complete* to get the flow of packages per unit time.

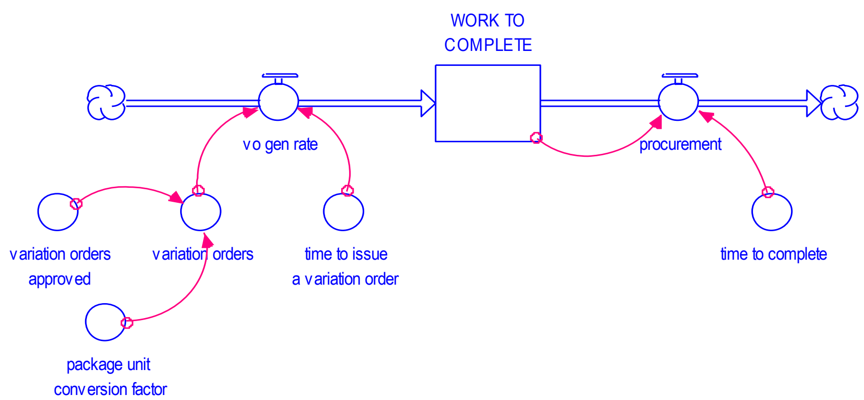


Figure 30: Fragment 4 Flow of Work Packages

OUTFLOWS:
procurement = (WORK_TO_COMPLETE/time_to_complete)*sequencing_index

packages/months = (packages/months)*unitless

In the next fragment I proceed and introduce a convertor called *sequence index*. The *sequence index* ranges from 0 to 1. Under normal circumstances it is 1, but when change orders and other disruptions are introduced, it changes to a number between 0 and 0,999 thereby reducing the rate by which the *WORK TO COMPLETE* stock is depleted. I made the *sequence index* into a graphical function. The *sequencing index* is used to multiply the *procurement* flow.

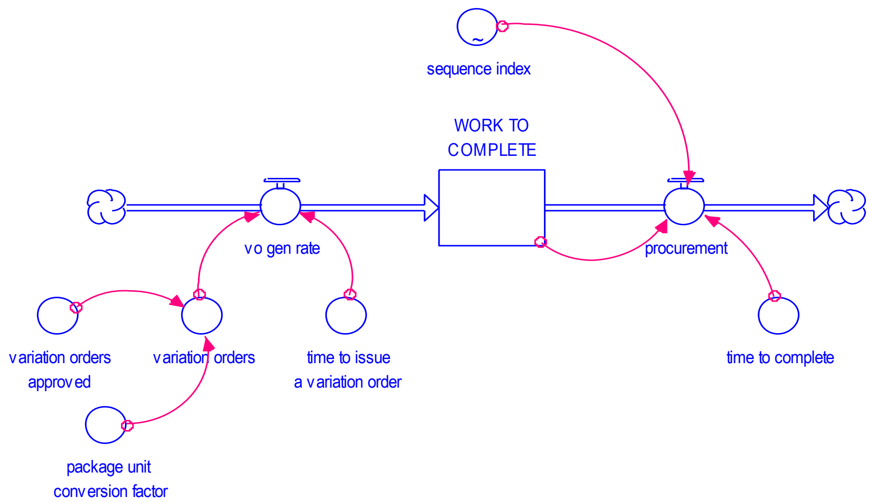


Figure 31: Fragment 5 Flow of Work Packages

OUTFLOWS:
procurement = (WORK_TO_COMPLETE/time_to_complete)*sequencing_index

packages/months = (packages/months)*unitless

sequencing_index = GRAPH(variation_orders__approved)
(0.00, 1.00), (5.00, 0.98), (10.0, 0.945), (15.0, 0.91), (20.0, 0.85), (25.0, 0.765), (30.0, 0.665), (35.0, 0.535), (40.0, 0.405), (45.0, 0.24), (50.0, 0.00)

The graphical function of the sequencing index is represented by a decreasing exponential graph. When there are no variation orders, the sequencing index is 1 and reduced to zero when there are 50 variation orders. This inadvertently meant that I had placed a boundary on the system model which says that when the project approaches 50 variation orders there is almost a zero ability to execute the work as originally planned. This may not always be true but it is important to note that once there are too many variation orders, the project team must pull back and be given an opportunity to reassess the overall impact of the additional work on the original. This reassessment process will always carry a time and/ or cost impact.

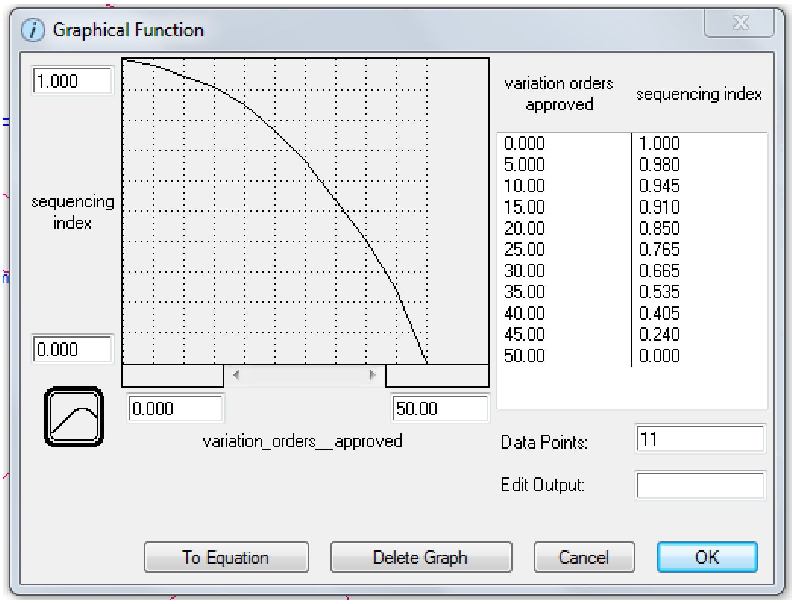


Figure 32: Graphical Function for the Sequence Index

It may also result in a whole new project with terms and conditions different to the original plan. As highlighted in the second chapter, the reworks which sometimes stem from change orders will affect output, morale, productivity and errors within the project system.

In the next fragment I introduce a new stock called *WORK IN PROGRESS*. The stock starts off at 0 packages. As can be noted from the diagram the box representing this stock is different to the *WORK TO COMPLETE* box. In iThink this stock is called a conveyor. It is used to represent a delay in the system. When *WORK TO COMPLETE* is released in increments, it starts to accumulate in the *WORK IN PROGRESS* stock. However the work spends some time in the *WORK IN PROGRESS* stock before starting to flow out into the next stock.

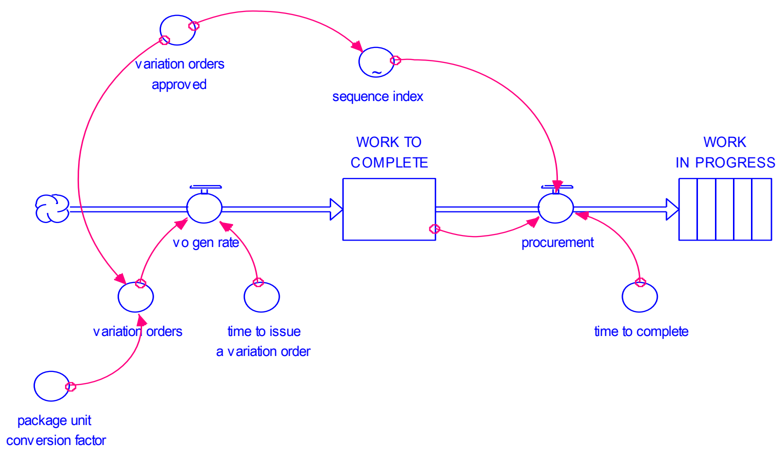


Figure 33: Fragment 6 Flow of Work Packages

variation_orders__approved = 0packages

In the succeeding fragment I add a new flow called *fabricating installing commissioning* that depletes the stock *WORK IN PROGRESS*. This stock is the rate at which the work moves to the fabricator and released for installation and commissioning.

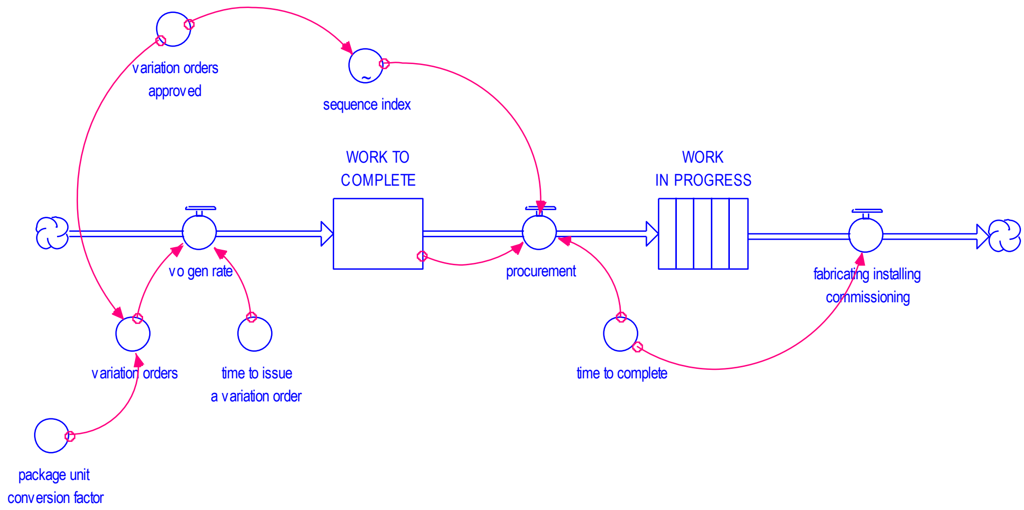


Figure 34: Fragment 7 Flow of Work Packages

WORK__IN_PROGRESS(t) = WORK__IN_PROGRESS(t - dt) + (procurement - fabricating_installing_commissioning) * dt

Packages = packages + (packages/months)*months

INIT WORK__IN_PROGRESS = 0packages
TRANSIT TIME = varies
INFLOW LIMIT = INF
CAPACITY = INF

INFLOWS:
This is the outflow of the WORK TO COMPLETE stock which has already been discussed

OUTFLOWS:
fabricating_installing_commissioning = CONVEYOR OUTFLOW
TRANSIT TIME = 3*time_to_complete

The convertor called *time to complete* is also shown to be related to the depleting rate.

I now proceed to introduce the last stock called *WORK COMPLETED* into which all packages installed and commissioned flow into. This stock starts at 0 packages.

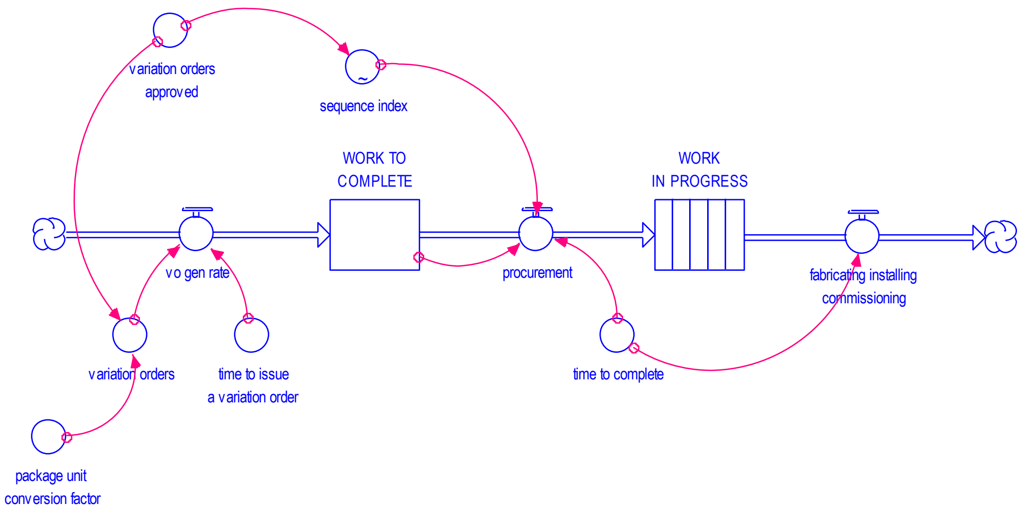


Figure 35: Fragment 8 Flow of Work Packages

WORK_COMPLETED(t) = WORK_COMPLETED(t - dt) + (fabricating_installing_commissioning) * dt

Packages = packages + (packages/months)*months

INIT WORK_COMPLETED = 0packages

INFLOWS:
fabricating_installing_commissioning = CONVEYOR OUTFLOW
TRANSIT TIME = 3*time_to_complete

As discussed earlier in this section, there are three important areas of cost accumulation:

- Exploration;
- Fabrication and;
- Installation

These costs were therefore treated as different fragments which all work on the same logic, the only difference being that fabrication and installation supervision costs are not incurred for change orders not approved while the exploration cost are always incurred. All three fragments were modelled using daily rates but their behaviors are presented as costs per month. The Installation supervision fragment is used to explain the costs fragments. This fragment captures the behavior of man-hour costs.

5.4 Costs Module and Story Development

In this section I now introduce the fragments that represent the major costs areas for the engineering organization. I start off with a stock called *INSTALLATION SUPERVISION* costs. Bear in mind we are only focusing on costs that are attributable to change orders. The only way to build up this stock is by selling man-hours either on an hourly or daily basis. The rate of selling hours is represented by the flow *accumulating installation rate* which is a fixed selling rate.

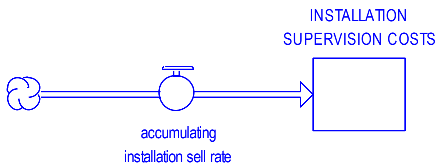


Figure 36: Basic Man-hour Costs Structure

INSTALLATION_SUPERVISION_COSTS(t) = INSTALLATION_SUPERVISION_COSTS(t - dt) + (accumulating_installation_sell_rate) * dt

ZAR = ZAR + (ZAR/months)*months

INIT INSTALLATION_SUPERVISION_COSTS = 0ZAR

INFLOWS:
accumulating_installation_sell_rate = the equation for this flow is discussed in the next fragment

In the next fragment I take this fragment a step further and show two convertors that combine to form the flow. The convertor *(rate 02)* is the daily rate for supervising the installation process. The *duration of installation* convertor is the number of days required to complete the supervision process. Multiplying these two convertors give the total cost of supervising the installation. At this point I must state that this fragment at present assumes a single variation order.

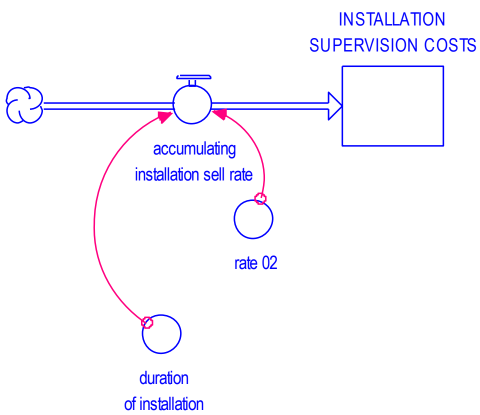


Figure 37: Man-hour Costs Structure with Convertors

INFLOWS:
accumulating_installation_sell_rate = duration_of_installation*rate_02

ZAR/months = days*ZAR/days/months

In the next fragment I then introduce a new convertor called *variation orders*, which is pulled from the work flow relationships already discussed earlier in this section. This convertor is used to multiply the *accumulating installation rate.* So for one packages the installation rate is X (units) and with additional packages it is X (units) multiplied by the number of variation orders. The number of additional packages is the same as the number of *variation orders*.

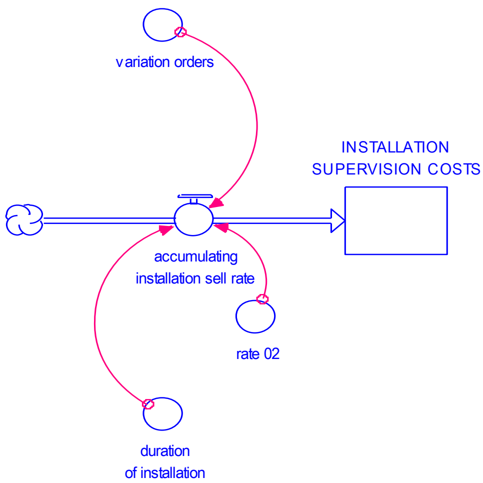


Figure 38: Man-hour Costs Structure with Convertors factoring in No of Variation Orders

INFLOWS:
accumulating_installation_sell_rate = duration_of_installation*rate_02*variation_orders

ZAR/months = days*ZAR/days/months*unitless

I now proceed to introduce an additional convertor called *rejection index* that acts on the *duration of installation.* This convertor's equation carries an IF function. The reason for this is that not all change orders requested will eventually be approved. Therefore the IF Function detects whether the change orders are approved or not and only includes the approved ones in working out the cost of the installation supervision.

The *rejection index* has a range between 0 and 1. At 1 it means all change orders requested are subsequently not approved (100% rejection rate) and 0 means all change orders requested are approved. If the project is modeled in retrospect it is easy to determine this and agree how many change orders requested were subsequently approved. If the project is modelled prior to execution then any factor can be inputted to test the effect on the overall project.

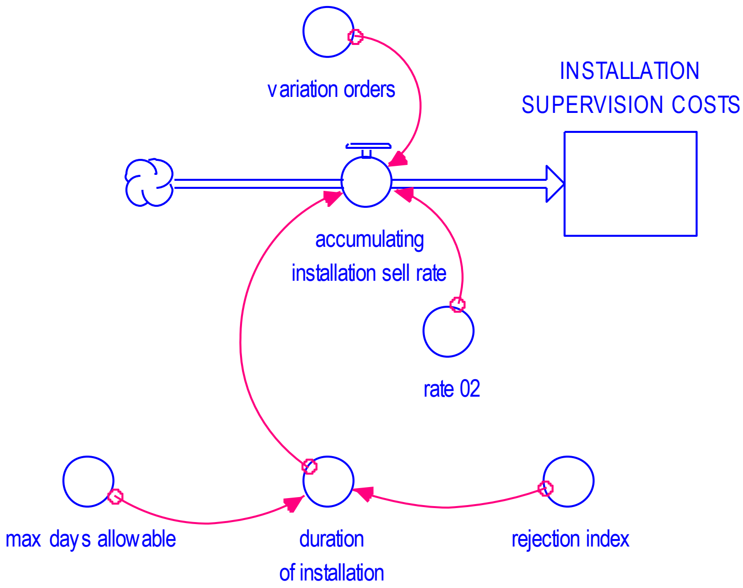


Figure 39: Man-hour Costs Structure with Convertors factoring in the Rejection Index

duration_of_installation = (IF(max_days_allowable*rejection_index<1) THEN 0 ELSE max_days_allowable*rejection_index)

days = (days*unitless) else (days*unitless)

max_days_allowable = 5days

rate_02 = 6800ZAR per days per month

rejection_index = 1unitless

The last addition to the EXPLORATION COSTS fragment is the convertor called time to issue a variation order. This convertor factors in the duration of compiling each variation order before it gets out to the market.

This same logic that I just explained for *INSTALLATION SUPERVISION COSTS* also applied to the other costs fragment called the *EXPLORATION COSTS.*

5.5 Ideal Conditions Simulation

The following graph represents the simulation for ideal conditions.

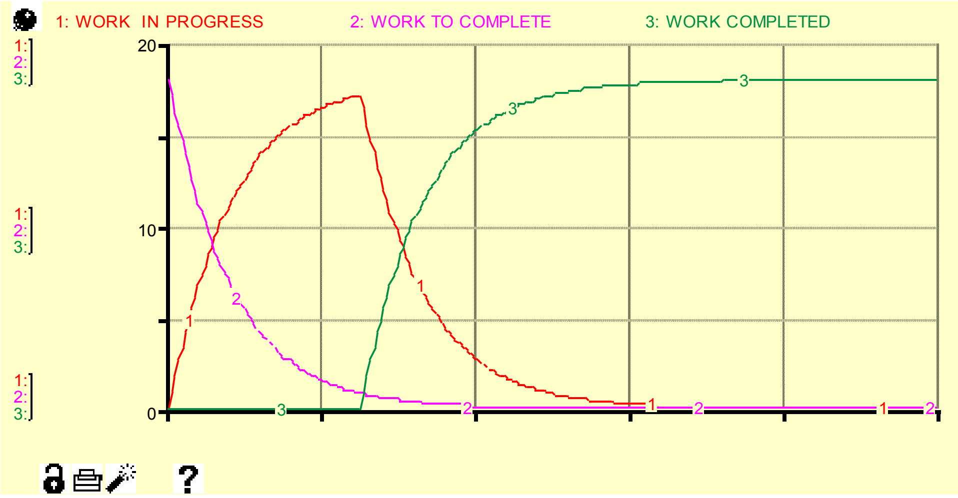


Figure 40: Behavior over Time of the Project under Ideal Conditions

The behavior of the three stocks is in line with my expectations shown in the reference mode discussed at the beginning of this chapter. There is a delay in the accumulation of the WORK COMPLETED stock. The WORK IN PROGRESS stock builds up for some time before starting to deplete. At commencement of the depletion process for the WORK IN PROGRESS, the WORK COMPLETED starts building in line with reference mode.

The following plot shows the cost behavior for the two costs fragments.

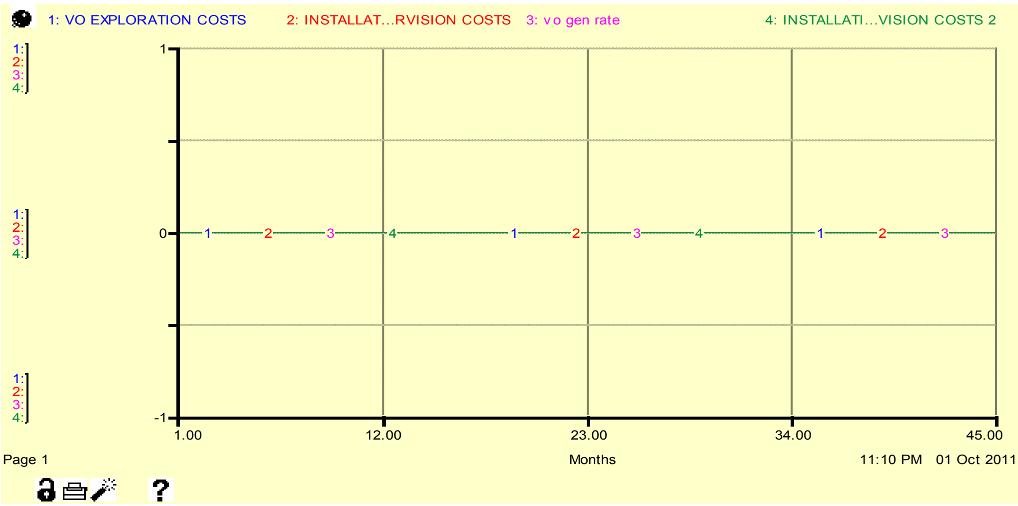


Figure 41: Costs Behavior for No Variation Orders

Logically, if no variation orders are issued there will be no additional costs incurred.

5.6 The Complete Model

The complete model is presented in the next diagram. An electronic copy of the model is presented as an attachment to the report for further scrutiny.

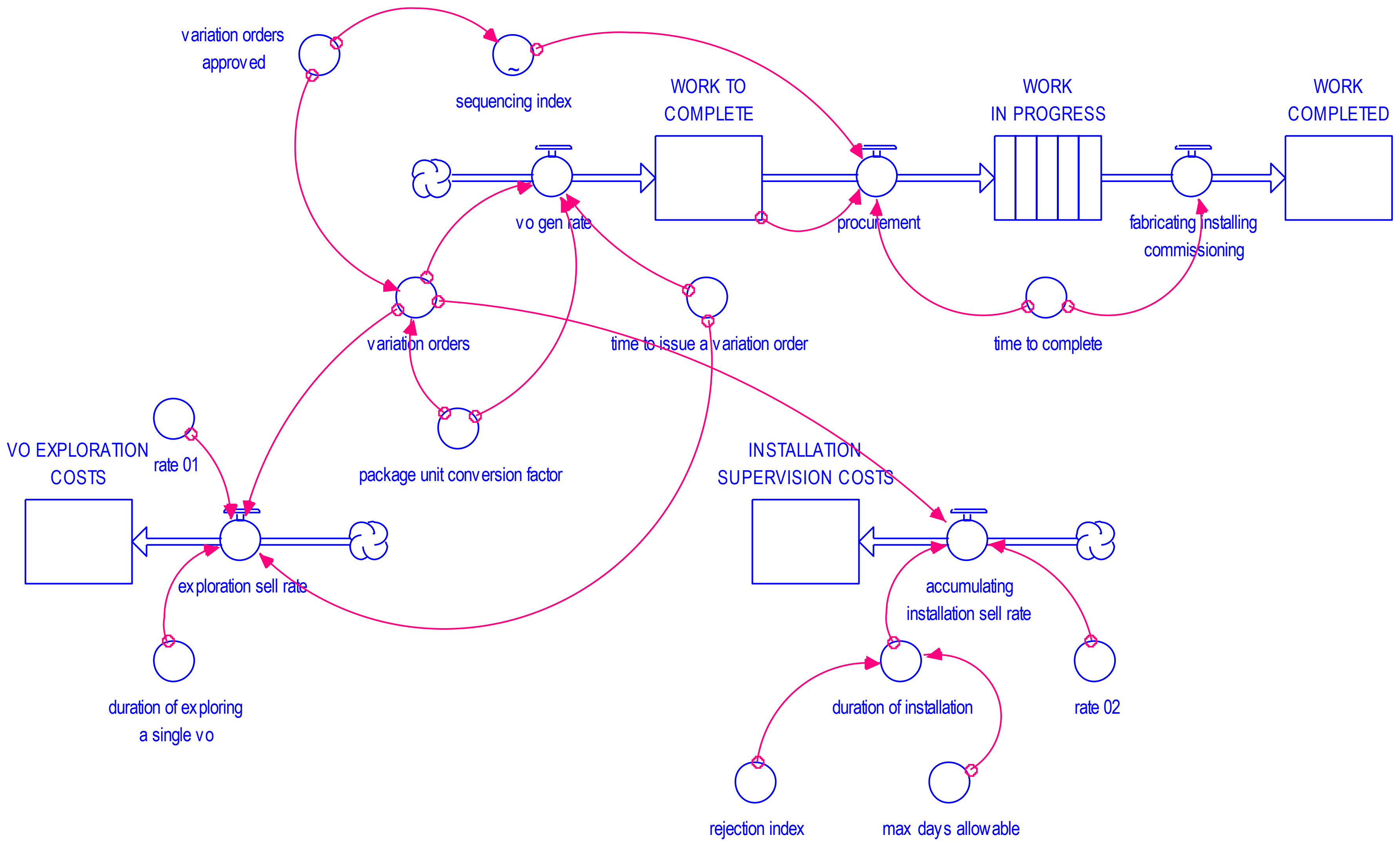


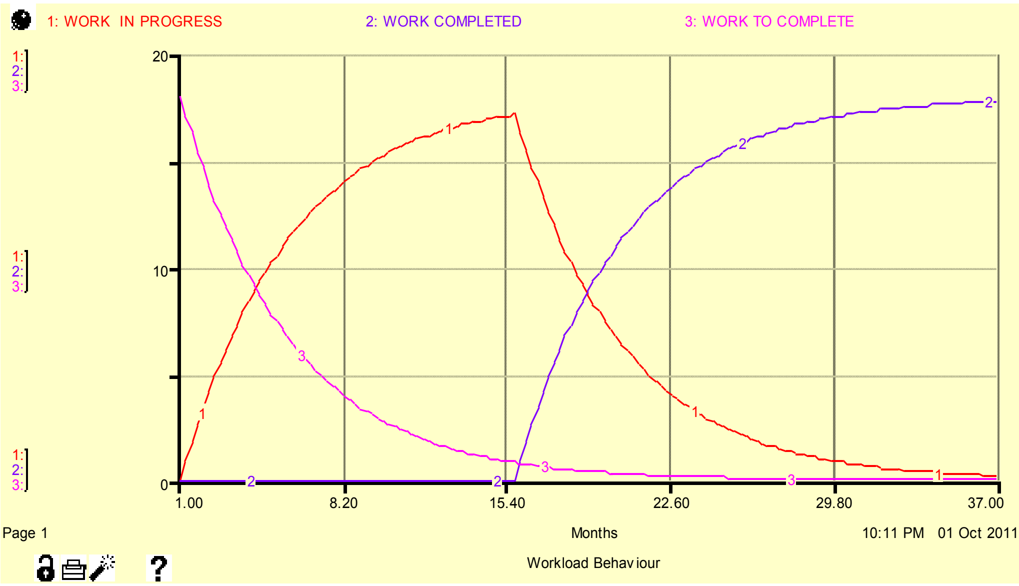
Figure 42: The Complete Model

5.7 Some Scenario Simulations

In the following section I explore the behavior of the model under various scenarios:

(0) Variation Orders

In this simulation we find that when no variation orders are issued, the project is completed at (33) months. As already discussed earlier the behavior is non-linear but easy to understand. As the (WORK TO COMPLETE) reduces the (WORK IN PROGRESS) builds up. Only when the (WORK IN PROGRESS) peaks does the (WORK COMPLETED) begin to increase.



09:44 PM 2011/11/21 Table 1 (Behaviour of Work Packages)

Months	WORK TO COMPLETE	WORK IN PROGRESS	WORK COMPLETED
28	0	1	17
29	0	1	17
30	0	1	17
31	0	1	17
32	0	0	18
33	0	0	18
34	0	0	18
35	0	0	18
36	0	0	18
37	0	0	18

Figure 43: Workload Behavior: (0) Variation Orders

As there is no variation order generated during this simulation, there are zero costs incurred by the company (the engineer organization).

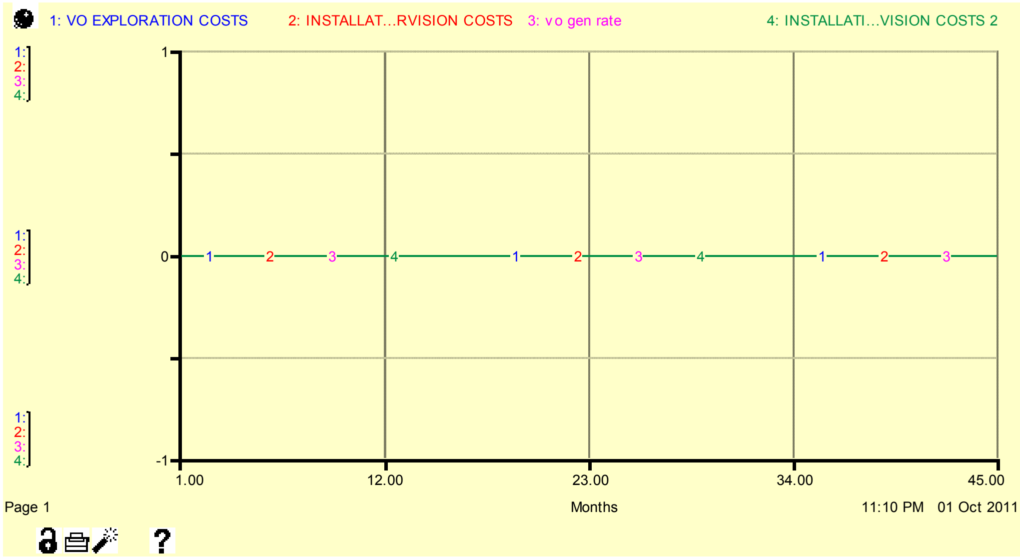
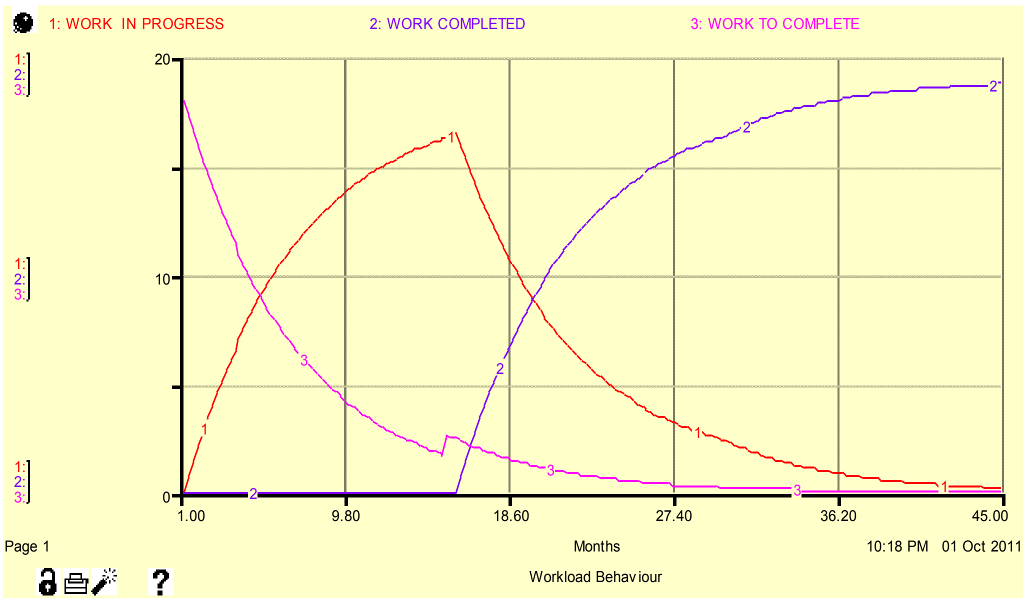


Figure 44: Man-hour Costs Behavior: (0) Variation Orders

These two results are in line with the ideal conditions simulation discussed earlier.

(1) Variation Orders

In this simulation I introduce (1) variation order at month (15).



09:54 PM 2011/11/21 Table 1 (Behaviour of Work Packages)

Months	WORK TO COMPLETE	WORK IN PROGRESS	WORK COMPLETED	variation orders approved
29	0	2	17	1
30	0	2	17	1
31	0	1	17	1
32	0	1	18	1
33	0	1	18	1
34	0	1	18	1
35	0	1	18	1
36	0	1	18	1
37	0	0	19	1

Figure 45: Workload Behavior: (1) Variation Orders

The following simulation plot shows the behavior of the various cost fragments which are zero until the month where the variation order is introduced and approved.

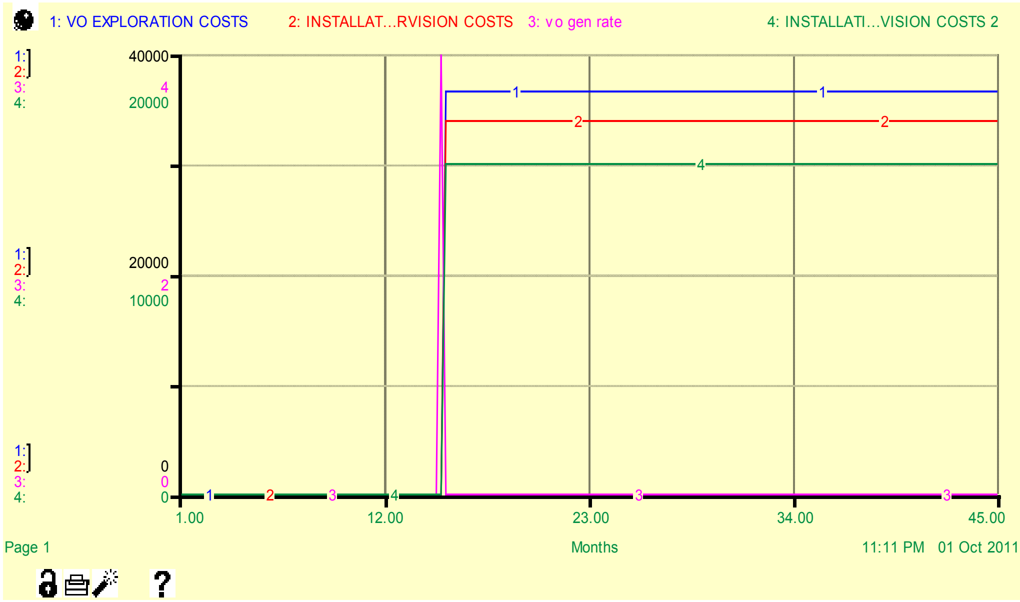


Figure 46: Man-hour Costs Behavior: (1) Variation Orders

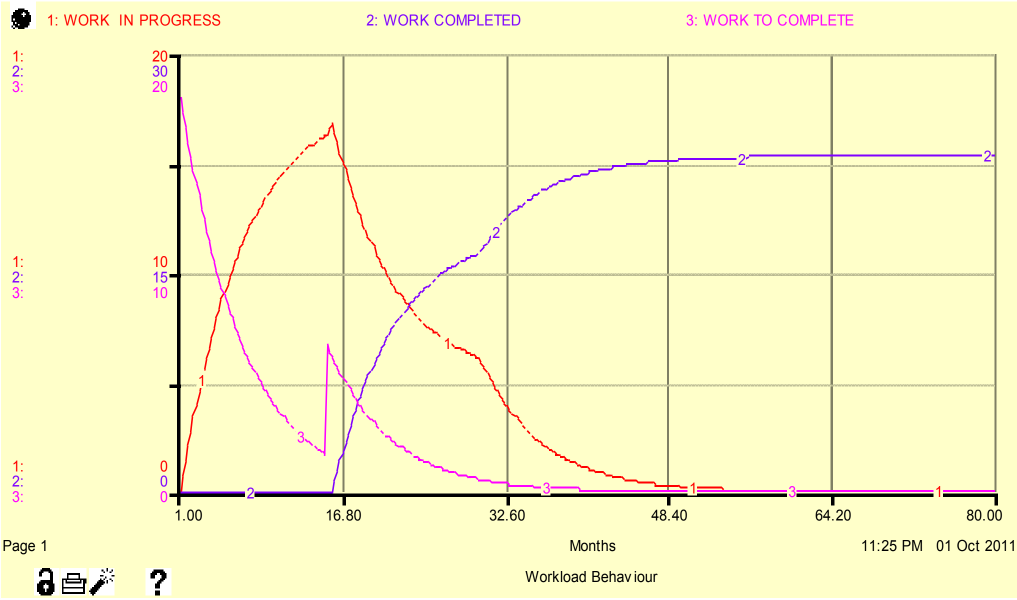
The cost simulation results are very linear as can be seen with simulation and the subsequent ones. These can be easily modeled on a spreadsheet as was later done in this research (see appendix). The reason for the linearity is the simplistic assumption that we make within the company based on experience that:

- Five visits are generally sufficient to monitor the fabrication process and;
- Five days are enough to install a typical sugar mill vessel when it is supplied fully built.

However in retrospect this was simplistic of me. Basically I had reverted back to linear thinking that promotes rules of thumb thinking that we use on a regular basis. Ideally for the non-linear costing of the impact of change orders, I should have a way of accumulating the additional time resulting from the change orders and use that to subsequently calculate the costs. This subsequent calculation may not necessarily happen within the system dynamics software.

(5) Variation Orders

In this simulation I introduce (5) variation orders at month (15). As is evident in this simulation and the next one, once this model has been properly calibrated, the behavior of the system is easy to understand and explain.



10:00 PM 2011/11/21 Table 1 (Behaviour of Work Packages)

Months	WORK TO COMPLETE	WORK IN PROGRESS	WORK COMPLETED	variation orders approved
34	0	2	20	5
35	0	2	21	5
36	0	2	21	5
37	0	1	22	5
38	0	1	22	5
39	0	1	22	5
40	0	1	22	5
41	0	1	22	5
42	0	0	22	5
43	0	0	23	5
44	0	0	23	5
45	0	0	23	5
46	0	0	23	5
47	0	0	23	5
48	0	0	23	5
49	0	0	23	5

Figure 47: Workload Behavior: (5) Variation Orders

The following costs simulation shows the behavior of the cost fragments. As already stated the results are very linear and easy to model on a spreadsheet.

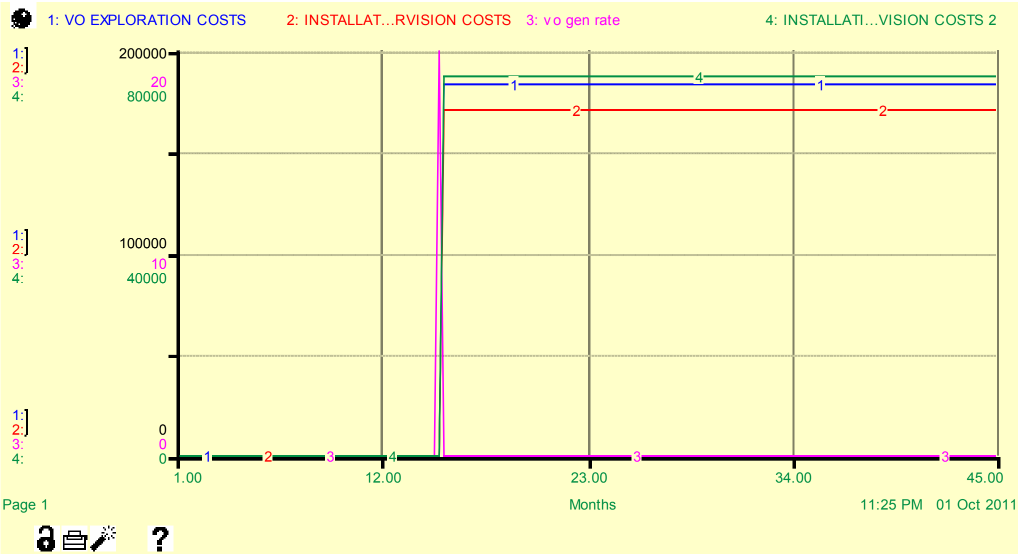
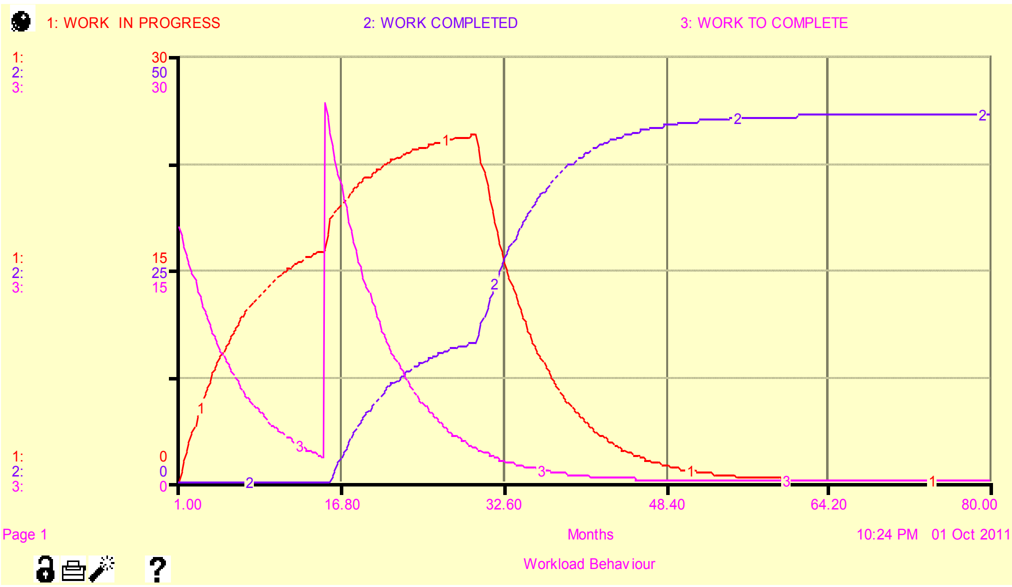


Figure 48: Man-hour Costs Behavior: (5) Variation Orders

(25) Variation Orders

In this simulation I introduce (25) variation orders at period (15).



10:01 PM 2011/11/21 Table 1 (Behaviour of Work Packages)

Months	WORK TO COMPLETE	WORK IN PROGRESS	WORK COMPLETED	variation orders approved
52	0	1	42	25
53	0	1	42	25
54	0	1	42	25
55	0	0	42	25
56	0	0	43	25
57	0	0	43	25
58	0	0	43	25
59	0	0	43	25
60	0	0	43	25
61	0	0	43	25
62	0	0	43	25
63	0	0	43	25

Figure 49: Workload Behavior: (25) Variation Orders

The following plot shows the results for the costs.

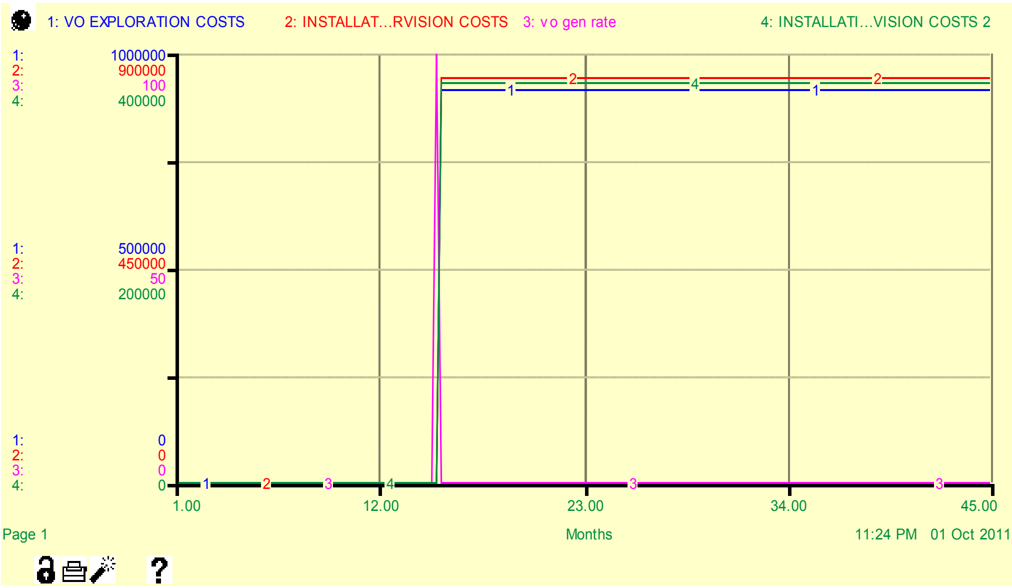


Figure 50: Man-hour Costs Behavior: (25) Variation Orders

5.8 Biases

An interesting but potentially dangerous thing happened during the development and simulation of the models. This brought home the point about the risk that biases present in model development. As stated earlier the initial models were very linear and too simplistic but were in essence representative of the system behavior. I was tempted to accept these results and to alter my reference mode. But with gruesome interrogation from my supervisor and personal reflection on a deeper I knew that accepting this would be counterproductive and purpose defeating. I then went back to the drawing board and generated a few more different models some of which gave behavior that were not immediately in line with my expectations or did not make sense to me. Further model refining eventually led to the final model presented in this report and this model gave the reference mode behavior.

Many system dynamics authors state the importance of first having a reference mode before commencing to build the model. This for me serves as a moral anti bias compass as it prevents changing ones understanding of the system to fit the results.

5.9 General Observations

The following general observations were made during the simulation stages.

WORK TO COMPLETE: This stock exhibits exponential decay behavior.

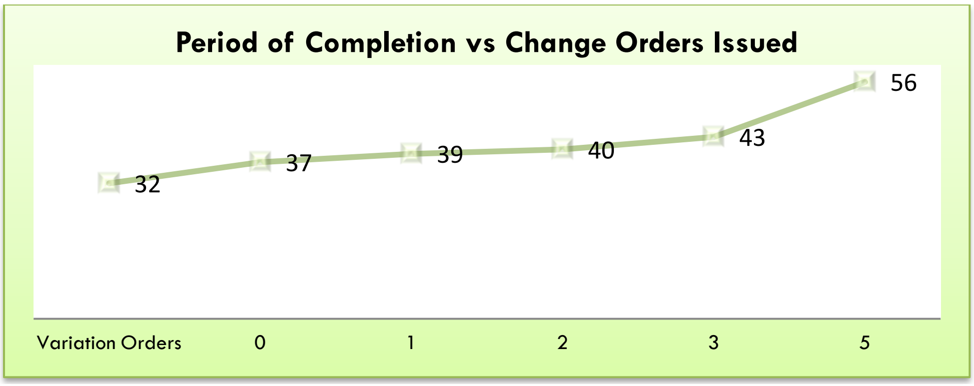
WORK IN PROGRESS: This stock exhibits exponential growth behavior. At time (t) it then starts to decay exponentially until the project is completed.

WORK COMPLETED: This stock initially exhibits a horizontal linear behavior when there is no work coming into it. At time (t) it then starts to grow exponentially until the end of the project.

The introduction of additional work disturbs the decay process of the WORK IN PROGRESS. The work spikes upwardly by the number of variation orders approved and then resume the exponential decay process. When additional work is introduced, the behavior of the WORK TO COMPLETE and the WORK COMPLETED stocks form a new smooth step. While their decay and growth are still exponential, they no longer continue on the same trajectory as prior to when the variation orders were introduced.

What these behaviors reflect, is the fact that once a project has been disturbed it is very difficult to get it back to track the original plan. However in reality this is difficult for us to grasp, as there is a belief that throwing additional resources at a strained project does not help in any way and is more likely to add to the problems, in the short term (Sterman; 1992: 6).

The model compensates for the negative impact that affects the sequencing of activities when additional activities are added to full loaded resources. It also captures the reality that not all change orders explored will be approved. This surprisingly exposed the weakness in the current approach which was that the client was not charged for exploration costs on change orders not approved.



Period of Completion vs Change Orders Issued
32
37
39
40
43
56
Variation Orders
0
1
2
3
5

the parameters used are the duration of analyzing and generating a variation order and the associated man-hour costs;

- **Extreme Conditions:** This test is important for discovering flaws in a model structure (Forrester & Senge; 1979: 13). One of the extreme conditions test performed was to test the impact of zero variation orders generated. This test is easier to manage when a model is built up incrementally in fragments as was done for this research;

- **Boundary adequacy:** This test checks for the appropriateness of the aggregation level applied (Forrester & Senge; 1979: 14). The aim of the research was to focus on the areas that are affected by the investigation and generation of change orders. For this reason the boundary chosen was sufficient for the purposes of this research. However the boundary could have been expanded to cover other areas, but it was not necessary for the stated purpose of the research;

- **Dimensional consistency:** Dimensional consistency was done and verified thereby ensuring that I was comparing apples with apples;

- **Behavior prediction (pattern prediction, event prediction, shifting-mode prediction):** These tests examine whether the model generates qualitatively correct patterns (Forrester & Senge; 1979: 23). Qualitative data had been obtained from the participants and project and cost schedules. The future behavior of man-hours was quantitatively verified on a spreadsheet**.** Excel was used to predict the behaviour of some of the fragments during the development of the model. The model behavior was consistent with the excel predictions.

5.11 Post Group Modelling Insights

The Dashboard Effect

The power of system dynamics lies in the "dashboard effect". A dashboard in a motor vehicle presents and keeps the critical information in front of the driver. Information such as speed, engine temperature and fuel levels. It also provides engine revolutions, which have no immediate value to someone who has no clue about the background workings of an engine. However if one has been using a car for a long time and the usual engine speed range is around 3000rpm and then suddenly the engine starts hovering around

6000rpm, the driver will know that something is wrong even though they may not know what that wrong thing is.

System dynamics presents the modelling participants will the results upfront, like the dashboard in a car, and saves them the background mathematics. Unlike the ignorant driver, modelling participants know how the engine was put together and how it works and therefore understand the meaning of changed behavior unlike the ignorant driver who will take some time to get to know or identify that there is a system problem. The overall effect of teaching a driver to build an engine with deep rooted understanding of the mechanics provides for a deep learning opportunity and a permanent and possibly continuous upgrading of inferior mental models.

Weakness of the Current Approach

The current approach, while not official policy within the participant organization is that when a client requests changes, he gets the exploration of the impact at no cost. As shown in the simulation, the exploration process takes about seven days, and this cost is felt by the engineer organization regardless of whether the client approves the variation order or not. Only once the variation is approved does the company charge the client for the service. This is not normally a problem for small projects and when there are not many similar requests coming from the client, but the problem arises with big projects when a number of variations are explored but never approved.

Besides the cost impact, there is also a time impact due to the change orders, regardless of whether the client approves the order or not. The seven days spent by the project team analyzing and reviewing the impact of a request, is critical and can be a deciding factor whether a project is considered successful or not. Having seen the portfolio effect of a variation order, it requires introspection on the part of the company. In my opinion, it should not be at the project manager's discretion whether the exploration process is charged to the client or not. For each project, the company should communicate upfront the costs of exploring change orders so that the client knows the cost impact of changing his mind, as some change orders are considered frivolous by the engineer's team members.

The simulation participants noted that human beings are very graphic beings, especially engineers, who seem to better grasp concepts when they can visualize them. All the participants agreed that they all had no appreciation of the cumulative effect of exploring variation orders that do not get approved until this simulation exercise.

The graphic presentation of the behavior of each of the variables over time helps in appreciating the cumulative effect of change orders.

Systems Thinking is not a Natural Act

Persistently, people think and honestly believe that they are systemic thinkers and possess the ability to see the big picture. This flies against proven research results where it was found that systems thinking is not a natural act and not everyone can learn to think systemically (Valerdi; 2011). This belief can only be explained by the need to reaffirm ones position in society and the need to be seen to be adding value.

Project managers are more likely to suffer from this belief because their work requires that they have the skill and the ability to see the big picture. It is difficult to teach someone who should already know something and who honestly believes that they already know. This could help explain why so many projects fail to meet their planned targets when the people to run them are supposed to be able to ensure that they meet their targets.

Glass Box Modelling

System dynamics model building processes lay bare (in a glass box) all the assumptions underlying the model and these are auditable by anyone looking at the model. There is no element that is hidden (black box) to the observer or enquirer.

5.12 Answers to the Questions

In responding to the research statements and questions, it is important to note that people are not aware that organizations have capacities. There is a cap on the number of projects that an organization can manage at any given time. The lack of appreciation makes us believe that we can keep piling on responsibility for as long as the client is willing to pay for it.

In reality it means that there is a certain threshold that we should not pass if we are to deliver the current project on time and within budget. I have discovered that we are not fully aware of what that threshold point is. Taking work past the threshold point means we must employ additional resources to carry the additional load or the existing staff should work long hours to keep up with the demands of the project. This would have similar results to the rework cycle effects (errors, fatigue, and reduced morale) discussed earlier in this report. Besides the normal work that we bid for, the other big source of work are variation orders. In the simulations and through the literature review I have shown that change orders are multifaceted variables impacting on a large number of other variables. They have the ability to impact on future work even though they seem unrelated.

1. **Proposition 1:** All parties in the project chain either gain or lose revenue when a change order is requested by the client;

2. **Proposition 2:** Clients and service providers are oblivious to the true impact of change orders on time and cost;

Response: During the analyses of the research and experiment results I decided to address and respond to the first two propositions together.

It is true that people are oblivious to the true impact of change orders. This was reaffirmed by the dynamic behavior experiment where people show a lack of understanding of the dynamic relationship between three variables. I have been arguing throughout this report that change orders have a complex and dynamic impact on other critical variables in projects. I have also been arguing that our natural way of thinking hinders us from seeing the true overall impact of dynamic systems.

I therefore maintain the first two propositions as being valid.

3. **Proposition 3:** Revealing the true nature of change orders will discourage clients from requesting non-essential changes in projects;

Response: The outcome of the research and deep introspection now tell me that I am no longer as certain about this proposition. Experience and history have shown that some clients will use a time bar clause to avoid paying what they know is due to the contractor.

However I am convinced that the exercise did reveal the true nature of change orders and hence the engineer's personnel should be now better equipped to manage future change orders. The knowledge about the problems that stem from change requests is no longer purely intuitive as they have seen it simulated and have a better grasp of the undesirable effect that change orders may have on the organization and their performance bonuses.

4. **Proposition 4:** Revealing the true nature of change orders will make it easier for service providers to justify seemingly disproportionate costs and time claims even post project completion;

Response: This proposition ties up with proposition three. It is true that after a dynamic simulation of a project it becomes easier to show the indirect impact of a change order. Therefore the contractor can quantify costs stemming from the change order and present to the client. The underlying assumption however in proposition four is that the client is willing to pay for the additional services. This assumption may be naïve as clients have been known to reject valid claims purely on contractual grounds. As I mentioned earlier this is usually the commencement of the litigation process.

By undertaking this research I was aiming to:

5. Model project management change order systems, on whose analyses I will reveal the weaknesses of the current generally accepted approaches;

Response: The major common weakness of project management methods is that they are static. The methods do try to capture the interrelationships between variables but do so only on the planning side with tools such as Gantt charts. On evaluating change orders, the approach is partitioned as the method does not evaluate the change order and present a broad picture of its effect. This partitioned assessment prevents people from making the necessary connections that stem from the variation order. Ideally if using the partitioned method, the project manager should engage all stakeholders. This ideally should be done as a group but the constraints of a fast paced environment prevent this.

System dynamics modelling of projects does not supersede or invalidate the traditional project management tools. I see them as complementary. The planning of a project with different tools is a scaffolding exercise. The traditional tools are more like the lower levels of the scaffolding and as one goes higher and the complexity increases one needs system dynamics.

6. Gain insights on the system structure and behavior of the systems modelled;

7. Review the robustness of current methods which are believed to be best practices;

8. Use the model to inform the generation, assessment and approval of change orders;

Response: This response jointly addresses statements six, seven and eight. The combined simulation model was sufficiently detailed for the information I wanted to extract from the exercise. It provided insight to the system structure and how we are blind to the full long term impact of short term decisions. A common occurrence in projects is that the client will request the engineer to do a high level impact assessment of the variation order before issuing a firm instruction that it be generated. This high level exercise has no apparent cost impact on the client but requires that the engineer’ s staff commit resources to the high level analysis. At the least the high level analysis will take a day. In these instances the engineer is not paid for the high level analysis, they only get paid if the permission to proceed with variation order is granted by the client. Another problem with this high level assessment is that it has to be accurate because once the order is placed the client will not accept huge variances in price and duration. For this reason it was agreed with the research participants that a reasonable time for exploration of a variation order is seven days.

The system dynamics model developed during this research provided sufficient evidence to alter the beliefs of the research participants. The knowledge about the negative impact of pursuing or exploring the possibility of a variation is now explicit and they can engage the client upfront. The model has empowered me and the participants to better deal with this common occurrence of projects.

Discussion with the research participants shows that it is normal occurrence for variations to die during the high level analysis stage. This means it is a common occurrence for the engineer to lose money for entertaining client requests.

Static planning methods are not robust enough when used to plan for fast paced dynamic environments and hence decisions made from the information gained from these methods are unlikely to be robust for a number of situations.

Additional to the aims and propositions above I planned to answer the following questions:

1. What are the cost implications of adopting the system dynamics methodology?

Answer: This is a difficult question to answer and I am now unsure as to how to best answer it. What became clear for me during the research is that the persistence and the dominance of static analytical methods is implicit for us, at work and in life in general. This is because for most of our analyses these methods are sufficient even though sub-optimal. Therefore if we continue to use static methods to manage dynamic systems we will continuously expose the company to inefficiencies which have a potential to bankrupt the company, through lawsuits and un-claimable costs incurred. Further to this, it is a matter of time before some organization adapts system dynamics for application within the project management environment which will obviously give it a competitive edge over other organizations in the same competitive market space.

The costs may be indirect and intangible but they definitely exist in the form of opportunity costs.

2. How does system dynamics modelling compare to other modelling techniques?

Answer: In chapter two, I briefly contrasted system dynamics against the measured mile method. This was a short-sighted approach on my part because during the research the modelling process revealed other arenas that are more meaningful. My mindset at the beginning was that of using system dynamics in an adversarial context and trying to get the maximum amount from a client. There is plenty of evidence that in those situations system dynamics is far superior then the measured mile method. During the course of the research I however learnt that it would be more powerful and beneficial if system dynamics was used in a preventative manner so that the engineer's team can use insights gained from the research simulations to prevent exploitation in future projects.

Additionally, as stated in the second chapter, the engineer is appointed to act in the best interest of the client. It is the engineer's duty to protect the client from uncertainties and from himself.

CHAPTER 6

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6. DISCUSSION & CONCLUSIONS

6.1 Reflection

In one of the earlier iterations of the model my supervisor asked me why I could not have done the model on a spreadsheet as the resultant behavior had been very linear and could be easy to determine or model on a spreadsheet, see Appendix 5. At that stage I was adamant that my draft model was sufficiently representative of the project's behavior. While initially defensive of the model, on reflection I arrived at a point where I felt that my defensiveness was counterproductive to the aims for this research and went against my justification for this research which was to show that projects behave non-linearly.

I then revisited the model and the major changes were:

- The WORK TO COMPLETE stock was changed to a depleting template. This template was more representative of reality because the completion rate or people's productivity adjusts and are dependent on the amount of work that has to be completed. The more work to be done, the harder the effort they put in;

- The WORK IN PROGRESS stock was changed to a conveyor. The initial iterations of the model did not accurately capture the delay experienced before the work gets to site for installation. This inaccuracy oversimplified the complexity of the project and therefore reduced the value of the model. By changing the stock to a conveyor, it accurately depicted reality and reinforced my reason for proposing that the model be developed using system dynamics;

Now in retrospect I also feel I should have revisited the cost modules because their behavior in the model presented here are still linear. The linearity comes from the assumptions embedded within the cost modules. These are that I still use "rule of thumb" to:

- Determine the duration of change order exploration;

- Determine the required number of visits for installation;

- Determine the duration of installation;

The initial hesitancy to change the cost modules came from the change in perspective. Towards the end of the draft modeling process I was more focused on showing that projects are non-linear and less focused on quantifying the costs for my organization. As stated earlier the cost quantification was a short sighted approach, so while I did not need it in the revised model I still felt it would be a powerful tool for the group modelling session as people are more sensitized to monetary losses in the projects.

6.2 Spreadsheets and their Weaknesses

There is a criticism that system dynamics models are indicative only and do not provide precise results [Kennedy (1997), on System Dynamics website accessed 22 September 2011], the results of the work he has done however dispute this criticism.

A large number of modelling exercises, financial or otherwise are done using spreadsheets. They rule the arena of organizational modeling initiatives. These spreadsheets can be simple one page documents to large and highly complex multi-page ones. While spreadsheets dominate the world of business models, it has been proven that 80% (Kennedy; 1997) of spreadsheet models contain errors and omissions that are difficult to diagnose and resolve. Spreadsheet models suffer from:

- Difficulty to maintain overall control;
- Documentation and logical errors

With increasing complexity it is difficult to audit the model assumptions and to manage the input data. Where spreadsheets are used to facilitate learning and alteration of mental models, it is difficult to fully pass on the system structure to new participants not familiar with the system. Auditing of the assumed structure is near-impossible and it is difficult to ascertain that there is a shared vision and common understanding amongst the participants.

Kennedy has shown that participants of system dynamics modelling have been impressed by "… the self documenting of the tool and the ability to audit the logic of the model even by new system users". Stocks and flows used in system dynamics modelling always have real world counterparts and therefore serve as an accurate metaphor for real world learning (Myrveit; 7). A system dynamics model is greater than the sum of its parts. This is because fragments that individually behave simplistically and linearly can be found to be very non-linear when they interact with other simple linear fragments. In the real world it is this interaction of simple elements that results in non-linear confounding behavior. Understating this reality is the key to deep learning by model building.

Without advanced skills in spreadsheet usage, it is difficult to capture the interrelationships between variables. While the results can be presented graphically in the spreadsheet, it is difficult to audit the structure that results in that behavior. There is limited potential to test "what if" scenarios unless if the model was built from the start with that requirement.

Even with all the results captured in one spreadsheet tab, the model would still behave in a fragmented manner, because for the fragments to capture the dynamics one would require the advanced mathematics that works in the background of system dynamics modelling.

The graphic user-interface of system dynamics software is intuitive, auditable and reflects and captures all assumptions made about the system structure. In contrast, spreadsheets one has cells and rows which do not guide you in the model building process. The spreadsheet modelling process requires that the model builder have the clarity of thought right from the beginning while with system dynamics even with a fuzzy thought process you can build the model that ultimately results in the clarity of thought. This is achieved by incrementally building the model. System dynamics with the other systems thinking tools, such as influence and causal loop diagrams, force you to expose your thoughts to scrutiny from the onset thereby quickly exposing erroneous and incomplete mental models. This forces long term learning and behavior alteration.

Spreadsheets carry an assumption that you know and understand the system; all that you want to do is to predict the variables of interest. Obviously then, spreadsheets built on erroneous mental models and carrying errors typical in complex spreadsheet models will likely provide incorrect results.

6.3 Discussion and Conclusion

The research started off as a way to understand the complexities of change orders with a bias towards using it to support litigation and to claim the maximum amounts incurred from clients requesting change orders. As I delved deeper into the research process I started to unearth areas of project management which exhibited complex behavior and in my opinion were sources of cost build up but were neglected in project when compiling the costs of a variation order. There was intuitive understanding that these things were sources of costs but anecdotal evidence showed that people assumed these costs to be negligible.

As shown in the data analyzed in this research, negligible costs can quickly accumulate and build up to difficult to ignore costs. A one percent decrease in profit may sound acceptable but losing one percent of one hundred million Rands is not easy to ignore, especially when you find in retrospect that you could have easily prevented such a loss.

Additionally it became clear that making a connection between variables that change with time does not come naturally to people. The bathtubs experiment reinforced the findings by Sterman et al as discussed in the literature review. It became apparent without a doubt that even technical education does not provide people with the ability to understand dynamic behavior. It actually may be risky in that people who have advanced education may think that they can perceive and predict dynamic behavior.

I thought my initial models were simple and did not contain any unnecessary information. When comparing the final model of the impact of variation orders against the original iterations, this model contained fewer stocks. This reiterated Richmond's recommendation of incorporating only the details necessary to explain the behavior of the system. The model and the resultant simulations became a source of deep learning for me and the participants. It allowed me the opportunity to connect the dots and move from intuitive knowledge to explicit knowledge. This means that the information that was there but not clear or solid started to gel and formed a recognizable shape.

The power of system dynamics lies in its ability to present the results of the simulation right in front of you and in pictorial form. In some respects, system dynamics based learning is better than real life learning in that it provides rapid feedback and the ability to test assumptions and mental models. The metaphor of reservoirs is easy to understand especially for people with an engineering background. As shown in the literature review chapter, metaphors are a powerful tool for learning and for altering mental models. They provide an opportunity for people to make links between variables in front of them but that were not linked in the person's head.

Group model building is powerful because insights that arise come more from the process rather than the final product of the study [Lane; 1999: 504 quoting Richardson and Pugh (1981)]. The group modelling process allows participants to have a common representation of the system for meaningful discussion (Riasat et al 2008: 539). This process results in a profound understanding of the system. The significance of system based learning is that it allows the learners to test their hypotheses about how a system will behave in different circumstances.

The analyses and understanding of the variables simulated in this research is generally compartmentalized into isolated processes. I hope that the model simulated will be a starting point for further work by the participants and will be expanded to include all relevant variables to enhance our understanding of project dynamics. I have a new found appreciation of the multi- dimensional nature of the influence of change orders and from the post modelling feedback it is obvious that the participants agree.

> *"Old mental models and decision habits are deeply ingrained; they do not change just because of a logical argument."*
>
> Forrester (1995: 14)

To change people's behavior it is important to help people discover for themselves that their behavior is below aspiration levels. This is quite often difficult to see, but computer simulations have a potential to address this shortfall. Huber (1991: 91) acknowledges that one of the ways to facilitate learning is to increase the feedback about cause and effect relationships. Mental model formation involves the process of filling in the gaps from the descriptions and forming a coherent and continual picture in one's head (Grune-Yunoff; 2009: 94).

It is important in any learning environment to move from the "consultant mode" and sufficiently involve individuals in the modelling process so that they:

> *"... internalize lessons about the dynamic feedback behavior... "*
>
> Forrester (1995: 14)

System dynamics simulations foster accelerated learning and altering of mental models in a safe and controlled environment.

6.4 Possible Area of Future Research

In this research it became apparent that when variables are analyzed individually (reductionist perspective), they behave in a simplistic and linear manner. Even if they are put together they still behave in an easy to understand manner regardless of whether the feedback loops are fully captured or ignored. However our brains have a very limited capability to comprehend and store accumulation.

I found it intriguing that the model was able to result in a better appreciation that explored but unapproved variation orders were one of the big sources of financial loss for the engineer organization. While everybody knows that the client must pay for all work done, why is it that they are rarely charged for the exploration of unapproved variation orders? What has been hindering the participants from claiming what is rightfully due to their organization?

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7. REFERENCES

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8. APPENDIX

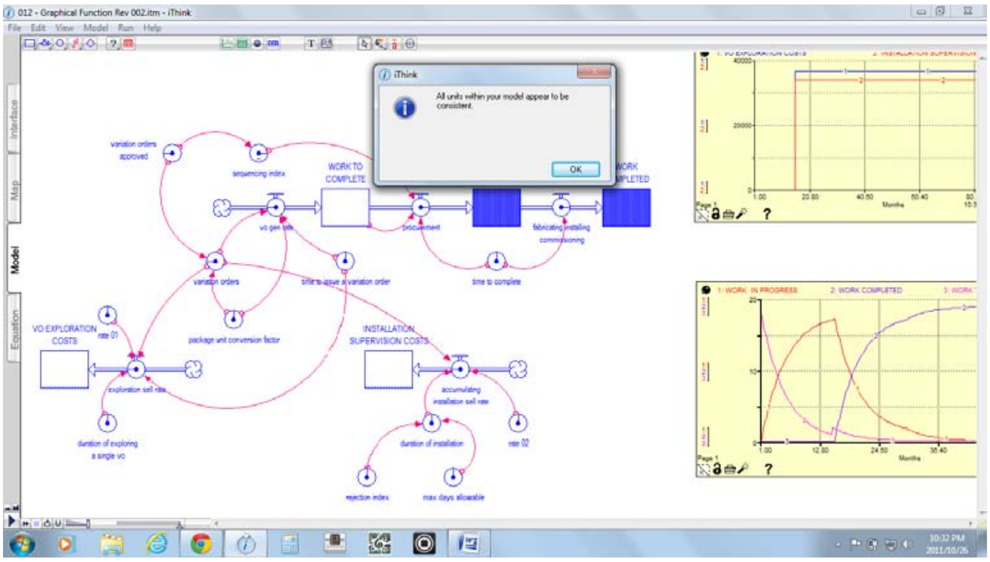
8.1 APPENDIX 1: Equations

EQUATIONS AND DIMENSIONAL CHECK SCREENSHOT

INSTALLATION_SUPERVISION_COSTS(t) = INSTALLATION_SUPERVISION_COSTS(t - dt) + (accumulating_installation_sell_rate) * dtINIT INSTALLATION_SUPERVISION_COSTS = 0
INFLOWS:
accumulating_installation_sell_rate = duration_of_installation*rate_02*variation_orders
VO_EXPLORATION_COSTS(t) = VO_EXPLORATION_COSTS(t - dt) + (exploration_sell_rate) * dtINIT VO_EXPLORATION_COSTS = 0
INFLOWS:
exploration_sell_rate = duration_of_exploring_a_single_vo*rate_01*variation_orders/time_to_issue_a_variation_order
WORK_COMPLETED(t) = WORK_COMPLETED(t - dt) + (fabricating_installing_commissioning) * dtINIT WORK_COMPLETED = 0
INFLOWS:
fabricating_installing_commissioning = CONVEYOR OUTFLOW
TRANSIT TIME = 3*time_to_complete
WORK_TO_COMPLETE(t) = WORK_TO_COMPLETE(t - dt) + (vo_gen_rate - procurement) * dtINIT WORK_TO_COMPLETE = 18
INFLOWS:
vo_gen_rate = (variation_orders)*package_unit_conversion_factor/time_to_issue_a_variation_order
OUTFLOWS:
procurement = (WORK_TO_COMPLETE/time_to_complete)*sequencing_index
WORK__IN_PROGRESS(t) = WORK__IN_PROGRESS(t - dt) + (procurement - fabricating_installing_commissioning) * dtINIT WORK__IN_PROGRESS = 0
TRANSIT TIME = varies
INFLOW LIMIT = INF
CAPACITY = INF
INFLOWS:
procurement = (WORK_TO_COMPLETE/time_to_complete)*sequencing_index
OUTFLOWS:
fabricating_installing_commissioning = CONVEYOR OUTFLOW
TRANSIT TIME = 3*time_to_complete
duration_of_exploring_a_single_vo = 7
duration_of_installation = (IF(max_days_allowable*rejection_index<1) THEN 0 ELSE max_days_allowable*rejection_index)
max_days_allowable = 5
package_unit_conversion_factor = 1
rate_01 = 7*750
rate_02 = 6800
rejection_index = 1
time_to_complete = 4.9
time_to_issue_a_variation_order = 1
variation_orders = PULSE(variation_orders__approved,15,0)/package_unit_conversion_factor
variation_orders__approved = 1
sequencing_index = GRAPH(variation_orders__approved)

(0.00, 1.00), (5.00, 0.98), (10.0, 0.945), (15.0, 0.91), (20.0, 0.85), (25.0, 0.765), (30.0, 0.665), (35.0, 0.535), (40.0, 0.405), (45.0, 0.24), (50.0, 0.00)

Dimensional Check Screenshot



8.2 APPENDIX 2: Bathtub Experiment

8.3 APPENDIX 3: Post Group Modelling Questionnaire

8.4 APPENDIX 4: Group Modelling Register

8.5 APPENDIX 5: Excel Data Inputs and Fragment Verification Sheets

8.6 APPENDIX 6: Ethical Clearance Letter