REDUCING RISKS IN LARGE SCALE PROJECTS: INVESTIGATING THE INTEGRATION OF SYSTEMS ENGINEERING PRINCIPLES INTO PROJECT MANAGEMENT

THESIS

by
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Declaration

I, Johan van Heerden, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety, or in part, submitted it at any university for a degree.

Date: March 2013

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Abstract

Project management (PM) is a very important field in engineering as a whole. The management of most projects has become more complex in recent times, due to greater technical complexity and the requirement of diversified skills. The management of risks is a very important process to improve the performance of a project. This is due to the link between project risks and objectives. However, this aspect of PM becomes increasingly more difficult to manage with increasing project complexity. For these reasons a need exists for more efficient PM methods.

This thesis had three objectives. The first was to understand the processes and principles of PM, systems engineering (SE) and risk management. This was achieved by doing a literature study on the three fields. The second objective was to identify areas of greater risk within the management of projects. The final objective was to develop an effective generic model that illustrates the integration of SE principles into PM, with the goal to reduce the identified risks.

Five risks were identified during this research. They were considered to be the most important in project management. This was accomplished by means of a questionnaire that was sent out to experts in the industry. It was established from this investigation that the following five risks, in order of importance, pose the biggest threat to the success of a project:

1. Poorly defined requirements;
2. Poor communication;
3. Poor risk management;
4. Lack of customer involvement; and
5. Inaccurate estimates.

These risks were addressed by integrating the principles of SE into PM. SE is an iterative process that needs a diverse set of people, with a variety of skills, to achieve customer requirements. Various SE approaches and strategies were developed throughout the years. They were investigated to obtain insight into which of them can be used to improve PM. The top-down iterative development principles of SE offer a great advantage, and therefore it was appropriate to integrate these principles into PM.

A model was developed as part of this thesis to illustrate the integration of SE principles into PM, and the importance of risk management. The model was named “Project Management Integrated with Systems Engineering Principles Model”. This tool can be used by engineers and their project teams to enhance the management of projects. It is also a generic tool that can be used for any project.

The final step of this research was the validation of the model. This was done by means of expert evaluation. The purpose of this validation was to test whether the objectives of the research were met, and if the model was valid in the sense of ease of use and usefulness. The final objective of the validation process was to determine if the integration of systems engineering (SE) principles into project management (PM) were successful, and if it will reduce risks in large scale projects. It was concluded from this evaluation that its objectives were met and that the model successfully demonstrated the integration of SE into PM to reduce risks in large scale projects.

Several recommendations were made that may enhance this study. They main recommendations are:

1. Researching the impact of communication on projects, by using case studies.
2. SE principles are mainly used in the first two phases of the model. Further investigation of using SE principles in phase three may be researched.
3. Customer involvement may be used during changes in the project. For this reason it is recommended that future studies may include investigation of the impact the customer has on project changes and the change management process.
4. The model could be tested in the industry on an active project. This will greatly improve the validity of the model.

Opsomming

Projekbestuur is 'n baie belangrike veld in ingenieurswese as geheel. As gevolg van die toenemende tegniese kompleksiteit en die vereiste van verskillende vaardighede, het die bestuur van meeste projekte meer gekompliseerd geraak met tyd. Die bestuur van risiko's is 'n baie belangrike proses om die uitvoering van 'n projek te verbeter. Hierdie aspek van projekbestuur het egter al hoe moeiliker geword om te bestuur. Dus hiervoor bestaan daar 'n behoefte vir meer doeltreffende projekbestuur metodes.

Hierdie tesis het drie doelwitte gehad. Die eerste doelwit was om die prosesse en beginsels van projekbestuur, stelsels ingenieurswese en risikobestuur te verstaan. Dit was bevredig deur 'n literatuur studie wat gedoen is in die drie velde. Die tweede doelwit was gestel om die areas van groter risiko binne die bestuur van projekte te identifiseer. Die finale doelwit was die ontwilkkeling van 'n effektiewe generiese model wat die integrasie van stelsels ingenieurswese beginsels binne projekbestuur demonstreer, met die doel om die geïdentifiseerde risiko's te verminder.

Vyf risiko's, wat as die mees belangrikste in projekbestuur beskou word, was geïdentifiseer. Hierdie risiko's was deur middel van 'n vraelys, wat aan deskundiges in die industrie gestuur was, geïdentifiseer. Die risiko's, gelys in volgorde van belangrikheid, was:

1. Swak bepaalde vereistes;
2. Swak kommunikasie;
3. Swak risiko bestuur;
4. Onnoukeurige skattings; en
5. Geen kliënt betrokkenheid.

Vervolgens was hierdie risiko's deur die integrasie van stelsels ingenieurswese beginsels in projekbestuur toegespreek. Stelsels ingenieurswese is 'n herhalingsproses wat die kliënt se vereistes bevredig, deur gebruik te maak van 'n diverse groep mense met 'n verskeidenheid van vaardighede. Verskeie stelsels ingenieurswese benaderings en strategië is deur die jare ontwikkel. Hierdie benaderings en strategië was geondersoek om vas te stel watter van hulle toegepas kan word om projekbestuur te verbeter. Die *"top-down"* herhalende ontwikkeling beginsels van stelsels ingenieurswese bied 'n groot voordeel, en dit was om hierdie rede toepaslik om dié beginsels in projekbestuur te integreer.

'n Model was ontwikkel as deel van die navorsing om die integrasie van stelsels ingenieurswese beginsels binne projekbestuur te illustreer, asook die belangrikheid van risikobestuur. Die model is genoem "Project Management Integrated with Systems Engineering Principles Model". Hierdie

model kan deur ingenieurs en hul projekspanne gebruik word om die bestuur van projekte te versterk.

Die finale stap van die navorsing was die evaluasie van die model. Dit was gedoen deur middel van deskundige evaluasie. Die validasie proses het twee doelwitte gehad. Die eerste doel was om te bepaal of die doelwitte van die ondersoek bereik was, asook om vas te stel of die model geldig was in die sin van gemak van gebruik en bruikbaarheid. Die tweede doel van die validasie proses was om te bepaal of die model suksesvol die integrasie van stelsels ingenieurswese binne projekbestuur gedemonstreer het, en of hierdie integrasie risiko's in groot skaalse projekte sal verminder. Dit was afgelei van die evaluasie dat die model wel suksesvol die integrasie van stelsels ingenieurswese binne projekbestuur demonstreer om risiko's in grootskaalse projekte te verminder.

Verskeie aanbevelings was gemaak wat hierdie navorsing kan versterk in waarde. Die hoof aanbevelings was:

1. Die impak wat kommunikasie op projekte het kan geondersoek word deur middel van gevallestudies.
2. Stelsels ingenieurswese beginsels is hoofsaaklik gedurende die eerste twee fases van die model gebruik. Die gebruik van stelsels ingenieurswese beginsels in fase drie kan verder ondersoek word.
3. Kliënt betrokkenheid gedurende veranderinge in 'n projek kan gebruik word. Om hierdie rede word dit aanbeveel dat verdere studies die kliënt se impak op projek veranderings en verandering in bestuursproses ondersoek word.
4. Die model kan getoets word in die industrie op 'n aktiewe projek. Dit sal die geldigheid van die model grootliks verbeter.

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List of Acronyms

Acronym		Description
PM	-	Project Management
SE	-	Systems Engineering
PMBOK	-	Project Management Body of Knowledge
WBS	-	Work Breakdown Structure
PV	-	Planned Value
AC	-	Actual Cost
EV	-	Earned Value
SD	-	Status Date
PVEV	-	PV = EV
SV	-	Schedule Variance
TV	-	Time Variance
CV	-	Cost Variance
CPI	-	Cost Performance Index
SPI	-	Schedule Performance Index
BAC	-	Budget at Completion
ETC	-	Estimated Cost to Complete
EAC	-	Estimated Cost at Completion
TQM	-	Total Quality Management
QP	-	Quality Planning
QC	-	Quality Control
QI	-	Quality Improvement
QA	-	Quality Assurance
SEMP	-	Systems Engineering Management Plan
TEMP	-	Test and Evaluation Master Plan
RAD	-	Rapid Application Development
GUI	-	Graphical User Interface
DBMS	-	Database Management Systems

JAD	-	Joint Application Development
SE	-	Systems Engineering
CE	-	Concurrent Engineering
QFD	-	Quality Function Deployment
HOQ	-	House of Quality
XP	-	Extreme Programming
FDD	-	Feature Driven Development
DSDM	-	Dynamic Systems Development
PERT	-	Program Evaluation and Review Technique
FTA	-	Fault Tree Analysis
FMEA	-	Failure Mode and Effect Analysis

1. Introduction

1.1 Background

Projects are managed by everyone, everywhere. It ranges from small day-to-day projects to very large, complex projects. The nature of large projects has become much more complex in recent times. Many modern projects involve great technical complexity and require more diversity of skills to complete a project successfully within the expectations of time, quality and cost. These complex activities have led to the development of new forms of project organisations and new practices of management, such as project management (PM) (Nicholas & Steyn, 2008). The main aspect of PM that gets increasingly more difficult to manage, due to the increase in complexity and manpower, is risk (Dinsmore & Cabanis-Brewin, 2006).

Risk management is a very important process to improve the performance of a project, due to the clear link between risks and objectives (Dinsmore & Cabanis-Brewin, 2006). For example, PMI (2008) states: "Project risk is an uncertain event or condition, if it occurs, has a positive or negative effect on at least one project objective". The aim of risk management is to identify those uncertainties, assess them, and develop actions to stop or minimise them. Dinsmore & Cabanis-Brewin (2006) states: "Where risk management is ineffective, a project can only succeed if the project team is lucky. Effective risk management optimises the chances of success, even in the face of bad luck". For that reason, risk management gives a structured mechanism to provide visibility into threats to project success (Fourie, 2011).

The research reported in this document attempts to integrate the principles of systems engineering (SE) into PM to reduce risks in large scale projects. SE is an iterative process that needs a diverse set of people, with a variety of skills, to achieve customer requirements (Stem, Boito, Younossi, & Obaid, 2006). It is also described as a comprehensive top-down and iterative problem solving process that is applied throughout the stages of development. This is achieved by organising the interconnections between elements of a system. These elements are typically organisational and include work tasks as in PM. However, it also extends to design activities, customer satisfaction, optimisation, and support for decision making.

The main differences between PM and SE are that SE requires more "technical" skills but not technical expertise and PM requires more "managerial" skills but not management (Baldwin, 2010). PM is a more standardised process, with the primary purpose to identify tasks and sequence them in a timeline with a well-defined solution plan. On the other hand, SE requires a thoughtful application to each situation under examination. It can be said that SE emphasises the importance of the entire system and the interdependence of its parts, as opposed to the hierarchical decomposition of PM. However, it is acknowledged that similarities and overlaps do exist between SE and PM.

Various SE approaches, that represent the life cycle of a system, were developed throughout the years as additional unique and custom applications (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Examples of these approaches are the waterfall, spiral, V-model and rapid application development, etc. These models, and more, are investigated and discussed later in this document.

The top-down iterative principles of SE offer a great advantage, and therefore it will be appropriate to integrate these principles into PM. A model, acting as an illustrative tool, will be developed to illustrate the researched PM, SE and risk management principles, and that they are integrated.

1.2 Research Purpose and Questions

Risks are high in modern day projects due to the complex nature of these projects, as stated earlier. Many projects also fail to meet the three goals of PM, which is mainly due to the failure of managing risks, inadequate articulation of requirements and inadequate technical skills. Progress over the years in reducing project failures are also very little, which will be proved in Chapter 2. Due to this, a need exist for more efficient PM methods. These methods should be beneficial to the project manager with regards to the coordination and planning of a project to ensure its completion within the time, budget and quality constraints.

The application of SE principles is not used in normal project management. For this purpose, a model will be developed that illustrates the integration of SE principles into PM, and reduce major project management risks. The research conducted will aim to reduce risks related to the early processes of project management, i.e. requirements and specifications identification, communication, and planning. Engineers and their project teams will be able to use this tool to enhance the management of projects. It should be a generic tool that can be used for any project.

The research purpose leads to the following research questions:

1. Is the management of large scale projects successful?
2. Is risk management essential in project management?

3. Are there similarities or differences between project management and systems engineering?
4. Will the integration of SE principles into PM enhance the application of PM?
5. Will the integration lead to a more systematic PM approach?
6. Will the integration reduce process related risks in large scale projects?

1.3 Research Objectives

The research of this thesis has three main objectives:

1. The first is to understand the processes and principles of PM, SE and risk management.
2. The second objective is to identify areas of greater risk within the management of projects. The idea behind this objective is to use the principles of SE to reduce those identified risks.
3. The last objective is to develop an effective generic model that illustrates the integration of SE principles into PM. The aim of the model is to reduce risks in projects.

1.4 Report Structure

The literature study is carried out in Chapter 2. This study is divided into three sections; PM, SE and risk management. These disciplines are researched to provide insight into their methodologies and to obtain a general understanding of them.

Chapter 3 reports the research methodology. This chapter outlines the strategies or action plans that were designed to achieve the study objectives, as stated above.

In Chapter 4 and 5 various SE approaches and strategies, which may be helpful in the development of the PM model, are investigated. Conclusions are drawn to establish what can be used in the model.

Chapter 6 describes and discusses the development of the model. This includes the motive for the model development, model requirements and parameters, and a general description of the completed model.

In Chapter 7 the model is validated. The model is analysed and tested in this chapter. Feedback from various experts in the field of PM is also discussed.

Chapter 8 reports the conclusions and recommendations. This chapter will indicate whether or not the hypotheses made above were true or false.

2. Literature Study

2.1 Chapter Introduction

The aim of the research reported is to develop a model that illustrates the integration of systems engineering (SE) principles into project management (SE). The goal of this integration is to ultimately reduce identified project risks. The literature study will consist of four sections: 1) PM, 2) SE, 3) Risk Management, and 4) Integration.

In the PM section a background is initially provided. The aim of this is to point out the main reasons why, and how many, projects fail, to show that the research problem does exist. After this, the field of PM is researched in order to provide insight into the methodology behind it.

SE is researched in the second section of the study. A background is given to provide an understanding of SE principles, and what the way of thinking is in SE. The field of SE is also researched to provide insight into the methodology behind it.

The third part of the literature study is a discussion of risk management. The identification, handling and prevention of risks have a significant contribution to the success of a project. This section will provide insight into how, and why, risk management should be performed. Major process related PM risks are also identified in this section.

The final part of the study is a discussion on the integration of PM, SE and risk management. Differences and similarities, benefits of integrating, and gaps in the researched literature are provided.

2.2 Project Management

2.2.1 Background

The main difference between general and project management (or any other form of management) relates to the definition of a project (Burke, 2006). As a result a project must be defined before a definition of project management can be given.

The project management body of knowledge (PMBOK) defines a project as a temporary endeavour undertaken to create a unique product or service (PMI, 2008). It is therefore a sequence of unique, complex, and connected activities having one goal or purpose, and that must be completed by a specific time, within budget, and according to specification (Wysocki, 2007).

Project management is defined by Nicholas and Steyn (2008) as the management to define and execute everything necessary to complete a complex system of tasks to achieve an end result that is unfamiliar and unique. This must be done at the target completion date with constrained resources and an organisation that is cross-functional and newly formed (Nicholas & Steyn, 2008). Therefore, the primary purpose of conventional PM is to identify tasks and sequence them in a timeline. It relies on the existence of a well-defined solution path where the individual tasks can be anticipated at the initial planning stage.

A general criterion exists to determine when to use project management. These are (Nicholas & Steyn, 2008):

- When the project is somewhat unfamiliar.
- If greater effort is required.
- If the project is in a changing environment.
- When a multifunctional effort is required.
- If the reputation of the organisation is at stake.

A conventional project has three interrelated goals or objectives, which can be seen in Figure 2, below. The goal of a project is to hit the three dimensional target: complete the work for the customer or end-user in accordance with budget, schedule, and performance requirements (Nicholas & Steyn, 2008). The budget is the allowable cost of the project, the schedule is the time in which the work has to be done, and the performance is the required features of the end-item (Nicholas & Steyn, 2008).

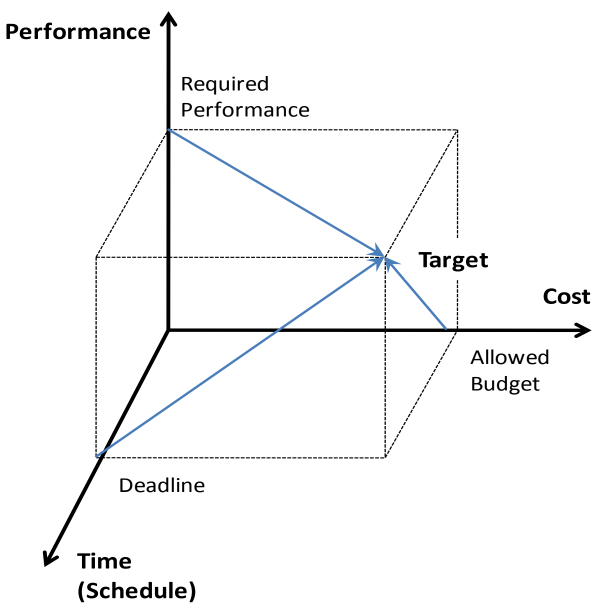


Figure 2: Three goals of a project (Redrawn from Fourie, 2011)

Projects are almost always carried out under different and uncertain conditions (Fourie, 2011). As a result a "function" exists that relates the three goals in Figure 2 (Meredith & Mantel, 2006). The main task of a project manager is to decide how to trade off one project goal against another (Fourie, 2011). For instance, if the project is not on schedule more resources must be assigned, which will cause a budget overrun (Fourie, 2011).

The complexities of large modern day projects pose many risks and may lead to the failure of projects. This is mainly due to its technical complexity, which requires a greater diversity of skills. (Nicholas & Steyn, 2008). Many projects also fail to meet the three goals of project management. The reasons for this are the failure of adequate planning, managing risks, inadequate articulation of requirements and inadequate technical skills (Thomas & Mengel, 2008). Other reasons for project failure are lack of communication skills, proper tracking of the project and lack of an end-to-end, high level view of the project (Flores *et al.*, 2012). Calleam Consulting Ltd. (2012) gathered data from several surveys, conducted by different organisations, to illustrate that problems exist across the project management industry.

Table 1, on the next page, provides a summary of the different surveys. The research aim of them was to obtain project success/failure rates. It can be seen from Table 1 that problems exist in project management, because the percentages of project failures are too high. Another study reported in 1993 by Frigenti & Comninos (2002) also confirms that projects do not meet their schedule and budget goals. It is illustrated in Figure 1 that only 32% and 23% of the average project meet their schedule and budget requirements, respectively.

In comparing Table 1 and Figure 1 it can be concluded that the progress over the years in reducing project failures is very little.

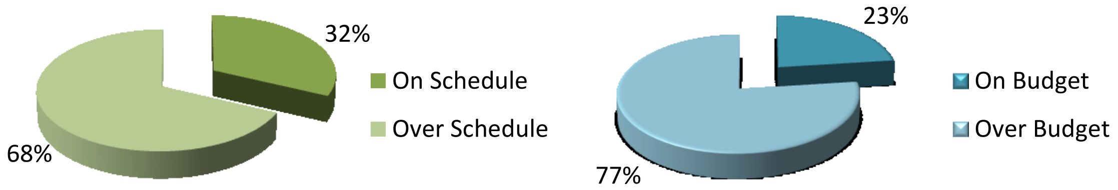


Figure 1: Average cost and time overruns (Adopted from Frigenti & Comninos, 2002)

Table 1: Surveys conducted by different organisations to illustrate success/failure rates (Adapted from, Calleam Consulting Ltd., 2012)

Source of Survey	Type of Survey	Facts and Figures
Geneca	Interview based (600 people) study of starting a software project	• 75% of project participants lack confidence that their projects will succeed due to fuzzy business objectives, uninvolved stakeholders, and excessive rework. • 78% of the respondents reported that the business is usually or always out of sync with the requirements of the project.
KPMG (New Zealand)	Survey of 100 businesses across a broad cross section of industries	• 70% of the organisations surveyed suffered at least one project failure in a calendar year. • 50% of the respondents indicated that their projects failed to consistently deliver for what they set out to achieve.
IBM	Survey of 1,500 change management executives to find the success/failure rates of their projects	• Only 40% of the projects met schedule, budget and performance requirements. • The best organisations are 10 times more successful than the worst organisations. • Biggest barriers to success are listed as people factors: Changing mindsets and attitudes - 58%; Corporate Culture - 49%; Lack of senior management support - 32%. • The underestimation of the project complexity is listed as a factor in 35% of projects.
Logica Management Consulting	Survey of 380 senior executives in western Europe to study success rates for business process change projects	• 35% of organisations abandoned a major project in the last 3 years. • 37% of business process change projects fail to deliver benefits
United States Government Accountability Office	Review of federally funded technology projects	• 49% federally funded IT projects are either poorly planned, poorly performing or both

Table 1: Continued

Source of Survey	Type of Survey	Facts and Figures
Information Systems Audit and Control Association (ISACA)	400 Respondents to a survey	• 43% of organisations have suffered a recent project failure. • 20% of technology investments are not fully realised at a typical enterprise.
Guardian Newspaper (UK)	Investigation into government waste in the UK since year 2000	• Study shows that government wasted $4 billion due to failed projects • Only 30% of the projects and programs are successful.
Dr Dobbs Journal	586 respondents to email survey (Dr Dobbs subscriber list)	• 70% of the respondents had been involved in a project they knew would fail right from the start • Success rates for Agile projects are 72% and that of traditional approaches 63%
KPMG - Global IT Project Management Survey	Survey of 600 organisations globally	• 49% of organisations suffered a project failure in a calendar year • In the same calendar year, only 2% of organisations reported <u>all</u> of their projects achieved its desired benefits • 86% of organisations reported a shortfall of at least 25% of targeted benefits across their portfolio of projects • Many organisations fail to measure benefits, so they are unaware of their true status in terms of benefits realisation

Bruzelius *et al.* (2002) performed a study on issues that characterised many large infrastructure projects. They found that cost overruns from 50-100% were common in these projects. The main reasons behind this were inaccurate forecasts and estimates. Furthermore, they also provided reasons why these forecasts and estimates were inaccurate, namely (Bruzelius, Flyvbjerg, & Rothengatter, 2002):

- Due to the time frames involved in major project development and implementation, politicians provide over-optimistic forecasts of project viability in order to have projects approved.
- Special interest groups can promote projects at no cost or risk to themselves.
- Contractors are eager to have their proposals accepted during tendering. They often are over-optimistic in their forecasts, because contractual penalties for producing over-optimistic tenders are often low compared to the potential profits involved. For this reason cost and risk are underestimated in tenders, which will lead to cost overruns.

This study correlates well with some of the surveys (e.g. Both of KPMG, IBM, United States Government Accountability Office and Dr. Dobbs Journal) done by Calleam Consulting Ltd (2012). The correlation illustrates that adequate planning is very important for a project to be successful.

Following conventional project management poses another threat to the success of complex projects. This approach does not include the involvement of all interest groups (especially external) at the start of a project (Bruzelius, Flyvbjerg, & Rothengatter, 2002). The risk of the customer being unhappy, due to reasons of feeling being left out and not knowing what is going on, may lead to an unsuccessful project. Another problem with this method is that it measures project success only to the three project goals discussed earlier. The measure of success should also involve additional dimensions, such as risk management and business results (Sauzer *et al.*, 2009; De Bakker *et al.,* 2010). It is also argued by Thomas and Mengel (2008) that for projects to become more successful its emphasis must move away from the conventional methods to methods supporting and fostering continuous change, creative and critical reflection, self-organising networking, virtual and cross-cultural communication and coping with uncertainty. Due to this a need exists for more efficient project management methods during planning.

It can be seen from the discussions above that project planning plays a very important role in the success of a project. Planning is performed during the first two stages of project management. For this reason the research reported in this thesis will mainly focus on these two phases. However, research should not be limited to only these phases, because implementation and control also contributes to the success of a project.

2.2.2 The Project Life Cycle

The four generic phases of a project life cycle are (see Figure 3):

- Initiation (Concept)
- Planning (Definition)
- Implementation (Execution)
- Closure (Completion)

Two variations may exist in the life span of a project. The first is a phased project. This is when the phases are treated somewhat independently (Nicholas & Steyn, 2008). As a result each phase requires justification and approval. The second variation is fast-tracking (Nicholas & Steyn, 2008). In this case the phases overlap, and work in successive phases happens simultaneously. Each of the phases is discussed in the following sections. It must be remembered that the management of risks is very important throughout the entire life cycle of a project. This is also discussed.

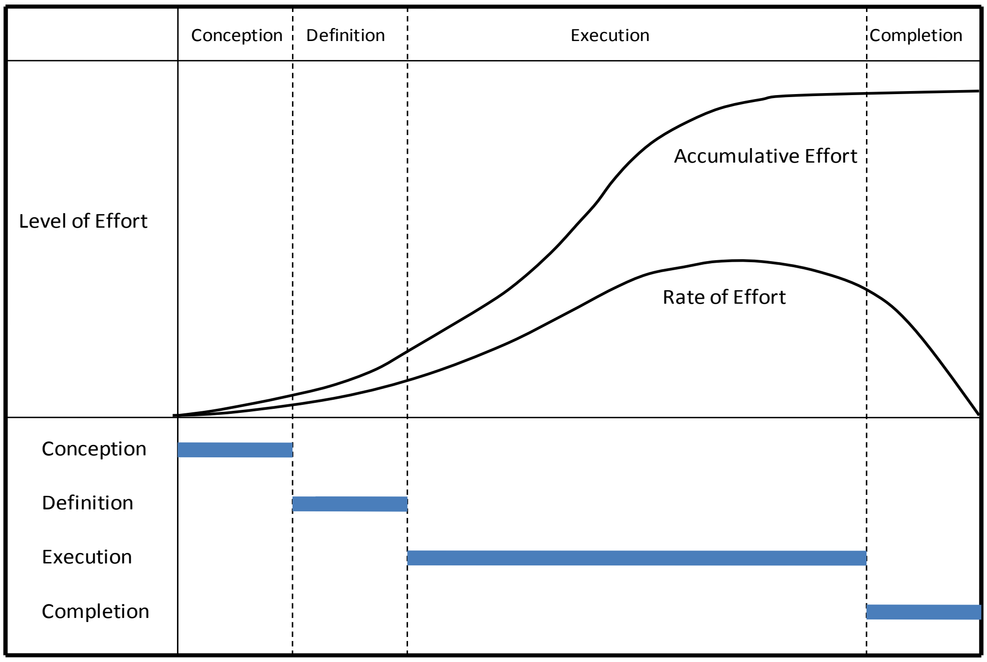


Figure 3: Project life cycle (Redrawn from Burke, 2006)

2.2.2.1 Initiation (Conception Phase)

Every project starts with an idea. The development of this idea is normally based on a perceived problem, opportunity, or need (Nicholas & Steyn, 2008). The feasibility of proceeding with the project is firstly investigated (Burke, 2006). The key activities that occur in this phase are the identification of the stakeholders and the preparation of a cost-benefit analysis. The output of this phase is the proposal, and on acceptance of it the project moves onto the next phase (Burke, 2006). Figure 4 shows the steps to initiate a project.

i. Define Project

It is stated by Dinsmore & Cabanis-Brewin (2006) that a project should be defined comprehensively from the start. This includes its purpose, ownership, technology cost, duration and phasing, financing, marketing and sales, organisation, energy and raw materials supply, and transportation (Dinsmore & Cabanis-Brewin, 2006). If the proper steps in defining a project are not followed from the start, key issues essential to its viability could be missed or given inadequate attention (Dinsmore & Cabanis-Brewin, 2006). These mistakes will ultimately result in a poor or even disastrous project.

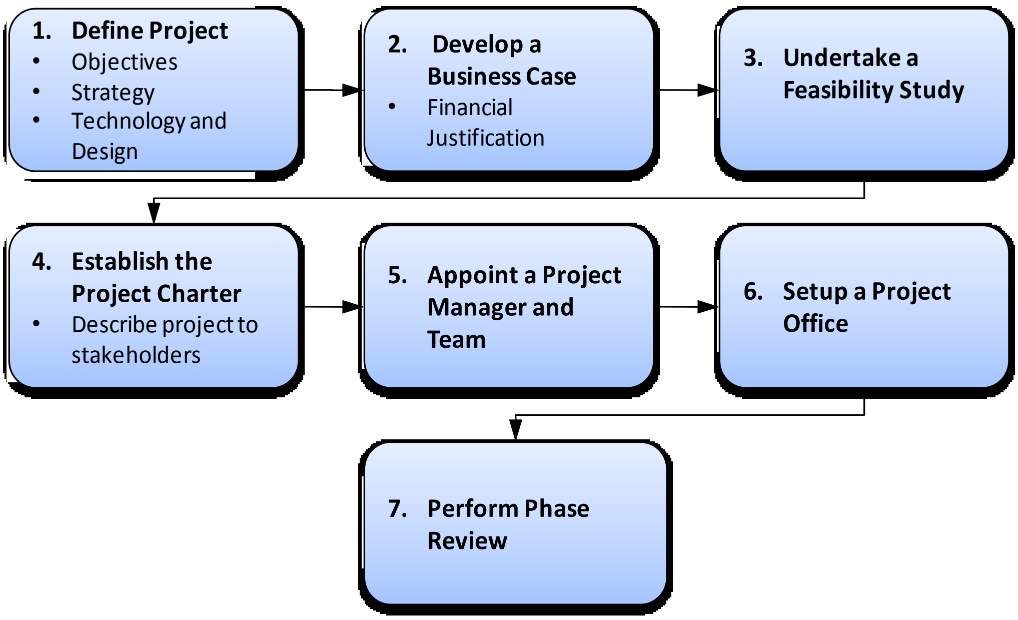


Figure 4: Steps to initiate a project (Redrawn from Method123, 2003)

ii. Develop a Business Case

Once the project is properly defined, a Business Case is prepared. This normally includes the following:

- An analysis of the potential solution options available, which includes documentation of potential benefits, costs, risks, and issues (Method123, 2003).
- A recommended solution and a generic implementation plan.

It is stated by Method123 (2003) that the business case is approved by the Project Sponsor and the required funding is allocated to proceed with the project.

iii. Feasibility Study

Feasibility studies are performed to investigate the likelihood of a solution achieving its benefits, as outlined in the business case (Method123, 2003). The steps in performing a feasibility study, according to Nicholas & Steyn (2008), are:

1. Obtain a full understanding of the user's problem, need, and current situation
2. Document the current system
    - Draw schematic diagrams that show inputs, outputs, elements, flows, etc.
    - All information should be summarised
3. Devise alternative solutions
4. Analyse the alternatives
5. Include the solution in the technical section of the project proposal

iv. Project Charter

The Project Charter is a declaration that management has approved a project (Nicholas & Steyn, 2008). This contains information necessary to give the reader a good overview of the project, i.e. vision, objectives, scope, deliverables, organisational structure, a summarised plan of the activities, resources, and the required budget to undertake the project (Method123, 2003).

v. Project Manager and Team

At this stage of the project the project manager and team are ready to be appointed. The primary role of the project manager is to integrate everything and everybody to achieve the three goals, as discussed earlier (Nicholas & Steyn, 2008). In order to achieve this, the project manager should possess certain abilities (Fourie, 2011). She/he should:

1. Have a good understanding of the nature of the project in order to make technical decisions;
2. Be efficient and innovative;
3. Have good personal charisma or style; and
4. Be a good facilitator and communicator.

vi. Project Office

The Project Office is the physical environment within which the team will be based (Method123, 2003). The components included in a successful project office are the location, means of communication (telephones, computer network, email, etc.), and documentation (methodology, processes, forms and registers) (Method123, 2003).

vii. Phase Review

A review is done after the conception phase. This review act as a checkpoint to make sure that the project has achieved its stated objectives as planned.

2.2.2.2 Planning (Definition Phase)

The guidelines set by the feasibility study are used during this phase to design the product, outline the build-method, and develop detailed schedules and plans for making or implementing the product (Burke, 2006). The output from this phase is the final baseline project proposal that will be used to implement the project. To accomplish a successful baseline plan (project master plan) the sequence of events, shown in Table 2 on the next page, should be followed.

Table 2: Elements of the Project Master Plan

WHAT?	•Scope and Statement of Work •Determine objectives, deliverables, and major tasks of the project •Obtain detailed customer requirements
HOW?	•Establish the work breakdown structure (WBS) •WBS becomes the basis for assigning project responsibilities
WHO?	•Determine the necessary resources and their resposibilities for the work tasks •Achieved by integrating the WBS and project organization •Then a responsibility matrix is created
WHEN?	•Use a Gantt Chart to schedule activities (relevant software is used during this step, e.g. Microsoft Project) •Important events and milestones are added
HOW MUCH?	•Determine the project budget •Can either be done top-down or bottom-up •Bottom-up is more accurate
WHAT IF?	•Risk management plan must be drawn up •Management of risks throughout the life cycle of the project is very important
HOW WELL?	•Performance tracking •Set up the appropriate control measures
OTHER ELEMENTS	•Other elements of the plan, as needed for, e.g. •Work review and testing, quality control, documentation implementation, communication/meetings, procurement, contracting and contract administration
PHASE REVIEW	• At the end of of the planning phase, a pase review is performed • It is done to ensure that the project has achieved its stated objectives as planned

2.2.2.3 Implementation (Execution and Control Phase)

In the execution and control phase the project is implemented and controlled as per the baseline plan developed in the previous phase (Burke, 2006). Several important processes occur during this phase, such as awarding contracts and issuing instructions, procurement management, and to make the product or solve the problem. The output from this phase is the certificate of completion. If this is approved the project moves on to the next phase. Figure 5 shows the activities performed during the implementation of a project.

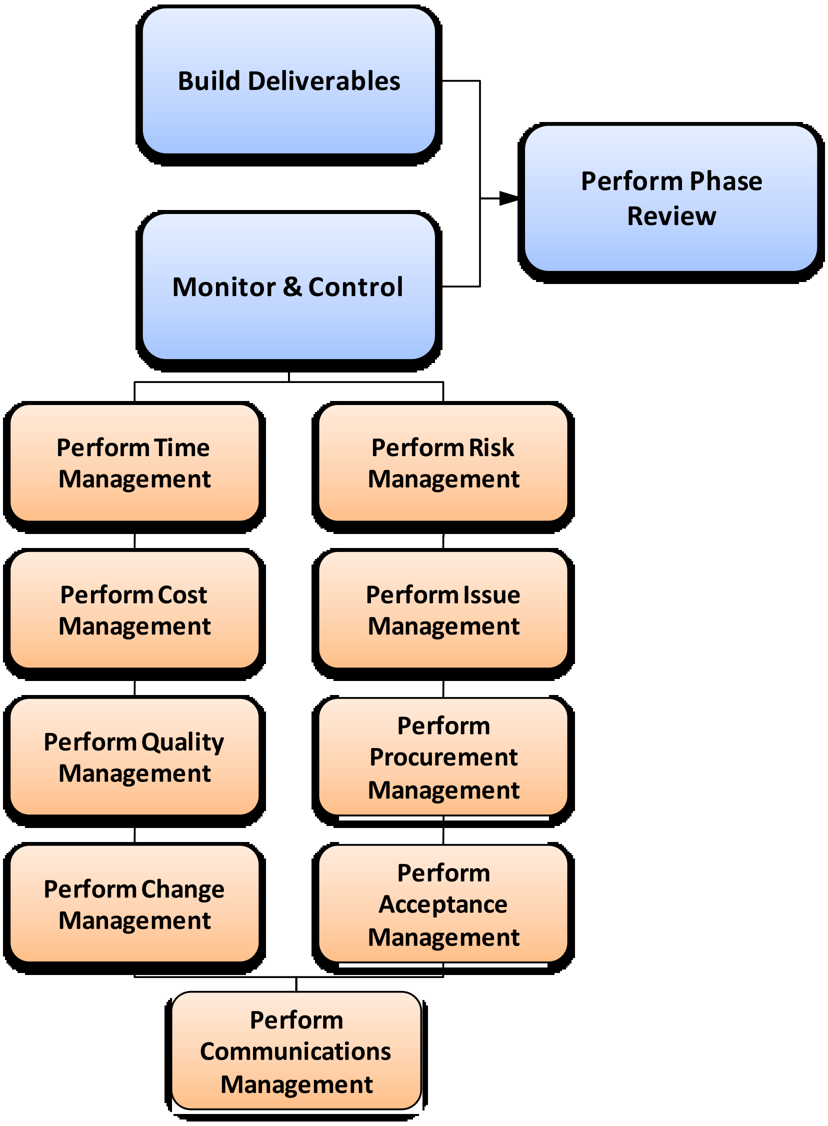


Figure 5: Activities performed during the implementation phase (Redrawn from Method123, 2003)

a) Build Deliverables

The execution of a project typically includes the stages of design, production/build, and implementation of each deliverable for acceptance by the customer (Method123, 2003). The actual stages, along with its activities undertaken to construct each deliverable, in a project will vary, depending on the purpose of the project (Nicholas & Steyn, 2008). For example, the stages in hardware development projects are design, development, and production, whereas in construction projects they are design and construction (Nicholas & Steyn, 2008).

Two methods are mainly used to construct the deliverables. The first being construction in a 'waterfall' approach. When using this method each activity is undertaken in sequence until the deliverable is finished (Method123, 2003). The second method is the construction of a deliverable in an 'iterative' manner until it meets the requirements of the customer (Method123, 2003). Careful monitoring and control processes should be utilised in order to ensure that the quality of the final deliverable meets the customer requirements, regardless of the method used to construct the deliverable (Method123, 2003).

b) Monitor and Control

A range of management processes are implemented by the project manager to monitor and control the project, whilst the project team is producing the deliverable (Fourie, 2011). An overview of each management process follows:

i. Time Management

This process manages the time which is spent by staff that undertakes project tasks, with the aim to keep the project on schedule (Method123, 2003). Schedule overruns can occur for reasons beyond anyone's control. Reasons for this may be necessary changes in project scope, weather problems, and material shortages (Nicholas & Steyn, 2008). Guidelines exist for controlling schedule variability and keeping projects on target. They are: Using time buffers; fighting the tendency to multitask; frequent reporting of activity status; and publicising the consequences of schedule delays and benefits of early finish.

Use Time Buffers: A time buffer is essentially a schedule reserve. It is an amount of time included in the schedule to account for uncertainty in completion time (Nicholas & Steyn, 2008).

Fight Tendency to Multitask: It is stated by Nicholas & Steyn (2008) that work on a particular task or project should not be interrupted by combining it with work from other tasks or projects. In other words, the tasks or projects should be prioritised and the most important tasks or projects should be finished first.

Frequently Report Activity Status: Tasks or work packages on the critical path should start at the earliest possible start. According to Nicholas & Steyn (2008), that can only happen if the status of their predecessors is known. As a result the status of each activity should be reported to successor activities on a daily basis (Nicholas & Steyn, 2008). These reports should state the expected days remaining to complete the activity and the earliest date when successors should expect to begin (Nicholas & Steyn, 2008).

Publicise Consequences of Schedule Delays and Benefits of Early Finish: Everyone who is part of the project (e.g. team members, suppliers, subcontractors, etc.) should be informed about negative consequences of a schedule overrun and the possible reward of finishing early (Nicholas & Steyn, 2008).

ii. Cost Management

The motive behind the cost management process is to track expenditures versus budgets to detect variances, and to eliminate unauthorised or inappropriate expenditures (Nicholas & Steyn, 2008). This control measure takes place at both work package- and project level. It is the responsibility of the project manager to review and compare actual and budgeted costs to assessments of the work completed. With this information it will be possible to estimate the project completion cost and date (Nicholas & Steyn, 2008). These methods are described next.

iii. Performance Analysis and Control Using Earned Value

The status of a project or any portion of it can be assessed with five variables, as seen in Figure 6 on the next page: Planned Value (PV), Actual Cost (AC), Earned Value (EV), Status Date (SD), and PVEV. These variables are defined below:

- **PV:** Is the sum cost of all work scheduled as specified in the original budget.
- **AC:** Is the actual cost of work completed to date.
- **EV:** Is the value of the work, for any given day, actually done in terms of the budget.
- **SD:** Is the status date (indicated on Figure 6 as the present time line).
- **PVEV:** Is the date where PV = EV.

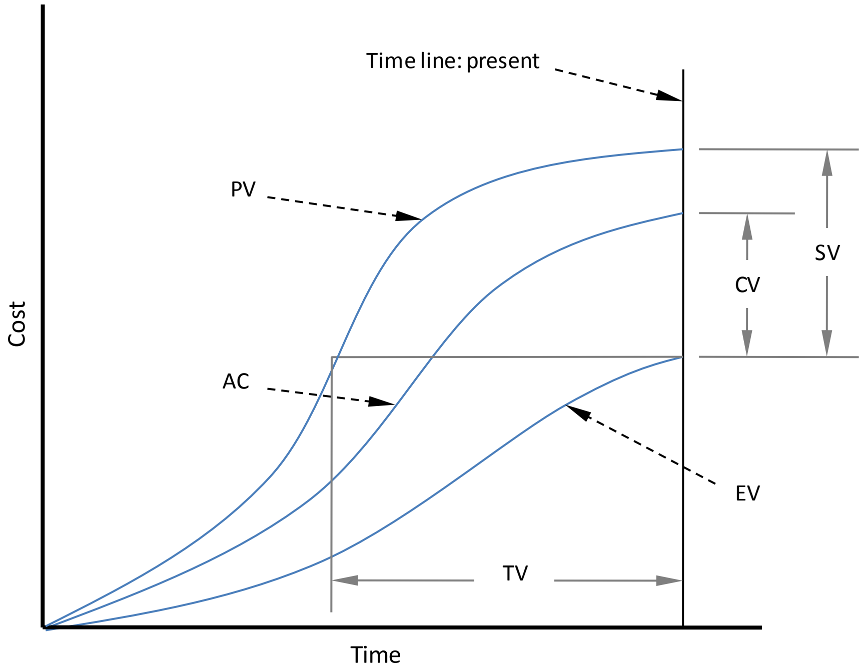


Figure 6: Project control using planned and earned value (Redrawn from Nicholas & Steyn, 2008)

By using the values of these variables, three kinds of variances can be determined:

Schedule Variance (SV)	=	EV – PV	(2.1)
Time Variance (TV)	=	SD – PVEV	(2.2)
Cost Variance (CV)	=	EV – AC	(2.3)

The SV will give you an indication if the project is in front or behind schedule. TV will give you an indication of how much (in time) the project is in front or behind schedule. CV gives an indication of the financial status of the work to date, indicating if you are over or under budget.

The efficiency of a project can also be measured by using a Cost Performance Index (CPI) and Schedule Performance Index (SPI). These indices are defined as the ratios of EV to AC and EV to PV, respectively:

CPI	=	EV/AC	(2.4)
SPI	=	EV/AC	(2.5)

Values of CPI and SPI greater than one indicate that work is under budget and ahead of schedule, respectively. Values less than one indicate the opposite.

Forecasting can also be done to estimate the amount of cost required to complete a project and the amount the project will cost at the end. First, the variables are defined:

- **BAC:** Budget at Completion (total budget which was initially established to complete the project)
- **ETC:** Estimated Cost to Complete the project
- **EAC:** Estimated Cost at Completion of the project

These estimates can then be calculated in the following manner:

$$ETC = (BAC - EV)/CPI \quad (2.6)$$

$$EAC = AC + ETC \quad (2.7)$$

iv. Total Quality Management

Total Quality Management (TQM) is defined as a management process that embraces all activities through which the needs and expectations of the customer, community and the objectives of the project are satisfied (Stashevsky & Elizur, 2000). It is the responsibility of the project manager to ensure that regular quality reviews are undertaken, and the results recorded in the quality register (Method123, 2003). The TQM process can be broken up into four subsections: Quality Planning (QP); Quality Control (QC); Quality Improvement (QI); and Quality Assurance (QA).

QP is the activity of setting quality goals and developing products and processes required to meet those goals (Hoyle, 2007). QC is the ongoing process of monitoring and evaluating work, and taking corrective action to ensure that the planned quality outcomes are met (Nicholas & Steyn, 2008). QC is mostly regarded as a post event activity, which can be avoided by installing sensors before, during, or after results have been created (Hoyle, 2007). According to Hoyle (2007) QI is a management process that focuses on increasing the ability to fulfill quality requirements. The aim of QA is to provide confidence that quality requirements will be fulfilled. According to Nicholas &Steyn (2008) QA reduces the risks related to features or performance of deliverables, and provides confidence that the requirements of the deliverable are met.

v. Change Management

No project entirely goes without change, because changes to the final deliverable and initial project plan are inevitable due to oversights, new opportunities, or unforeseen event or problems (Nicholas & Steyn, 2008). Examples of these changes are the modification of work, reorganising or adding personnel, and trading off among time, cost, and performance (Nicholas & Steyn, 2008). Change management is therefore the process by which changes to the project's scope, deliverables, schedules or resources are formally defined, evaluated and approved before the change is implemented (Method123, 2003). It is the responsibility of the project manager to manage change successfully. According to Nicholas & Steyn (2008) the project manager must understand the business and system drivers that require change in order to accomplish it. This involves documenting the benefits and costs of adopting the change and formulating a structured plan for implementing the change (Method123, 2003).

vi. Risk Management

Risks that pose a threat to the project are formally identified, quantified and managed during the risk management process. Risks can be identified at any phase/stage of the project. A more comprehensive study on risk management is given under the Risk Management section of the Literature Study (Section 2.4).

vii. Issue Management

This process manages the issues that are currently affecting the ability of a project to produce the required deliverable (Method123, 2003). Any issues, challenges and concerns are identified and logged into the issue register. Each issue is assessed by the project manager, and a set of actions are undertaken to resolve the issue at hand (Method123, 2003).

viii. Procurement Management

Products which are sourced from external suppliers are managed during this management process. To obtain these products, a purchase order must be approved by the project manager and sent to the supplier for confirmation (Method123, 2003). The status of ordered products is tracked by using a procurement register until the product has been delivered and accepted by the project team (Method123, 2003). Another responsibility that the project manager has is to ensure that the procured products are of acceptable quality. In order to maintain good quality the project manager should often visit and inspect the facilities of suppliers responsible for designing and producing these products (Nicholas & Steyn, 2008).

ix. Acceptance Management

Inspection and acceptance testing of the final deliverable produced by the project are performed during this management process. This is done to ensure that the requirements of the customer are met (Method123, 2003). In order to acquire the acceptance of the customer, an acceptance form is completed. This form describes the criteria from which the deliverable has been produced, and the level of satisfaction of each criterion (Method123, 2003).

x. Communications Management

During this process formal communications messages are identified, created, reviewed and communicated within a project. It is of great importance that the project manager prepares a clear communications plan in the definition phase, as the failure of many projects is due to the failure to communicate (Fourie, 2011). According to Method123 (2003) a project status report should be used to report the status of a project to the team and stakeholders, and a communications register is used to log any communication items released to the stakeholders.

c) Phase Review

A review is done after the conception phase. This review act as a checkpoint to make sure that the project has achieved its stated objectives as planned.

2.2.2.4 Closure (Completion Phase)

Projects are endeavors of limited duration, as per its definition. The completion phase confirms that the project has been implemented or built to its design specifications (Burke, 2006). The project deliverable is handed over to the customer in this phase. Two activities are performed during closure (activities shown in Figure 7 below):

1. The project is terminated and closed.
2. A project review is done upon completion.

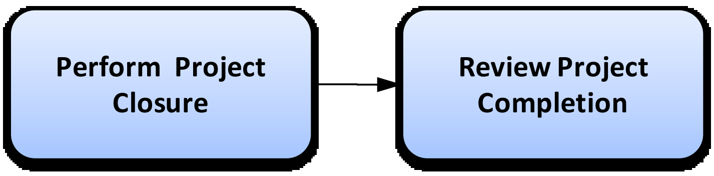


Figure 7: Activities performed during closure (Redrawn from Method123, 2003)

a) Project Termination and Closure

According to Fourie (2011) a project can be terminated in essentially three different ways:

1. Termination by extinction:
   - The project is stopped because it was a success and the deliverable requirements have been met.
2. Termination by addition:

- After the completion of the project, the project entities as a whole become part of the company.

3. Termination by integration:
   - Project entities are distributed among the body of the parent organisation after the project is completed.

In order to successfully terminate a project, by means of the three ways discussed above, a series of activities must be carried out. The project manager is responsible for the planning, scheduling, monitoring and controlling termination, and closeout activities (Nicholas & Steyn, 2008). These responsibilities, as listed by Nicholas & Steyn (2008), are shown in Table 3, below.

The activities shown in Table 3 are included in a project closeout report, which is submitted to the customer/project sponsor for approval (Method123, 2003). The project manager must complete all of these activities in order to close the project.

Table 3: Termination and closeout responsibilities of the project manager (Adapted from Nicholas & Steyn, 2008)

1. **Planning, scheduling, and monitoring closeout activities**	2. **Final closeout activities**	3. **Customer acceptance, obligation, and payment activities**
Obtain and approve termination plans from the involved functional managers	Close out all work orders and approve the completion of all subcontracted work	Ensure delivery of end-items, side-items, and ensure that the customer accept the items
Prepare and coordinate termination plans and schedules	Notify all departments of project completion	Notify the customer when all contractual obligations have been fulfilled
Plan for transfer of the project team members	Close the project office and all facilities occupied by the project organisation	Ensure that all documentation related to customer acceptance as required by the contract has been completed
Monitor completion of contractual agreements	Close project books	Expedite any customer activities needed to complete the project
Monitor disposition of any surplus materials and project equipment	Ensure the delivery of project files and records to the responsible managers	Transmit formal payments and collection of payments
		Obtain formal acknowledgement of completion from the customer that release the contractor from further obligation (except warranties and guarantees)

b) Review Project Completion

The final activities undertaken on any project is the revision and evaluation of its overall success and performance compared to the planned progress and performance (Fourie, 2011). According to Fourie (2011) various dimensions of success must be identified:

- The efficiency in meeting both the budget and schedule;
- Customer impact satisfaction;
- Direct success for the business; and
- Future potential.

The purpose of the evaluation process is to continuously improve future projects through experience gained from completed projects (Nicholas & Steyn, 2008). Basically, it serves as a set of recommendations for future projects.

2.3 Systems Engineering

2.3.1 Background

It was shown earlier in Subsection 2.2.1 that a problem exist in the management of projects, due to their high failure rates. SE is researched in this section of the literature study to establish if its principles can be used in PM to reduce risks. It is stated by Sharon *et al.* (2011) that PM and SE are two tightly intertwined domains. However, differences and similarities do exist between them, which will be pointed out in Section 2.5.

A system is defined as an integrated complex combination of people, products, and processes that provides the capability of satisfying needs or objectives (DoD-USA, 2001). Consequently, SE is defined as an interdisciplinary approach, and means, to enable the realisation of successful systems (INCOSE, 2007; Ören & Yilmaz, 2012). The purpose of SE is to solve complex problems, by organising the interconnection between elements to meet user needs. It focuses on defining customer needs and required functionality early in the development cycle, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Performance, Test, Manufacturing, Cost and Schedule, Training and Support, and Disposal (Ören & Yilmaz, 2012). Therefore, SE seeks to apply a holistic approach to the development of a system, which incorporates structure (how things fit together), processes (what happens), and human elements (attitudes, feelings, emotions, etc.) (Stewart & Fortune, 1995).

Complex systems require great diversity. Embedding and integrating functionalities from different disciplines is a major source of innovation and an important factor in today's market competition (Königs, *et al.*, 2012). In order to successfully execute a project, organisations and systems engineers, should apply systems thinking to projects. This way of thinking is a discipline for seeing 'wholes', which will allow for an understanding of the complicated relationship between various socio-technical factors (Ferreira & Faezipour, 2012; Frank, 2012). Frank (2012) identified several characteristics related to the application of systems thinking, namely:

- Understand the whole system and see the big picture
- Understand interconnections
- Understand system synergy
- Understand the system from multiple perspectives
- Understand the implications of proposed change
- Understand analogies and parallelism between systems
- Understand limits to growth

- Be creative (allow for innovation)
- Define boundaries clearly
- Be able to take into consideration non-engineering factors
- Be able to optimise

These characteristics should be inherent to all organisations, and systems engineers, that execute complex projects. However, successful SE does not only depend on systems thinking characteristics. These characteristics should be used in the following four key SE principles to ensure that projects are successful: 1) Stakeholder Value-Based System Definition and Evolution, 2) Incremental Commitment and Accountability, 3) Concurrent Multidiscipline System Definition and Development, and 4) Evidence-Based and Risk-Based Decision Making (Boehm *et al*., 2012).

The first SE principle allows for the identification of which stakeholders are success-critical to the system. This is done to determine their value propositions, and to define, design, develop, and evolve a mutually satisfactory system (Boehm, *et al.*, 2012). If all the stakeholders are not included from the outset they may frequently feel little commitment to the project and either underperform, decline to use, or block the use of the results (Boehm, *et al.*, 2012). This highlights the importance of including all stakeholders (external and internal) from the outset of a project.

The second SE principle emphasise the importance of incremental commitment and accountability of all success-critical stakeholders. No trust can be built between stakeholders without commitment and accountability. If they are not accountable for their commitments, they may not provide necessary commitments or decisions in a timely manner and are likely to be drawn away to other pursuits when they are most needed (Boehm, *et al*., 2012). Therefore, clear visibility of progress versus plans must be available to ensure that all stakeholders are committed and can be held accountable for success or failure.

The increasing pace of change in technology, competition, organisations, and life in general has made assumptions about stable, pre-specifiable requirements unrealistic (Boehm *et al.*, 2012). For this reason the third SE principle ensures that concurrent multidiscipline system definition and development are performed. It emphasises the concurrent execution of projects rather than sequential, especially during the early phases.

The fourth SE principle allows for evidence-based and risk-based decision making. This emphasises the use of evidence in making decisions at milestone reviews, which moves away from the traditional PM schedule-based or event-based reviews (Boehm, *et al.*, 2012). The link between evidence-based and risk/opportunity-based decision making is that shortfalls in evidence are uncertainties or probabilities of loss or gain (Boehm, *et al.*, 2012).

The SE principles discussed above holds many benefits for complex projects. These benefits are summarised below:

- Applying systems thinking allows systems engineers to understand the relationship between socio-technical factors, i.e. hardware, software, and human factors. They look at the 'big picture', a holistic view, and analyses everything that may have an influence on a project (opportunities or threats). This ensures thorough definition and planning of a project.
- SE principles, in general, are focused on detailed identification and definition of user requirements from the outset of a project. This is accomplished by involving all stakeholders (internal and external). In doing this, it will help minimise reworks and changes later in the project.
- SE principles also stress the importance of good communication within the team, as well as with customers and other external stakeholders. This ensures that all the stakeholders are aware of what needs to be done and what the status of the project is. Misunderstandings, that may lead to rework, can be avoided if proper communication is carried out from the outset of the project.
- Stakeholders are held accountable for their successes and failures throughout a project. This enables trust building between stakeholders, because everybody knows that each and every one is pulling their 'weight'.
- SE utilises concurrent development, especially during the early phases. This is beneficial in today's fast changing markets. However, critical success factors to this are proper documentation and project change tracking. Concurrent development also reduces development time, and therefore costs.
- Decisions made during reviews are based on project feasibility evidence collected to date. This may lead to the use of incentive programs, i.e. review planning and preparation can become subject to earned value management, which is factored into progress payments and award fees. Investments in feasibility evidence have been found to pay off significantly in development rework avoidance (Boehm, *et al.*, 2012).
- The structured nature of SE ensures that no corners are cut throughout the entire project. This also allows for detailed planning and the insurance that plans are followed from the outset of the project.

The discussions above prove that SE holds many possible benefits for PM. The integration of SE principles into PM are researched further in Section 2.5, which highlights important differences and similarities, benefits of integrating, and possible gaps in the research. The subsections (2.3.2 and 2.3.3) that follow are a literature review on the basic methodology of SE as a whole. Different SE approaches and strategies are investigated later in the document. This investigation will form part of the research design, which is discussed in Chapter 3.

2.3.2 Systems Engineering Process: An Overview

Figure 8 gives a basic representation of the processes in SE. A more detailed discussion on the life cycle of a system is given in the following subsection. As shown by Figure 8 the process includes: inputs and outputs, requirements analysis; functional analysis and allocation; requirements loop; synthesis; design loop; verification; and system analysis and control. These features are described next.

2.3.2.1 Process Input

The inputs to the process consist primarily of, but are not restricted to, the customer's needs and requirements (Stem, Boito, Younossi, & Obaid, 2006). Further information that should be included is the objectives, the technology that is going to be used, and project constraints. The inputs may also consist of output requirements from a previous phase of the process, e.g. program decision requirements or specifications and standards to be used (Stem, Boito, Younossi, & Obaid, 2006).

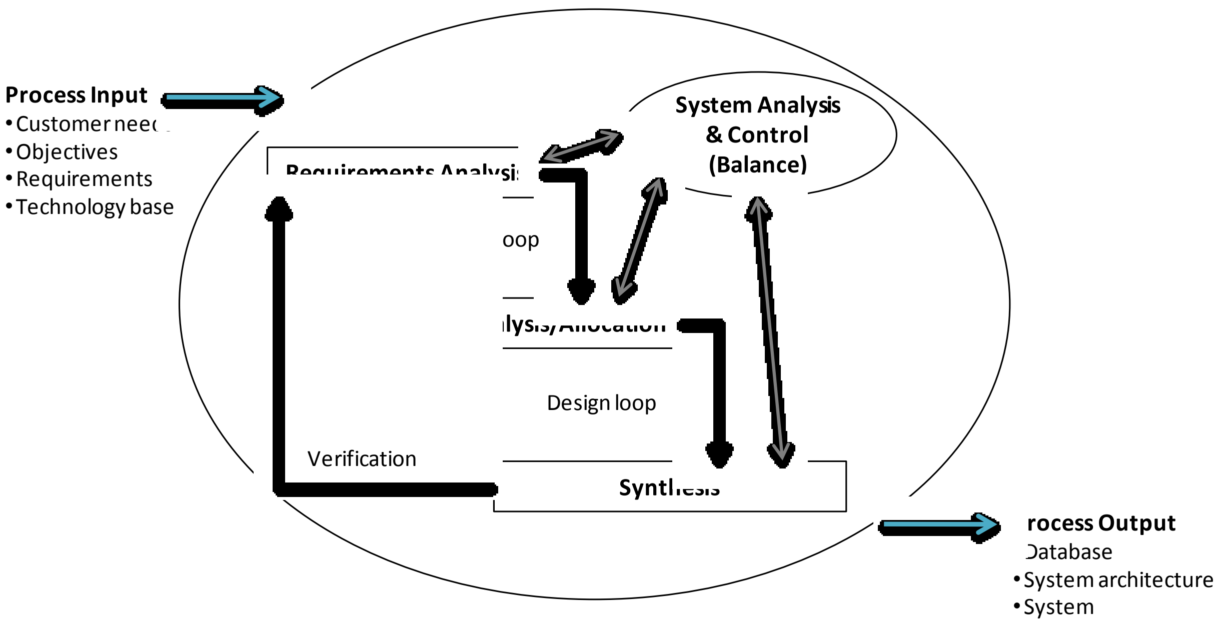


Figure 8: SE process (Redrawn from Eisner (2002), Kossiakoff *et al.* (2011) and Stem *et al.*, 2006)

2.3.2.2 Requirements Analysis

The first iterative step in the SE process is the requirements analysis. During this step the process inputs are analysed to translate the requirements of the customer into a set of functional and performance requirements that define what the system must do and how well it must perform (DoD-USA, 2001).

2.3.2.3 Functional Analysis/Allocation

The goal of this second step (functional analysis/allocation) of the SE process is to analyse functions by decomposing higher-level functions identified through the requirements analysis into lower-level functions (DoD-USA, 2001). This is done with the intention to assign discrete tasks or activities to the lower-level functions with the aim to fulfill the higher-level requirements (Stem, Boito, Younossi, & Obaid, 2006).

This step of the SE process allows for better understanding of what the system has to do, in what ways it can do it, and it provides information that is important to the optimisation of physical solutions (DoD-USA, 2001).

2.3.2.4 Requirements Loop

The requirements loop is an iterative process that revisits the requirements analysis as a result of the functional analysis (DoD-USA, 2001). The aim of this feedback loop is to re-examine the lower-level functions to ensure that they meet the overall requirements at the primary level (Stem, Boito, Younossi, & Obaid, 2006).

2.3.2.5 Synthesis

During this step of the SE process the allocated requirements are satisfied through the collection of design solutions at the lower levels, otherwise known as the physical architecture (Stem, Boito, Younossi, & Obaid, 2006). This collection of design solutions must satisfy the functional architecture derived during the functional analysis and allocation step (Stem, Boito, Younossi, & Obaid, 2006). The physical architecture that is derived during this step forms a basic structure for the generation of specifications and baselines (DoD-USA, 2001).

2.3.2.6 Design Loop

During the design feedback loop, the functional architecture is revisited to verify that the physical architecture can perform the required functions at required levels of performance (DoD-USA, 2001). The loop is important because it reassesses the manner in which the system will perform its task, and this helps optimise the synthesised design (DoD-USA, 2001).

2.3.2.7 Verification

The verification loop in the SE process compares the solution with the original requirements to ensure that the system meets its objectives (DoD-USA, 2001). Four methods are used to check if the designs are verifiable. These are examination, demonstrations, analysis (including modeling and simulation), and testing (Stem, Boito, Younossi, & Obaid, 2006).

2.3.2.8 System Analysis and Control

System analysis and control are used throughout the SE process to balance the requirement analysis, functional analysis/allocation, and synthesis with cost, schedule and performance risks (Stem, Boito, Younossi, & Obaid, 2006). This is done to ensure that the resulting system is affordable, operationally effective, and that the customer needs are being met (Stem, Boito, Younossi, & Obaid, 2006).

Activities associated with system analysis include tradeoff studies, effectiveness analysis, and design analysis (DoD-USA, 2001). Risk management, configuration management, data management, and performance-based progress measurement are the main control activities (DoD-USA, 2001).

2.3.2.9 Process Output

The final output of the SE process, which is dependent on the level of development, is a design that satisfies the needs of the customer (DoD-USA, 2001). The output will include a decision database, a system or configuration item architecture, and the baselines (DoD-USA, 2001).

2.3.3 System Life Cycle Analysis

As with PM, systems also have a life cycle. Various SE models, that represent the life cycle of a system, were developed throughout the years as additional, unique and custom applications (Kossiakoff, Sweet, Seymour, & Biemer, 2011). These models will be discussed later in Chapter 4. The life cycle of a system consist of three principle stages, as seen in Figure 9. According to Kossiakoff *et al.* (2011) the first two stages represent the development part of the life cycle, and the third the post development period.

The stages will be referred to in this report as (I) The *concept development* stage; (II) the *engineering development* stage; and (III) the *post development* stage. Each of these stages has different phases, which will be discussed in the sections that follow.

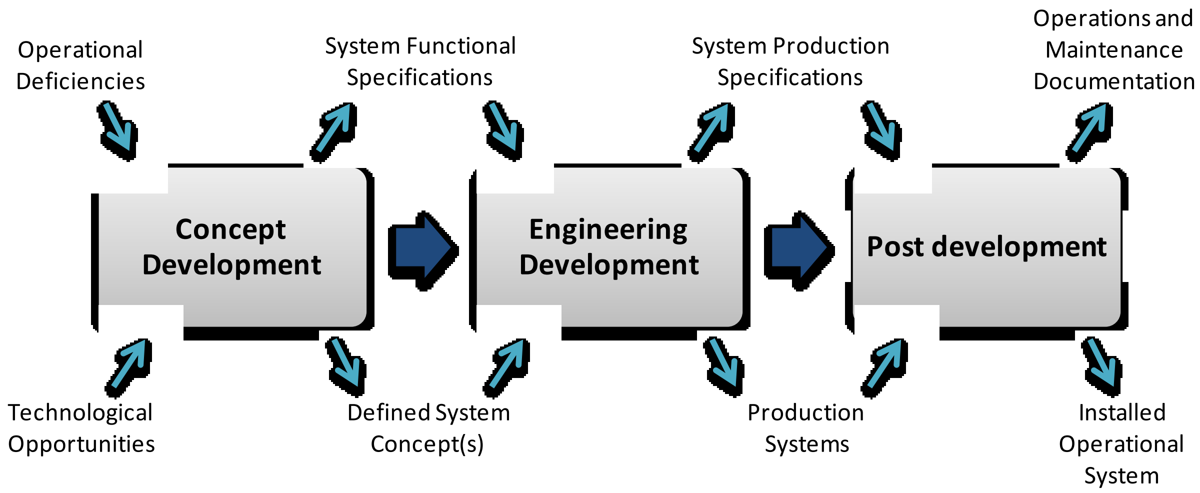


Figure 9: Principle stages in a system life cycle (Redrawn from Kossiakoff *et al.*, 2011)

2.3.3.1 The Concept Development Stage

The concept development stage is the initial stage where the formulation and definition of a system concept is derived with the goal to satisfy a need (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This initial stage of the system life cycle consists of three phases: N*eeds analysis*, *concept exploration*, and *concept definition*. These phases, their activities, inputs and outputs are illustrated in Figure 10, which has a format analogous to Figure 9.

a) Needs Analysis Phase

The primary objective of this phase is to show that a valid operational need exists for a new system or a major upgrade to an existing system (Kossiakoff, Sweet, Seymour, & Biemer, 2011). It is critical that the purposes associated with this phase are successfully addressed. In doing so, the likelihood of a match between the system that is truly needed and the one that is developed will increase (Parnell, Driscoll, & Henderson, 2008). Typical activities of this phase include system studies, technology assessments, and operational analyses.

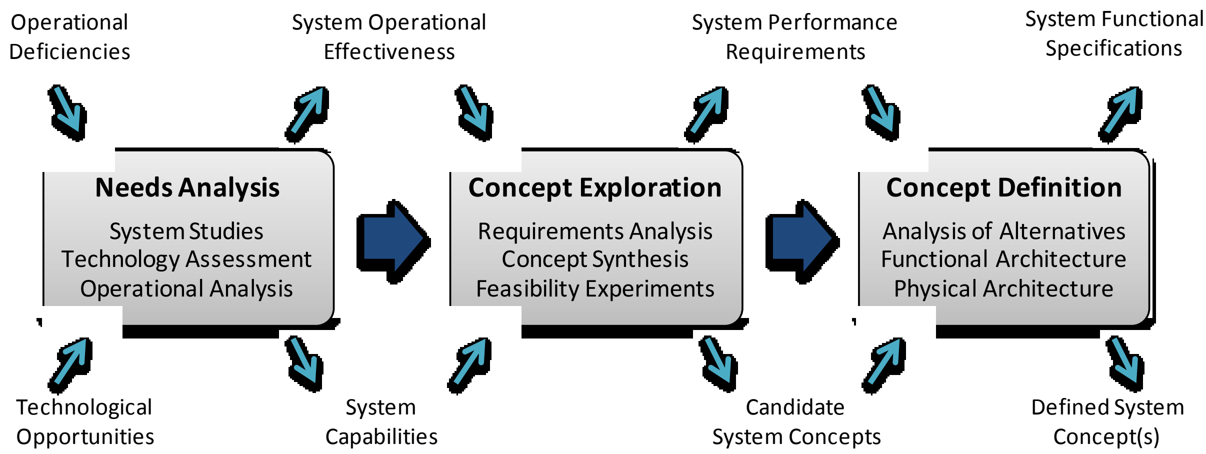


Figure 10: Concept development phases in a system life cycle (Redrawn from Kossiakoff *et al.*, 2011)

The problem or need that should be addressed by the new system is defined through analysing data gathered from existing documentation and performing personal interviews (Reilly, 1993). Other needs that should be identified during the system studies are that of the stakeholders (Parnell, Driscoll, & Henderson, 2008). The needs validation criteria are also defined during these studies.

The technology that could be used to develop the system must be assessed. This is done to explore, discover and refine the key ingredients necessary for the program to get off to a good start (Parnell, Driscoll, & Henderson, 2008).

The projected needs for the new system are analysed either in terms of deficiencies of the current system or the potential of improving performance, or lower cost, by the application of new technology (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This analysis will then produce the operational objectives and system capabilities. Risk factors should also be identified to create a draft initial risk management plan (Parnell, Driscoll, & Henderson, 2008).

b) Concept Exploration Phase

The main objective of this phase is to explore alternative concepts and to convert the operationally oriented view of the system, as determined in the needs analysis, into an engineering-oriented view (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This conversion is necessary to provide a clear and quantifiable basis for the selection of an acceptable functional and physical system concept (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Typical activities of this phase include requirement analyses, concept synthesis, and feasibility experiments.

Two sets of requirement analyses are performed in this phase; 1) The operational requirement analysis, and 2) The performance requirements formulation.

The first step in the operational requirements analysis is to analyse the operational objectives that were identified in the previous phase. During the second step operational requirements are refined, as required, to provide specificity, independence, to ensure compatibility with other related systems, and to provide the necessary information to ensure completeness (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The operational requirements identified are then used to formulate the performance requirements, which are stated in terms of engineering characteristics. This step includes the translation of operational requirements into system and subsystem functions, and formulating the performance parameters required to meet the stated operational requirements (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The concept synthesis involves exploring a range of feasible implementation technologies and concepts that offer a variety of potentially advantageous options that will deliver maximum value to the stakeholders (Kossiakoff *et al.*, 2011 & Parnell *et al.*, 2008). Functional descriptions for each concept are developed, and the associated system components are also identified.

This step in the concept exploration phase involves performing effectiveness analyses to define a set of performance requirements and to eliminate system concepts that are infeasible to consider further (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

c) Concept Definition Phase

During this phase the functional and physical characteristics of a new system (or major upgrade of an existing system) are defined (Kossiakoff, Sweet, Seymour, & Biemer, 2011). These characteristics are proposed to meet the operational need defined in the previous phases. It is stated by Kossiakoff *et al.* (2011) that the output of this phase is the selection, from a number of alternative system concepts, of a specific configuration that will constitute the baseline for development and engineering. Typical activities of this phase include an analysis of alternatives and the definition of the functional and physical architecture.

Alternatives are analysed to select the preferred concept. This is done by comparing the concepts by means of their relative performance, operational utility, development risk, and cost

(Kossiakoff, Sweet, Seymour, & Biemer, 2011). The system architecting, known as the concept description, can commence once the best scenario concepts have been chosen.

The functional architecture is a set of specifications that describe what the system must do, and how well (Kossiakoff, Sweet, Seymour, & Biemer, 2011). In other words, it is an arrangement of functions and their sub-functions that defines the sequence of implementation, the control or data flow conditions, and the performance requirements to satisfy the requirements baseline (IEEE, 2005). These allocated requirements are satisfied through a collection of design solutions, known as the physical architecture.

2.3.3.2 The Engineering Development Stage

The engineering development stage is the second stage in the life cycle of a system. This stage focuses on the implementation of the system concept, that was developed in the previous stage, hardware and software components, their integration into the total system, and the validation of the systems operational potential (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This second stage consists of three phases: *Advanced development, engineering design, and integration and evaluation.* These phases, their activities and inputs and outputs are illustrated in Figure 11, which has a format analogous to Figure 9.

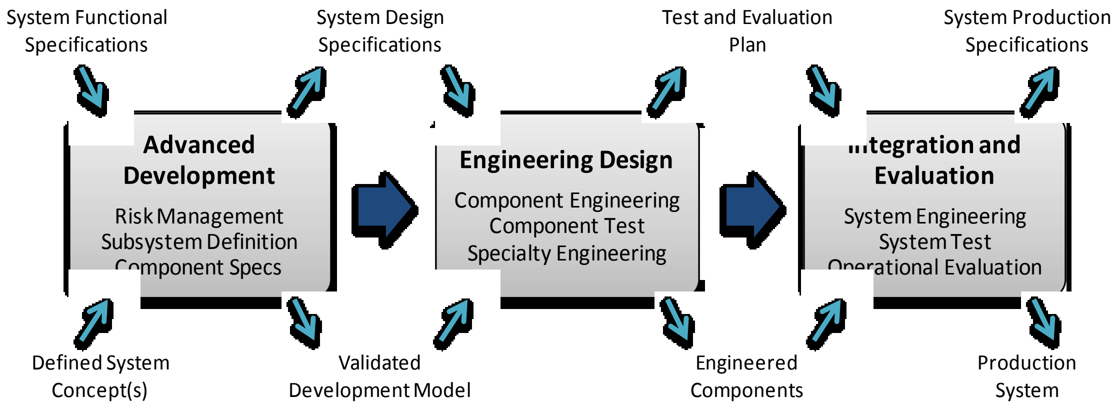


Figure 11: Engineering development phases in a system life cycle (Redrawn from Kossiakoff *et al.*, 2011)

a) Advanced Development Phase

The two primary outputs from this phase are the design specifications and a validated development model, as illustrated in Figure 11 (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Typical activities of this phase include risk management, subsystem definition, and defining the component specifications.

Risk management is a critical component in any system and project. It is done during this phase to provide a validated development model. Four main elements exist in the risk management process, although there are many different techniques of managing risks. These four elements are:

- Risk identification
  - Risks that may affect the system are identified.
- Risk assessment
  - During this step risks are assessed to understand their significance.
- Risk response
  - This step addresses the matter of how to deal with the risk.
- Risk tracking and control
  - Identified risks are documented and monitored.

The subsystems and component specifications are also defined in this phase. To ensure that full-scale engineering can commence with confidence, the definition of the system design and its description must be advanced from a system functional design to a physical system configuration (Kossiakoff, Sweet, Seymour, & Biemer, 2011). It is stated by Kossiakoff *et al.* (2011) that this configuration must consist of proven components that has defined design specifications. Thorough designs of subsystems and their components are especially crucial in new complex systems (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

b) Engineering Design Phase

During this phase the system is engineered in detail. For that reason, this phase is concerned with designing all the component parts so that they will fit together as an operating whole that meets the operational requirements of the system (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Program management planning documents are used and updated throughout this phase (Kossiakoff, Sweet, Seymour, & Biemer, 2011). These documents, the WBS, systems engineering management plan (SEMP), and the test and evaluation master plan (TEMP), are critical to the engineering of a safe and reliable system.

The two primary outputs from this phase are detailed test and evaluation plans and an engineered prototype, as illustrated in Figure 11 earlier. This prototype is a complete set of fully engineered and tested components (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Typical activities of this phase include component engineering and testing, and specialty engineering.

Components are designed and engineered during this phase by implementing the functional designs, defined in the previous stage, as engineered hardware and software components (Kossiakoff, Sweet, Seymour, & Biemer, 2011). These components must have compatible and testable interfaces to obtain test results that are reliable.

Test planning should begin very early given that test equipment requires extensive time to design and build (Kossiakoff, Sweet, Seymour, & Biemer, 2011). After the components are fully engineered qualification testing is performed. This is done to validate the components so that it can be released to integration. It is stated by Kossiakoff *et al.* (2011) that the test tools used must be consistent with the system integration process.

Specialty engineering is performed when issues regarding reliability, producibility, maintainability, and other "ilities", that have been considered in previous phases, arise (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Each issue is taken into account when the engineering process starts. This is done to ensure that all of the systems components accurately implement the functional and compatibility requirements in order to satisfy the issues of specialty engineering (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

c) Integration and Evaluation Phase

During this phase the engineered components of a system are integrated into a functioning whole that will meet all of its operational requirements. The goal is to qualify the system's engineering design for release to be produced and ultimately operated (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This phase can be seen as a separate phase of system development, because its objectives and activities differ from the preceding, engineering design, phase (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The two primary outputs from this phase are the production specifications of the system and the production system itself, as illustrated in Figure 11 earlier. The production specifications, also referred to as the production baseline, are used to manufacture the system. Typical activities of this phase include systems engineering and testing, and operational evaluation of the system.

The systems engineering part of this phase consist of the integration of the system, and defining the test requirements and evaluation criteria (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The activities that test planning consist of are: defining test issues, the scenarios in which the system will be tested, and the test equipment. The construction of complex facilities to evaluate the system's responses may also be required (Kossiakoff, Sweet, Seymour, & Biemer, 2011). The systems engineering process should then also be followed to construct such facilities.

Developmental system testing is done to verify that the system meets its specifications, and to establish if it is capable of meeting the operational requirements (Kossiakoff, Sweet, Seymour, & Biemer, 2011). The test environment should also be realistic and practicable (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Therefore, it is sometimes necessary to construct testing facilities. Effects that are impractical to reproduce should be evaluated by special tests. It is also important to have external inputs that are real or simulated (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

Before any system can be produced on a full scale it needs to be verified and validated through an evaluation within the operational environment, or a sufficient substitute for the operational environment (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

2.3.3.3 The Post Development Stage

The post development stage is the last stage in the life cycle of a system. This stage focuses on the production, installation, operations, and support of complex systems (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The post development stage consists of two phases: *Production and deployment,* and *operations and support.* These phases, their activities and inputs and outputs are illustrated in Figure 12 below, which has a format analogous to Figure 9.

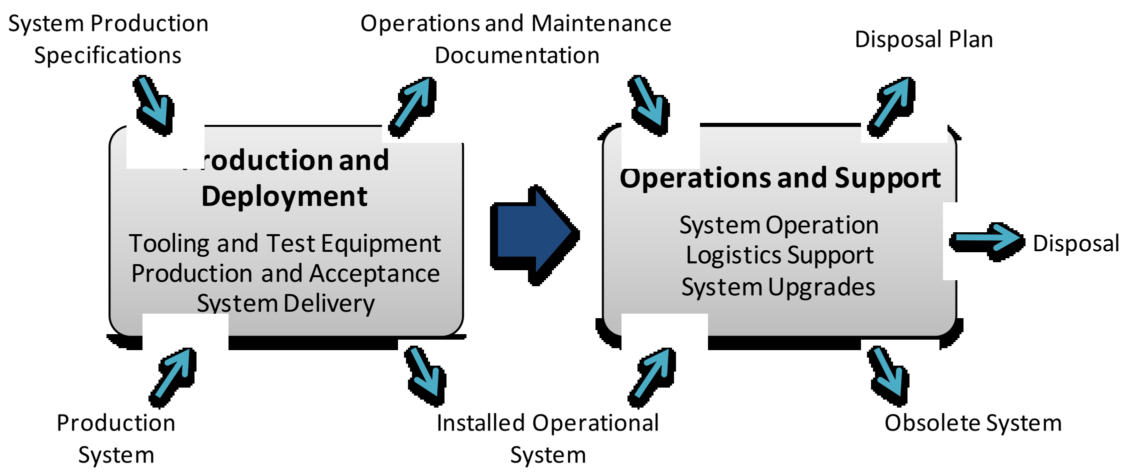


Figure 12: Post development phases in a system life cycle (Redrawn from Kossiakoff *et al.*, 2011)

a) Production and Deployment Phase

The main purpose of this phase is to ensure smooth production and delivery of the system with little problems. However, problems inevitably arise during production (Kossiakoff, Sweet, Seymour, & Biemer, 2011). It is therefore the duty of the systems engineer to minimise these problems. The system engineers should also ensure that the system performs as required, is affordable, and functions reliably and safely as long as required (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The two primary outputs from this phase are the installed operational system and the documentation for the operation and maintenance of the system, as illustrated in Figure 12.

b) Operations and Support Phase

During this phase of the system life cycle the products of the system development and production phases perform their operational functions for which they were designed (Kossiakoff, Sweet, Seymour, & Biemer, 2011).

The primary outputs from this phase are an obsolete system and plans for the proper disposal of the system. Typical activities of this phase include the operation of the system, logistics support and system upgrades.

A system can be operated after it is installed and tested. In practice, the operation of modern complex systems is never without incident (Kossiakoff, Sweet, Seymour, & Biemer, 2011). These incidents lead to scheduled maintenance in order to prevent them. Therefore, proper planning for this phase should be done. This planning includes the provision of a logistics support system and training programs for operators and maintenance personnel.

Most large complex systems prove to be too costly to be replaced in their entirety and therefore are subject to major upgrades as they age (Kossiakoff, Sweet, Seymour, & Biemer, 2011). This involves the installation of new subsystems in the place of outdated ones.

2.4 Risk Management

2.4.1 Background

PMI (2008) formally defines risk management as: "…the process concerned with identifying, analysing and responding to project risk (or uncertainty). It includes the maximising of the results of positive events and minimising the consequences of adverse effects". According to the ISO 31000:2009 risk management comprises of coordinated activities to direct and control an organization with regard to risk. Risk is defined as a combination of the consequences of an event and the associated likelihood (ISO 31000:2009)

The main purpose of risk management is to improve project performance and to achieve the three goals of project management, via systematic identification, assessment and management of project related risks (Fourie, 2011). This will be very beneficial in the development of a model that has a goal of reducing risks in large scale projects.

It is stated by Prasanta (2002) that positive project outcomes are harder to achieve in larger and more complex projects due to the increase in uncertainties. It can be seen in many cases throughout history that this statement is true. Effective and formal risk management processes plays an important role in the successful completion and execution of large projects. It gives a structured mechanism to the project team that provides visibility into the threats that may get in the way of project success (Fourie, 2011). The best way to perform risk management is to make use of a team approach. This will allow the various project stakeholders to collaboratively address their shared risks, and to assign responsibilities to mitigate the risks (Fourie, 2011).

It is important to realise that the management of risks is not just a once off process in project management. This process must be incorporated as part of the life cycle management of a project, which will encourage risk management throughout the entire project. Performing risk management in this manner will ensure that the process is proactive, rather than reactive.

2.4.2 Risk Concepts

Most literature on project risks defines it as an event that has an effect of uncertainty on objectives, i.e. the consequences of an event and the associated likelihood. Risks can also be seen as uncertainties that may have a positive (opportunities) or negative (threats) on the project if they occur (Dinsmore & Cabanis-Brewin, 2006). Therefore, it can be said that risks and opportunities go hand in hand, as illustrated in Figure 13.

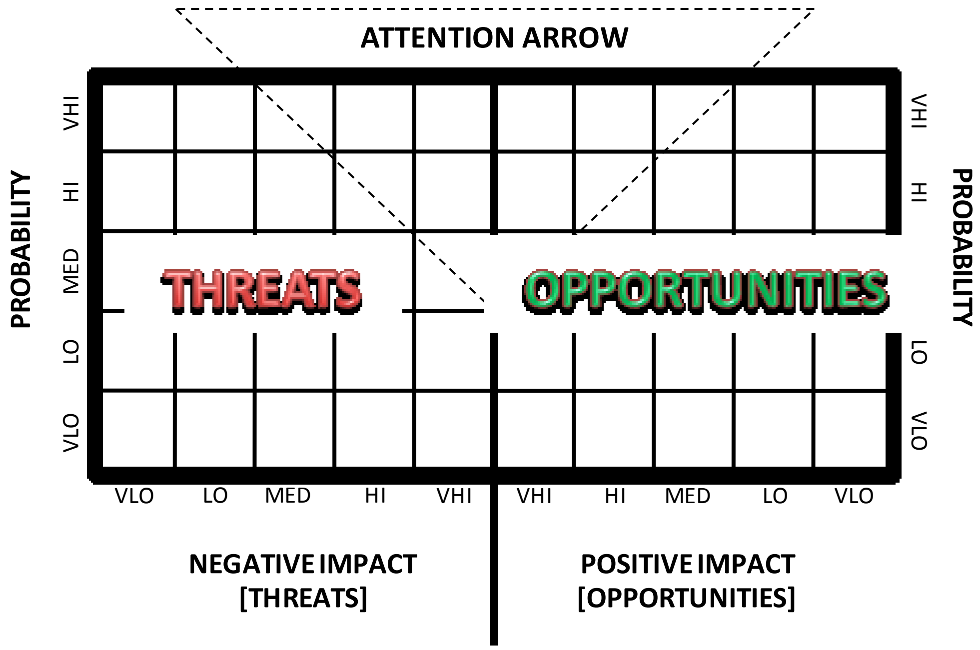


Figure 13: "Mirror" Probability-Impact matrix for threats and opportunities (Redrawn from (Dinsmore & Cabanis-Brewin, 2006))

It can be seen from Figure 13 that attention must be given to an uncertainty when its probability and impact are high. This uncertainty may either be a threat or an opportunity. Due to this PMI (2008) also defines risk management as the process to increase the probability and impact of positive events, and decrease the probability and impact of events adverse to the project. For that reason the aim of the risk process is to handle both threats and opportunities alongside each other (Dinsmore & Cabanis-Brewin, 2006).

2.4.3 Risk Management Process

The risk management process is a systematic application of management policies, procedures and practices to the activities of communications, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk (ISO 31000:2009). This process should form an integral part of management. The steps of the risk management process are shown in Figure 14.

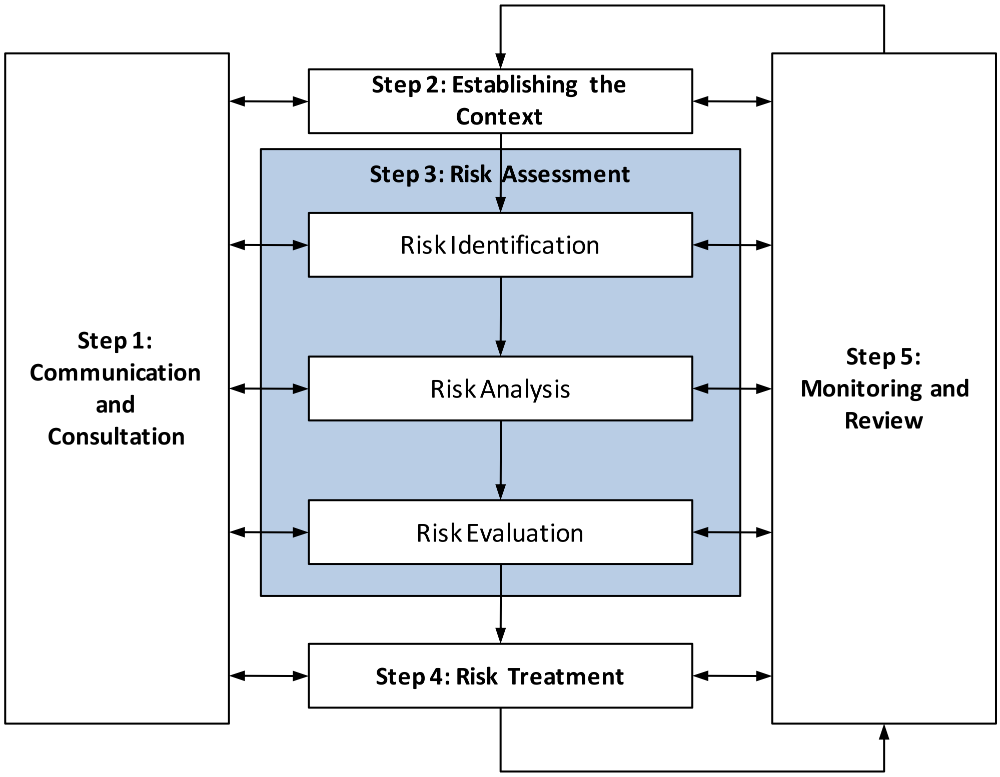


Figure 14: Risk Management Process (Adapted from ISO 31000:2009)

2.4.3.1 Communication and Consulting

The first step of the risk management process is communication and consultation with external and internal stakeholders. This should also take place throughout the entire risk management process, as illustrated in Figure 14. The main reason for this is to ensure that all the stakeholders understand the risk management process, and its related implications, for the entire duration of the process. It is therefore crucial that plans for communication and consultation are developed at an early stage to ensure that the process is effective. These plans should address issues relating to the risk itself, its causes, consequences, and the measure undertaken to treat them (ISO 31000:2009).

2.4.3.2 Establishing the Context

The second step is to plan risk management and to establish the context. This involves decision making on how to approach and conduct the risk management activities for a project (Dinsmore & Cabanis-Brewin, 2006), and defining the external and internal parameters taken into account when managing risk (ISO 31000:2009). This is done to ensure that the scope and risk criteria are defined for the risk assessment step that follows.

A number of factors need to be decided upon before the risk assessment process can begin (Dinsmore & Cabanis-Brewin, 2006). These include:

- Thresholds have to be set on the amount of acceptable risk for the project. This is accomplished by identifying tolerances of key stakeholders, resolving any differences, and communicating the conclusions to the team (Dinsmore & Cabanis-Brewin, 2006).
- Terms used in the qualitative analysis of risk likelihood and consequence have to be defined. The meaning of these terms must be agreed upon in order to provide a consistent framework (Dinsmore & Cabanis-Brewin, 2006).

The output of the risk management process is a risk management plan. This document must be clear on the methods used to identify and manage risks, the resources required to mitigate them, and the assigned responsibilities (Kerzner, 2009).

2.4.3.3 Risk Assessment

The third step is risk assessment. Figure 14 shows that risk assessment consist of three processes:

- Risk Identification
- Risk Analysis
- Risk Evaluation

a) Risk Identification

Risks that are likely to affect the project are identified during this step of the risk management process. Sources of risk, areas of impacts, events and their causes and potential consequences should be identified (ISO 31000:2009). This comprises of a list based on those events that might create, enhance, prevent, degrade, accelerate or delay the achievement of objectives (ISO 31000:2009). This list is commonly known as a risk register. Risk identification can be seen as the most important step in the risk management process, because only the identified risks will be analysed and mitigated against (Dinsmore & Cabanis-Brewin, 2006).Various techniques to identify risks exist. Some of the main techniques are:

- Analogy
- Risk Checklists
- WBS Analysis
- Process Flowcharts
- Ishikawa Diagram (Brainstorming)
- Delphi Technique
- Fault Tree Analysis
- Failure Mode and Effect Analysis

Analogy involves the investigation of records and post completion summary reports of similar projects to identify risks in new, upcoming projects (Nicholas & Steyn, 2008). The experience of the project team is also heavily relied upon when using this technique.

The second technique is the use of information from previous projects to create lists of factors that affect projects. These checklists are created by managers. The more experience they gain with projects, the more they learn about the risks, which in turn will lead to more comprehensive and valid checklists (Nicholas & Steyn, 2008).

The third technique is the analysis of the WBS to identify risks. All of the work packages are inspected for technical and potential problems it may have with management, customers, suppliers, and equipment and resource availability (Nicholas & Steyn, 2008). For each work package internal and external risks are assessed. Internal risks originate inside the project and external risks from sources outside the project (Nicholas & Steyn, 2008).

Examining process flow charts is the fourth risk identification technique. These charts illustrate the steps, procedures, and flows between tasks and activities in a process ((Nicholas & Steyn, 2008). Analysing these charts can pinpoint potential trouble spots and areas of risk.

The fifth technique is to identify risks through collective experience of project team members. They meet in brainstorming sessions to identify possible problems or hazards. These problems and hazards are then recorded on Ishikawa diagrams, as shown in Figure 15 (Nicholas & Steyn, 2008).

The diagram works in the following manner: (1) the project team identifies a potential outcome (effect), e.g. “project completion delay”; (2) potential causes are then identified that may lead to the effect, e.g. “staff shortage”; and (3) the causes can be broken down into more fundamental sources of risk that leads to the cause, e.g. the reason for “staff shortage” may be “inability to hire/train additional staff”.

The sixth technique is the Delphi technique, which comprises of a series of questions regarding risks in the project to which the respondent writes his opinions and reasons (Nicholas & Steyn, 2008). All the opinions, which are kept anonymous, of the respondents are summarised in a report and then returned to them. The respondents then have the opportunity to revise and modify their opinions. Opinions can be changed or not. However, a reason must be given for both of the options. This process continues until a collective opinion is (Nicholas & Steyn, 2008).

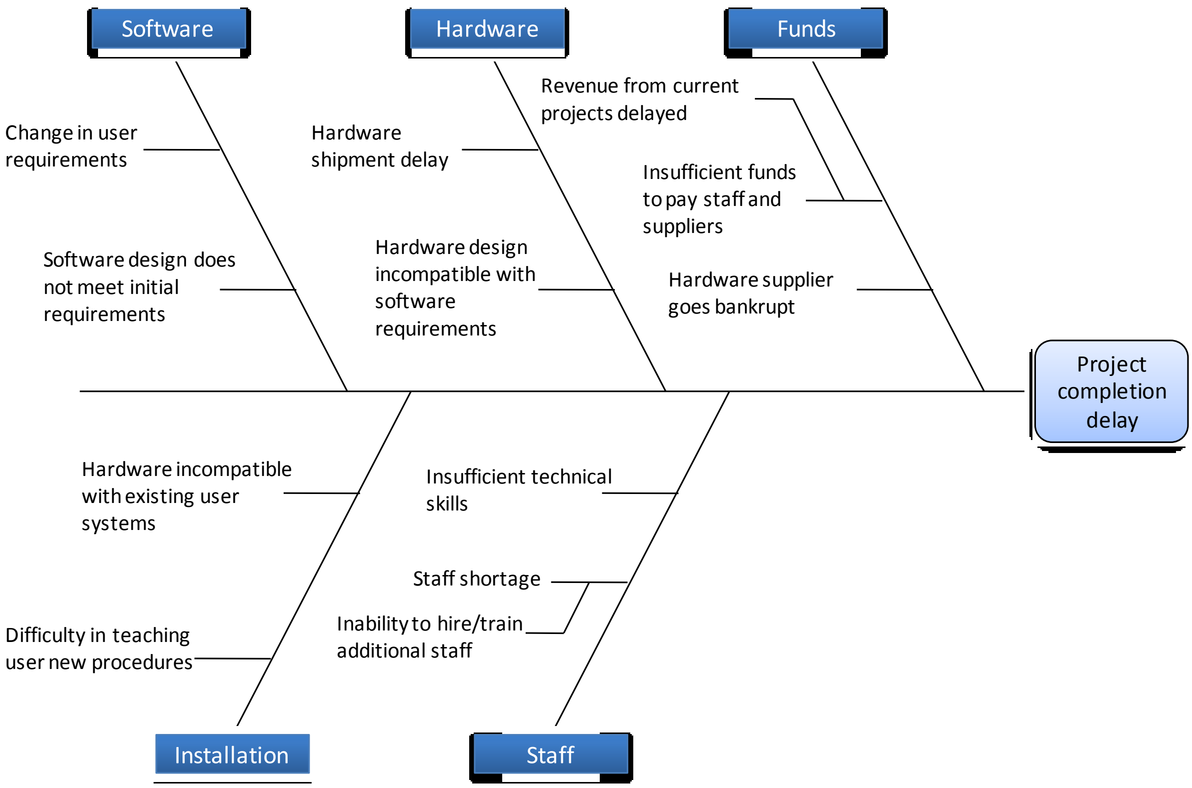


Figure 15: Ishikawa diagram (Redrawn from Nicholas & Steyn, 2008)

Another identification technique is Fault Tree Analysis (FTA). This technique uses a graphical tree-structured notation based on Boolean logic to identify the root causes of a top-level undesired event and to calculate the probability of these (Raspotnig & Opdahl, 2013). Therefore, one top event that may cause failure is identified, and all the situations that could cause this effect are added to the tree. This technique is very similar to the Ishikawa Diagram, because both of them are top-down methods.

The final technique discussed is Failure Mode and Effect Analysis (FMEA). This technique is concerned with analysing potential failure modes of a system and evaluating the possible effects (Raspotnig & Opdahl, 2013). In contrast to FTA, the FMEA technique is a bottom-up technique. It is good practice to apply both top-down and bottom-up techniques during the identification of risks, because risks may be identified in the one that were not identified in the other.

b) Risk Analysis

The purpose of the risk analysis is to develop an understanding of the identified risks. This step provides an input to risk evaluation and to decisions on whether risks need to be treated, and what strategies should be used (ISO 31000:2009). Risk analysis also considers the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. These risks are assessed to obtain quantifiable figures for their likelihood and consequences. The methods used to do this should be established in the second step of the risk management process. A quantitative and qualitative method is described here.

i) Risk Likelihood

The likelihood of an identified risk eventuating are determined. This can either be expressed as a numerical value between 1.0 (certain to happen) and 0 (impossible) or as a qualitative rating such as high, medium, or low. An example of determining the likelihood is given in Table 4.

ii) Risk Consequence

Secondly, the consequences the risk may have on the project, if it eventuates, are determined. Again, this can either be expressed as a numerical value between 1.0 (catastrophic) and 0 (not serious) or as a qualitative rating such as high, medium, or low. An example, which demonstrates the use of numerical and qualitative ratings, is given in Table 5 on the following page. It can be seen from this table that risk impact is specified in terms of time, cost and performance.

Table 4: Likelihood ratings

Title	Score	Description
Very Low	0-20	It is highly unlikely that the identified risk will occur. However, it still needs to be monitored as certain circumstances could result in the risk occurring.
Low	21-40	It is unlikely that the identified risk will occur, because the circumstances likely to trigger the risk are also unlikely to occur.
Medium	41-60	It is likely that the identified risk will occur
High	61-80	It is very likely that the identified risk will occur based on the circumstances of the project.
Very High	81-100	It is highly likely that the identified risk will occur, because the circumstances which will cause the risk to eventuate are also very likely to occur.

Table 5: Consequence ratings

Title	Score	Description
Very Low	0-20	The consequence it has on the project is insignificant. It is not possible to measure the impact.
Low	21-40	The consequence it has on the project is minor, e.g. <5% deviation in scope, scheduled end-date or budget.
Medium	41-60	The consequence it has on the project is measurable, e.g. 5-10% deviation in scope, scheduled end-date or project budget.
High	61-80	The consequence it has on the project is significant, e.g. 10-25% deviation in scope, scheduled end-date or project budget.
Very High	81-100	The consequence it has on the project is major, e.g. >25% deviation in scope, scheduled end-date or project budget.

c) Risk Evaluation

Risk evaluation involves the comparing of risk priorities, based on the outcomes of the risk analysis (ISO 31000:2009). After this assessment it can easily be seen which risks are the most significant. The output of this phase is a risk rating (priority score), which is used in the risk treatment step of the risk management process. Normally the risks that have the highest rating must be mitigated first. It should be remembered that all terms used in the rating of risks have to be defined clearly during the second step of the risk management process.

Determining the risk priority depends on the risk rating criteria used during analysis. For the examples used the priority can be calculated with the following equation:

$$\text{Priority} = (\text{Probability} + \text{Impact})/2 \qquad (2.9)$$

An example of priority scores is showed in Table 6. A colour-coded system is used to highlight the risks which require the most attention. This is as follow:

Priority Score	Priority Rating	Colour
0 – 20	Very low	Blue
21 – 40	Low	Green
41 – 60	Medium	Yellow
61 – 80	High	Orange
81 – 100	Very High	Red

Table 6: Priority Ratings

Risk ID	Probability Score	Impact Score	Priority Score	Priority Rating
1.1	20	20	20	Very Low
1.2	40	20	30	Low
2.1	60	40	50	Medium
2.2	80	60	70	High
3.1	100	80	90	Very High

2.4.3.4 Risk Treatment

The fourth step in the risk management process is risk treatment. During this step one or more strategies are identified, evaluated, selected and implemented in order to get an identified risk to an acceptable level (Kerzner, 2009). This includes:

- What should be done;
- Who is responsible;
- When should it be accomplished; and
- The cost involved.

Five risk treatment strategies exist, which are described in Table 7. These treatments provide or modify the controls, once implemented. Risk treatment involves a cyclical process of assessing risk treatment and deciding whether residual risk levels are tolerable, or not (ISO 31000:2009). If it is not tolerable a new risk treatment should be generated and the effectiveness of it should be assessed.

Advantages and disadvantages in the selection of a risk treatment strategy should also be considered. This involves balancing the costs and effort of implementation against the benefits derived, with regard to legal, regulatory, and other requirements (ISO 31000:2009). The values and perceptions of all stakeholders, and the most appropriate ways to communicate with them, should also be considered (ISO 31000:2009).

Table 7: Risk treatment strategies

Strategy	Description
Transfer risk	Risk can be transferred partly between the customer, contractor, or other parties using contractual incentives, warranties, penalties, or insurance policies
Avoid risk	A risk can be avoided by eliminating its source by altering the original concept, changing contractors, incorporating redundancies, safety procedures, etc.
Reduce risk	Reduce risks by being thorough and using the best team. Hire outside specialists for critical review and assessment of work.
Contingency planning	Study possible “what-if” scenarios for a risk and develop a plan for each.
Accept risk	Not every risk has a fatal impact. If the cost of avoiding, reducing, or transferring the risk is estimated to exceed the benefit, then “do nothing” might be the best alternative.

2.4.3.5 Risk Monitoring and Control

The final step in the risk management process is the monitoring and review of the identified risks. Monitoring and review processes should encompass all aspects of the risk management process for the purposes of ensuring that controls are effective and efficient in both design and operation, obtaining further information to improve risk assessment, analysing and learning lessons from events (including near-misses), changes, successes and failures (ISO 31000:2009). The project should also be continuously monitored for trigger symptoms of previously identified risks and for symptoms of risks newly emerging that were not previously identified (Nicholas & Steyn, 2008). It must be remembered that the monitor and review processes should also take into account the detection of changes in the external and internal context, including changes risk criteria and the risk itself (ISO 31000:2009). Changes like these will require a revision of the risk treatments and priorities.

The results of monitoring and review should be recorded. This is normally done by using the risk register that was developed. In this register it must be stated how the risks were mitigated, if it was successfully mitigated, and what strategies were used. If a risk is properly mitigated it must be indicated in the risk register that it is closed.

2.4.4 Project Management Risks

Many risks can be associated with a phase in the life cycle of a project. This is illustrated in Figure 16 on the next page. Risks that are present in each phase of the project (i.e. conception, definition, execution and closure) must be identified. It is agreed upon in literature that as the project progresses through the phases, the amount of risk in the project decrease and the financial value at stake increases.

The purpose of the research reported in this document, as discussed in Chapter 1, is to reduce process related PM risks by using SE principles. Major risks, identified from literature that may lead to unsuccessful projects, are identified below for each phase. These identified risks will later on be used in a survey to determine if they are as important as stated here. Many other PM risks also exist, and each of them should also be managed properly. Examples of them are mostly external factors such as physical conditions, local governments, relationships with suppliers and contractors (Stewart & Fortune, 1995). However, it is assumed that they are less important than process related risks and therefore they will not be included in the survey.

2.4.4.1 Conception Phase Risks

The first and probably one of the most important risks in the conception phase is poor definition of customer requirements and problem (Ferreira & Faezipour, 2012). This is mainly due to not knowing precisely what the customer wants. (Centerline Solutions, 2005). Other factors that contribute to poor requirements definition are lack of customer involvement and poor communication. Lack of customer involvement has proved fatal for many projects in the past (Coley Consulting, 2012). Customers should be involved in a project from the beginning. This will allow for accurate definition of requirements, which will keep the customer happy. Secondly, communication with the customer must be clear and unambiguous. It must be ensured that the customer is up to date with the progress of the project.

The second risk is the unclear definition of project objectives. The project team must be clear on the objectives from the start of the project. If not, it may lead to two other risks; poorly defined deliverables and inaccurate estimates. Poorly defined deliverables may pose problems on not knowing precisely when a project is finished (Centerline Solutions, 2005). Causes of this may be that the milestones and deliverables were not measurable or poor communication with the customer. The second risk, inaccurate estimates, poses problems with agreement on unrealistic timelines and budgets (Centerline Solutions, 2005). This will lead to the problem that the work will not be completed within the allocated time.

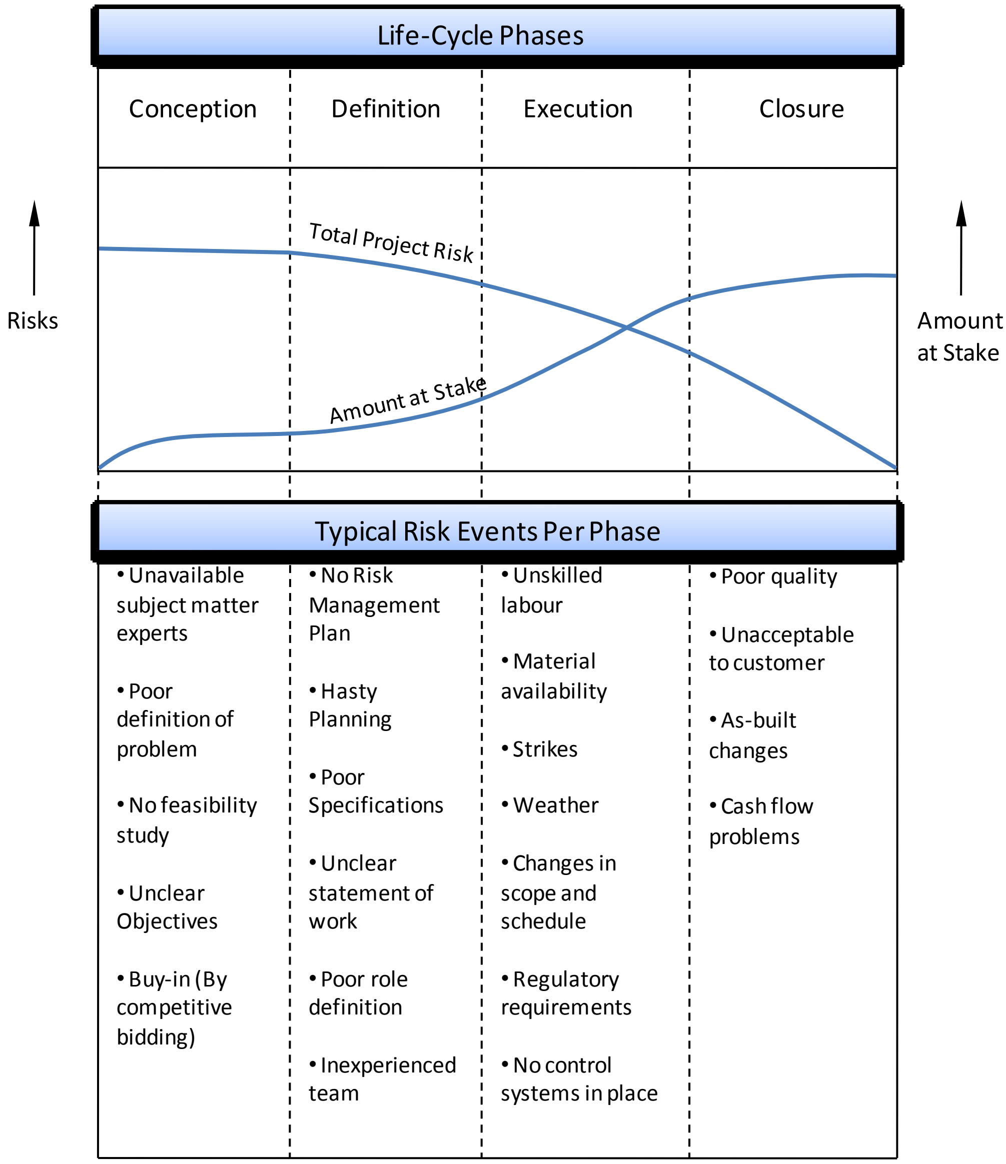


Figure 16: Project life cycle risks

The final major risk of the conception phase is not to perform a feasibility study. Feasibility studies are performed to determine if the project is worth pursuing and to investigate the possible alternatives (Nicholas & Steyn, 2008). If this study is not performed projects may be planned and executed with an infeasible solution that uses inadequate resources, which may lead to an unsuccessful project.

2.4.4.2 Definition Phase Risks

The definition of poor specifications is a big risk during the definition phase. This may be carried over from the conception phase due to poor definition of customer requirements, or the project team may be inexperienced and did not do a sufficient job. Problems with this risk may be that deliverables are of poor quality and to not meet the requirements of the customer (Ferreira &

Faezipour, 2012). To avoid this, the team must ensure that sound methods are followed to obtain specifications from the customer. These methods are discussed in Section 5.2 of this document.

Hasty and poor planning is another threat to the success of a project. This may lead to an unclear statement of work, and ultimately to poor role definition. It can also lead to inaccurate cost estimation, schedule overruns and lack of process discipline (Ferreira & Faezipour, 2012). To avoid this, management must ensure that the project team has sufficient time to perform the planning of the project. The main output from the definition phase is the project master plan and this plan must be completed thoroughly before the execution phase of the project can begin.

2.4.4.3 Execution Phase Risks

Poor communication between team members is a big risk in the execution of projects. The problem that arises with this is that team members do not have the proper information on what to do and when (Centerline Solutions, 2005). Causes of this are that a proper communications plan was not completed with enough detail during the definition phase.

Another big risk is the lack of change management. Changes will almost always occur in the duration of a project, which may lead to scope creep. The problem with this is that when no change management processes are implemented, projects can become longer and cost more without knowing why (Centerline Solutions, 2005). To solve this problem the project team must create a comprehensive change management plan during the definition phase of the project. Other changes that are unforeseen, but must be planned for, are changes in the environment, workforce (strikes), weather and material availability.

Inadequate resources are also a risk. This is when you do not have enough resources, lack of continuity in project staffing, lack of senior management commitment, inexperienced resources or a project team that is not committed to the project (Ferreira & Faezipour, 2012). These risks may lead to problems such as tasks that take longer to complete, deadlines and milestones missed and ultimately overworking resources to complete tasks on time (Centerline Solutions, 2005). To avoid these problems management must ensure that the correct resources are hired and that the project is supported fully (Centerline Solutions, 2005).

Another problem in projects is poor risk management. As stated earlier, effective and formal risk management is essential in the successful completion of a project. The overlooking of some risks for whatever reason may prove to be costly. To avoid this, the project team must create a comprehensive risk management plan in the definition phase, and management must ensure that it is adhered to in the execution phase.

The last major risk in the execution phase is not to have any control systems in place. Inadequate control over the project will lead to a failed project. To avoid this, management processes must be set in place to monitor the project. These processes are typically the management of time, costs, quality, changes, risks, issues, procurement, testing, customer acceptance and communication.

2.4.4.4 Closure Risks

Not planning for termination can pose as a major risk during the closure phase. If this planning is not performed it may be extremely difficult to decide when to terminate a project (Fourie, 2011). This may prove to be costly in terms of time and cost. Work orders stay open and labour charges continue to accumulate if a project has not been officially terminated (Nicholas & Steyn, 2008).

Another risk is the loss of enthusiasm and eagerness of the team members at the end of a project, which may lead to little attention given to termination. This should be avoided, because terminating a project is no less important than any other project activity (Nicholas & Steyn, 2008). One way to avoid this is for the project manager to inform team members of the importance of termination.

Poor quality that leads to an unacceptable end-item is also a risk. The main reasons leading to this are a project team that did not follow plans correctly and control systems that were inadequate. This may lead to cash flow problems, because the customer is unhappy and will not pay for the product.

2.5 Integration

Due to the complexity of modern day projects a need exist for careful process control over activities, as well as a formalised communication process and detailed planning. This can be achieved by integrating principles of SE into PM. SE, as discussed in sections 2.3 and 2.5, holds many benefits that may improve PM. The main benefits are the holistic nature of SE and that it is systematic and structured. Furthermore, risk management is also a very important process in the success of a project. As with SE, risk management is a systematic and structured approach that contributes to efficiency and to consistent, comparable and reliable results (ISO 31000:2009).

The integration of PM, SE, and risk management is researched in this section. The differences and similarities, benefits of integrating, and gaps for the three fields are researched in this section.

2.5.1 Differences and Similarities

The main similarities are that both PM and SE plan for producing a product or service, and both conduct a stakeholder analyses (Baldwin, 2010). Furthermore, they also account for scope, time, cost, quality, risk, and human resources to complete a project (Baldwin, 2010). Other similarities and processes used by both disciplines are shown in Table 8.

Table 8: Similar processes used in both project management and systems engineering (Adopted from Baldwin, 2010 and Zipes)

Similar Processes
Project Planning
Project Assessment
Project Control
Risk and Opportunity Management
Configuration Management
Information Management
Resource Management
Quality Management
Acquisition
Supply

The first difference between the two disciplines is that PM is accountable for the success of the entire program and all aspects of it, whereas SE is responsible for the technical success of the program (Baldwin, 2010). It is stated by Kapsali (2011) that PM is treated as an 'island', with closed boundaries that rely upon prescribed formulae to manage boundary relations and change through formalised communications and procedures. Therefore, the purpose of traditional PM is to identify tasks and sequence them in a timeline. This relies on the specification being well-defined at the outset, and the existence of a well-defined solution path where the individual tasks can be anticipated at the initial planning phase. This narrow emphasis is an obstacle to producing an explanatory and predictive framework for complex and innovative projects (Kapsali, 2011). Furthermore, traditional PM cannot cater for the practice and theorising of project innovativeness, because of its weakness to deal with different levels of uncertainty and complexity (Kapsali, 2011). The reason for this is that uncertainty and complexity of project activities make control more difficult, which may lead to plans deviating more often. Plans in conventional PM are formulated for a set of contingencies that cannot be preconceived, because they have no precedent. Due to these deficiencies in PM, it is worthwhile looking into SE to improve PM processes.

SE differs from PM in the sense that it follows a more holistic approach to solve complex problems, by organising the interconnections between the elements of a system. This approach caters for innovativeness, which is defined as the level of novelty or originality by virtue of introducing new ideas or innovations (Kapsali, 2011). Most modern projects are complex and innovative. These projects have a heavy dependence on interaction and communication, which is inherent to SE. Another difference between SE and PM is the rationale behind SE. It does not assume decomposition and predictability of project related activities, which is the case in PM.

Differences between the SE and PM processes are shown in Table 9. The most important differences in this table are that SE focuses more on requirements management and customer involvement during projects. These two principles are very important in the success of a project, as discussed above.

Table 9: Differences between project management and systems engineering (Adopted from Baldwin, 2010 and Zipes)

Project Management	Systems Engineering
Communication Planning	Functional Analysis
Team Building	Requirements Management
Procurement Management	Interface Management
Enterprise Environment Management	Architectural Design/Synthesis
Investment Management	Implementation
	Integration
	Verification
	Operation
	Maintenance
	Customer Involvement

Risk management is dynamic, iterative and responsive to change (ISO 31000:2009), which is similar to SE. Another positive principle of risk management is that it takes human and cultural factors into account, by continuously executing proper communication and consultation with internal and external stakeholders (ISO 31000:2009). This is also similar to SE in the way that the customer is involved in the decision making process. It will therefore be beneficial to use these principles of risk management in PM.

2.5.2 Benefits of Integration

Several benefits of SE principles were listed in subsection 2.3.1. All of these can be beneficial to the improvement of PM. Using SE principles in PM will enforce systems thinking. This way of thinking will allow for an understanding of the complicated relationship between various socio-technical factors (Ferreira & Faezipour, 2012). SE principles also accepts the social as equal to the technical, uncertainty and complexity of managing tasks, planning and control (Kapsali, 2011). Therefore, customer involvement is a very important principle of SE. Other advantages of integrating SE principles into PM are (Kapsali, 2011):

- SE suggests different levels of analysis and synthesis for different problems, i.e. from the activity to the supra-systemic.
- SE complements reductionism, analysis, cause and effect thinking, synthesis, and indeterminism (emergence and probabilistic thinking).
- SE is a conceptual framework which can utilise different theories, tools and techniques to help construct holistic, contingent perspectives and practices.

The holistic nature of SE, in effect, paints a picture of the behavior of an entire system over time. This allows for a more condensed frame of communication (Kapsali, 2011) that emphasises interconnectedness (Stewart & Fortune, 1995). This may be beneficial to PM if it is used to examine the standard parameters of a project, e.g. objectives, inputs, planned activities, outputs, etc. Furthermore, the holistic approach can also benefit aspects regarding risk management in the following two ways (Stewart & Fortune, 1995):

- Interactions: Such as those between the project and its operating climate and wider environment, and those within the project team and between the team and its clients.
- Human aspects: Such as conflicts of objectives, motivation problems and poor communication. These conflicts may threaten the success of a project on their own.

Risk management has similar attributes to that of SE, as discussed earlier. Its dynamic and iterative principles allows for the continuous detection and response of changes. It also recognises the capabilities, perceptions and intentions of external and internal people that can facilitate or hinder the success of a project. Furthermore, risk management is transparent and inclusive, which allows for the involvement of stakeholders, as with SE. This allows stakeholders to be properly represented and to have their views taken into account in determining the risk criteria (ISO 31000:2009). Again, this emphasise the importance of customer involvement.

2.5.3 Gaps

From the research on PM and SE it is obvious that tools that uses these holistic SE principles in PM do not exist. Therefore, research should focus on the creation and utilisation of specific tools and techniques under specific situations.

An example of such a tool is the use of simulators in SE processes. Very little research has been performed that considers the use of simulation to support SE related projects. This field of study requires SE simulation models that may provide a valuable means to understand and learn important concepts related to SE (Ferreira & Faezipour, 2012). Using simulators will allow the user to view a system's dynamic over time without having to build, interrupt or affect it (Ferreira & Faezipour, 2012). The research done on simulation is mainly focused on SE, but may be very beneficial in the future for PM. This is mainly due to the fact that projects are becoming much more complex, which requires more systems thinking rather than conventional PM thinking.

2.6 Chapter Conclusion

In this chapter three fields of studies were reviewed; PM, SE and risk management. The basic principles of each field were researched to obtain a background into the methodologies of them.

The aim of the first part of the literature study (Section 2.2) was to determine if a need exists for improved PM in large scale projects. It was discussed that many projects fail to meet the three goals (time, cost and performance) due to complexity of modern day projects. Other reasons were the failure of managing risks, inadequate articulation of requirements and inadequate technical skills. From these findings, a conclusion is drawn that a need exists to improve PM. This will be accomplished by integrating SE principles into PM.

The second part of the literature study (Section 2.3) investigated the field of SE to determine if it will be possible to use the principles of this field to improve PM. A background of SE principles in general was given. It is concluded from this discussion that the principles of SE hold many benefits that may improve PM.

Risk management was investigated in Section 2.4. The aim of this section was to determine if risk management is essential to the success of projects. It was discussed that formal and effective risk management processes plays an important role in the success of a project. Another important aspect of risk management was that it should be implemented throughout the entire life cycle of a project. It is concluded from this section that risk management will be very beneficial in the development of a model that aims to reduce risks in large scale projects. Major risks that may lead to unsuccessful projects were also identified during this section. These risks will be used in a survey to determine which of them are the most important. This investigation is discussed in Chapter 3.

The integration of the three fields researched in the literature study is discussed in the final section (Section 2.5) of the literature study. Differences and similarities, benefits of integrating, and gaps in the researched literature were discussed. It is concluded from the review that PM and SE are two tightly intertwined domains, but differences do exist. The main difference is that SE follows a more holistic approach that caters for innovativeness, whereas PM depends on detailed solution-plans and well-defined specifications from the start. SE emphasise the importance of requirements management and customer involvement. These two SE processes can also be beneficial to PM. Therefore, it is concluded that SE principles will improve the application of PM.

3. Research Methodology

3.1 Chapter Introduction

According to Denscombe (2010), research requires a strategy or action plan designed to achieve the desired objectives. Furthermore, Denscombe (2010) stated that a strategy requires the following:

- A research paradigm that provides an overview of the whole project as a basis for deciding how to approach the research.
- The research design that outlines the plan of action to achieve the research objectives.
- A research problem or hypothesis that provides a specific goal(s) to be achieved.

This chapter starts with the research paradigm, which is a summary of the applicable facts and findings of the literature review. After the paradigm, the research problem and objectives are discussed. The following step is to outline the design and methodology for the research and development of the model. The formation of the research hypothesis is the final result of this chapter.

3.2 Research Design

3.2.1 Paradigm

Project management (PM) is defined as the management of project activities and processes to complete a system of tasks that meet the requirements of the customer. These requirements must be met within the three interrelated goals of PM, which is to complete the work for the customer or end-user in accordance with budget, schedule, and performance requirements.

The management of project risks is very important due to the link between risks and project objectives. Risks can also be seen as uncertainties that may have a positive or negative impact on the project if they occur. The aim of risk management is to identify those uncertainties, assess them, and develop actions to stop or minimise them.

The literature study discussed in Chapter 2 aimed to answer various questions in order to understand the research paradigm of this thesis. These questions are:

- Is the management of large scale projects successful?
- Is risk management essential in project management?

- Are there similarities or differences between project management and systems engineering?
- Will the integration of SE principles into PM enhance the application of PM?
- Will the integration lead to a more systematic PM approach?
- Will the integration reduce process related risks in large scale projects?

Is the management of large scale projects successful?

The complexity of large modern day projects poses many risks and may lead to the failure of projects. This is mainly due to its technical complexity, which requires a greater diversity of skills. (Nicholas & Steyn, 2008).

It was discussed in the literature study that many projects fail. The reasons for this were the failure of managing risks, inadequate articulation of requirements and inadequate technical skills. It was also discussed that proper project planning plays a very important role in the success of a project. Three studies were compared and they all showed that problems exist in PM, because the percentages of project failures are very high. Due to this, a need exist for more efficient project management methods.

Is risk management essential in project management?

Risks and opportunities go hand in hand. It was discussed that attention must be given to an uncertainty when its probability and impact are high. This was due to the fact that it may either be a threat or an opportunity.

The main purpose of risk management is to improve the performance of a project by identifying, assessing and mitigating project related risks. Prasanta (2002) stated that it is harder to complete projects successfully the larger and more complex they get. Effective risk management will increase the chances of large projects being successful. However, it must be ensured that it is continuously performed throughout the entire life cycle of the project.

Are there similarities and/or differences between project management and systems engineering?

PM and SM are two tightly intertwined disciples. However, differences and similarities do exist. The main similarities are that both PM and SE plan for producing a product or service, and both conduct a stakeholder analyses. The major difference between the two is that SE utilises a holistic approach that caters for innovativeness, whereas PM depends on well-defined specifications and solution-path from the start of the project.

The outcome of this research was that there are processes used by SE, and not PM, which may be beneficial to the improvement of PM.

Will the integration of SE principles into PM enhance the application of PM?

The narrow emphasis and predictive framework of traditional PM is an obstacle in completing complex projects successfully. Using SE principles in PM will enforce systems thinking. This way of thinking will allow for an understanding of the complicated relationship between various socio-technical factors, i.e. hardware, software and human feelings, emotions, etc. Many benefits of SE and the integration of the disciplines were listed in subsections 2.3.1 and 2.5.2. It was concluded that these benefits will enhance the application of PM.

Will the integration lead to a more systematic PM approach?

SE is an iterative process and systems are developed in a step-by-step manner. After each step, it is determined if it is feasible to move on to the next (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Another factor is that SE uses specific methodologies to produce a product or service. This ensures that work is done thoroughly and that no corners are cut. These principles are very beneficial and may increase the likelihood of project success, if used correctly. Using these principles will lead to a more systematic PM approach being followed.

Will the integration reduce process related risks in large scale projects?

The discussions in the literature study showed evidence that the integration will reduce process related risks in large scale projects. Certain SE principles can be applied in PM that will reduce risks. However, this question can only be answered with confidence after the investigations conducted in the Chapters that follow, and upon validation of the model.

3.2.2 Problem

Risks are high in modern day projects due to the complex nature of these projects. Many projects also fail to meet the three goals of PM, as discussed in the literature study. Due to this, a need exist for more efficient PM methods. These methods should be beneficial to the project manager with regards to the coordination and planning of a project to ensure its completion within the time, budget and quality constraints.

The application of SE principles is not used in normal project management. For this purpose, a model will be developed that illustrates the integration of SE into project management. However, due to enormity of the three fields researched, and the evidence in the literature study that project planning is very important, only the first two phases of a project will be investigated and improved with SE principles. Engineers and their project teams will be able to use this tool to enhance the management of projects. It will be a generic tool that can be used for any project.

3.2.3 Objectives

The research of this thesis has three main objectives:

1. The first is to understand the processes and principles of PM, SE and risk management.
2. The second objective is to identify areas of greater risk within the management of projects. The idea behind this objective is to use the principles of SE to reduce those identified risks.
3. The last objective is to develop an effective generic model that illustrates the integration of SE principles into PM. The aim of the model is to reduce risks in projects.

3.3.3 Design

The thesis is divided into six phases, as illustrated in Figure 17 on the next page. Each of these phases is discussed below. The purpose of the first three phases is data collection by means of various research methods.

The first phase is a literature study in which PM, SE and risk management is researched. The literature study has two objectives. The first is to obtain insight into the methodology and principles of the three disciplines. Secondly is to confirm that PM is not successful and that the principles of SE and risk management can be used to improve the success rate.

Phase two is the investigation of various SE approaches and strategies. The aim of this research is to identify certain SE approaches and strategies that can be used in the development of the PM model. This research is conducted In Chapters 4 and 5.

In phase three data are collected in the form of a questionnaire that is sent out to experts in the industry. The aim of this questionnaire is to collect expert opinions to assess the importance and validity of identified process related project management risks. The goal of this risk investigation is to determine which processes in PM pose the highest risk.

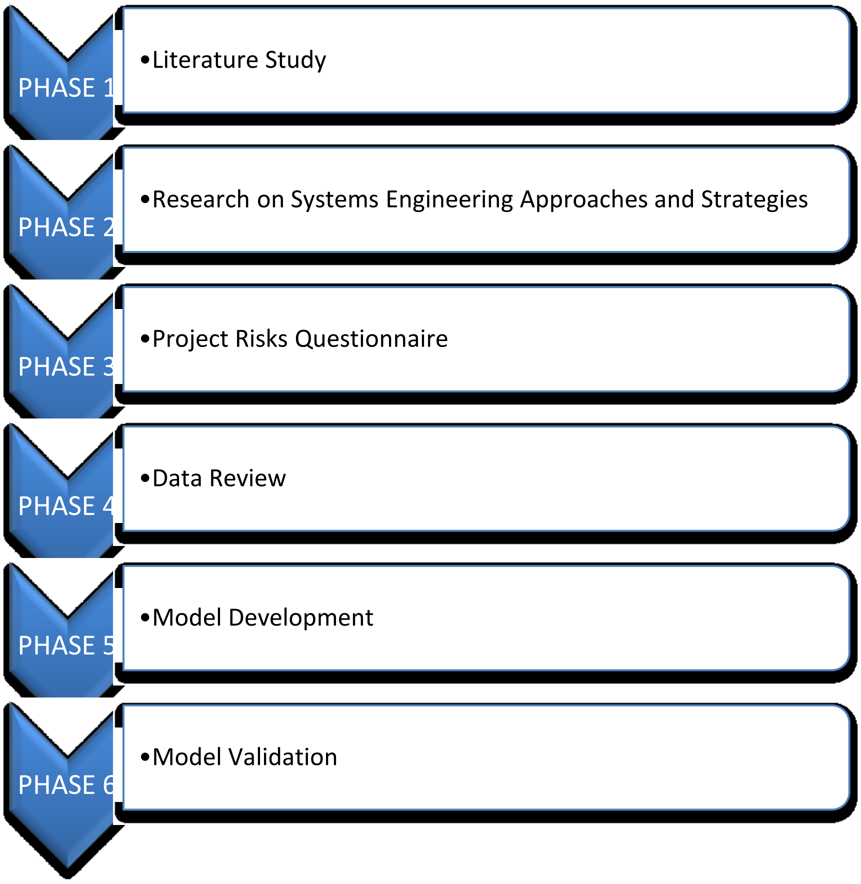


Figure 17: Research Design

The fourth phase entails the review of the data that are collected from the PM risks questionnaire. From this review it will be clear which areas in project management are the most risky.

Phase five entails the development of the model. The aim of the model will be to integrate the principles of SE into PM to illustrate the integration of SE principles into PM, and to reduce the risks identified in phase four.

The last phase is the validation of the model. It will be validated by experts in the industry. They will go through the model, test it and complete a review questionnaire. The purpose of this validation is to see if the objectives of the research were met, and if the model is valid in the sense of ease of use and usefulness. The final objective of the validation process is to determine if the integration of systems engineering (SE) principles into project management (PM) were successful, and if it will reduce risks in large scale projects.

3.3 Research Hypotheses

From the statements made in this chapter the following hypotheses are made:

1. The application of SE principles in PM will result in a more systematic approach; and
2. The integration of SE principles into PM will reduce risks in large scale projects.

3.4 Chapter Conclusion

The background and motivation, as well as the identified researched problem, for the initiation of the research were provided in this chapter. Furthermore, the research design followed for developing the PM integrated with SE principles model was also discussed.

4. Systems Engineering Approaches

4.1 Chapter Introduction

Various approaches and methodologies exist to develop a system. They can be seen as concrete models used to develop a system. Various methodologies were researched to determine which of them can be used in the development of the model.

4.2 Useful Systems Engineering Methodologies

4.2.1 Waterfall Model

The Waterfall Model is the earliest structured development model (Green & DiCaterino, 1988). Figure 18 illustrates that this model divides a project into linear sequential phases. This model is mainly seen as linear. However, some overlap and feedback are acceptable between the project phases. Although the Waterfall Model has been used extensively over the years, it is not without problems (CMS, 2008). The following advantages and disadvantages are given by CMS (2008):

4.2.1.1 Advantages

- Ideal for less experienced project managers and teams, or project teams whose position fluctuates.
- It has an orderly sequence of development steps and strict controls to ensure adequate documentation and design reviews. This helps to ensure good quality, reliability, and maintainability.
- The progress of the system development is measurable.
- It conserves resources.

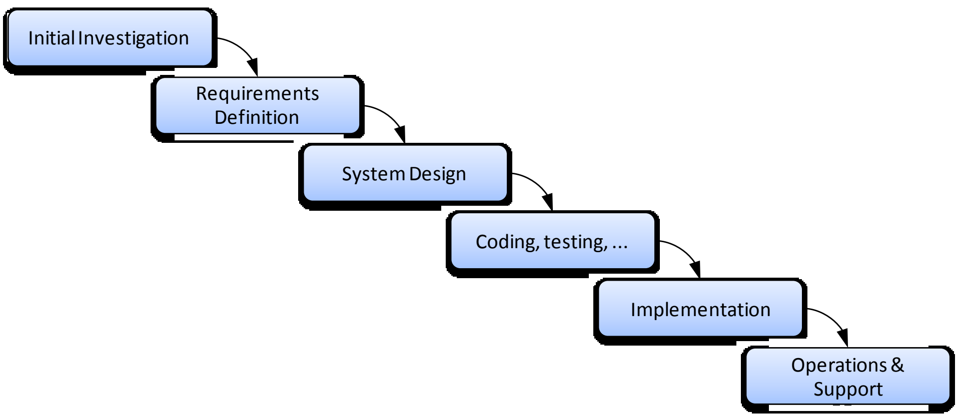


Figure 18: Waterfall model (Redrawn from CMS, 2008)

4.2.1.2 Disadvantages

- It is inflexible, slow, and costly due to the significant structure and tight controls.
- The project progresses forward, with only slight movement backward.
- Depends on early and clear identification and specification of requirements, which may not always be possible.
- Requirement inconsistencies, missing system components, and unexpected development needs are often discovered during design and coding.
- Problems are often not discovered until testing which is late in the system life cycle.
- It is difficult to respond to changes, because the changes occurring later in the life cycle are more costly.

CMS (2008) also listed the situations where this method is the most appropriate:

4.2.1.3 Situations Where Most Appropriate

- When the project is large, expensive, and complicated.
- If the project has clear objectives.
- If pressure does not exist for immediate implementation.
- If the project requirements can be stated unambiguously and comprehensively.
- The project requirements must be stable or unchanging during the life cycle of the system.
- Strict requirement exist for formal approvals at designated milestones.

4.2.2 V-Model

The main purpose in the design of the V-model was to simplify the understanding of designing complex systems (G2SEBoK, 2004). It is stated by INCOSE (2004) that the V shape is created by the concept of an evolving baseline that progressively increases in depth, as seen in Figure 19. Other factors contributing to the shape are change control and the fact that every stage is reviewed. The left leg of the V represents the Decomposition and Definition and the right leg represents Integration and Verification (G2SEBoK, 2004).

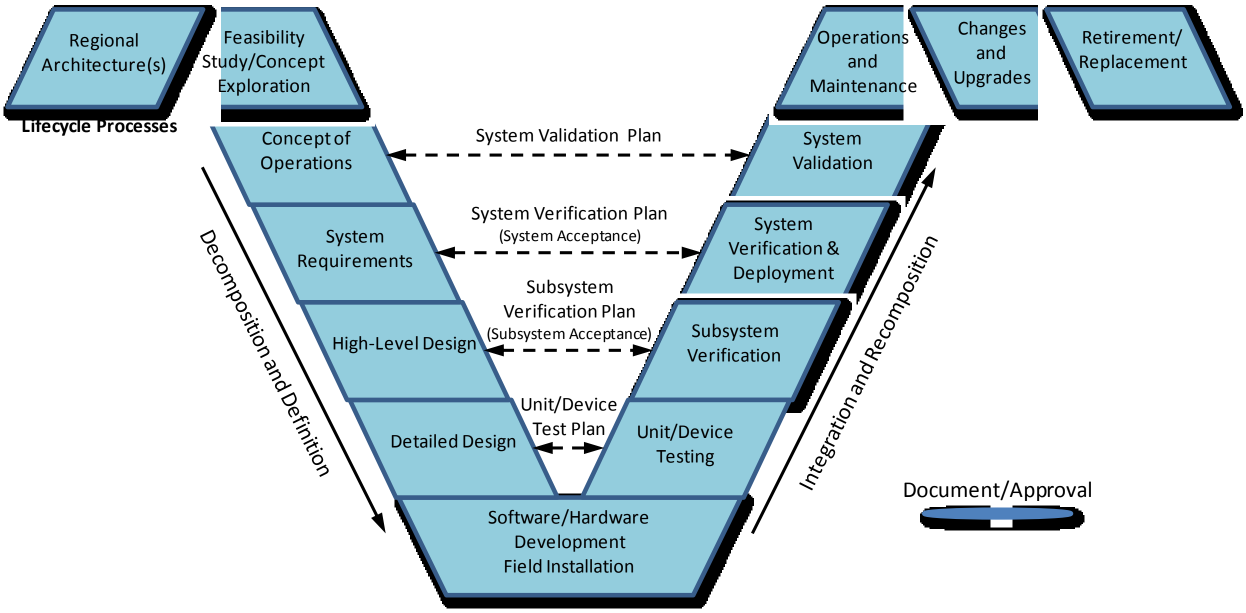


Figure 19: The V process model (Redrawn from Kossiakoff *et al.*, 2011)

As stated earlier, systems engineering (SE) is an iterative process which is important between the levels of decomposition in order to obtain a good baseline that would satisfy the customer. The right leg of the model allows for the investigation and resolution of anomalies that are discovered. This leg ultimately provides for correction and/or baseline modification, which is indicated on the figure as the dotted line between the legs. Advantages, disadvantages and situations where the model is most appropriate are given below (Bucanac, 1999):

4.2.2.1 Advantages

- The V-model can be modified to suit any project and provides concrete assistance on how to implement any activity.
- Every stage of the model is tested and verified.
- Changes can be made anywhere during the process. If a mistake happened in a stage you do not have to start the process from the beginning, due to the fact that the previous stage is tested and verified.

4.2.2.2 Disadvantages

- The model only addresses the development of the system rather than the entire organisation.
- The testing done after every stage can be costly and could take too long, due to more resources that are needed.
- It needs an established process in order to be implemented.
- If major changes to requirements occur, all the previous documents must be updated.

4.2.2.3 Situations Where Most Appropriate

- It is most appropriate to use in large scale projects, because reviews are performed after every stage.
- In projects where processes are well defined and established.
- If effective control of the project is available.
- If changes occur regularly in a project.
- In projects where the development of quality projects are emphasised. Testing and reviews after every stage will be beneficial to the quality of the product.
- If the project requirements can be stated unambiguously and comprehensively.

4.2.3 Shigley Model

Literature agrees that design models are iterative, and therefore almost generic. Differences do exist, but they are not major. For this reason, only one design model is looked at. It is stated by Shigley *et al.* (2004) that design is an iterative process with many interactive phases with the aim of satisfying a specific goal or to solve a problem. SE is based on these principles, as discussed in the literature study. Therefore, it is applicable to look at the model presented by Shigley *et al.* (2004), which is presented in Figure 20. It can be seen from this figure that the model starts with the recognition of a need and after many iterations, the process ends with the presentation of the plans to satisfy the need (Shigley, Mischke, & Budynas, 2004). This model is mainly applicable to the first two phases of project management (conception and definition), but it highlights its importance and that it should be iterative.

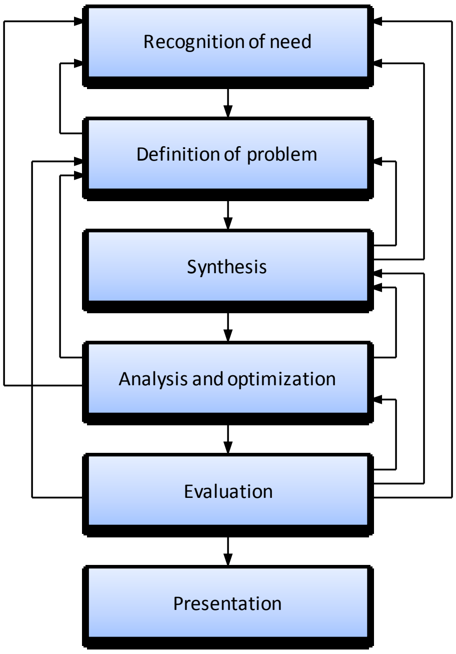


Figure 20: Shigley model (Redrawn from Shingly *et al.*, 2004)

4.3 Systems Engineering Methodologies Not Used

Several other SE methodologies do exist, but are not applicable to the development of the model. These approaches are more focused on the development of software, and utilise iterative development. This includes the building and quick release of prototypes. After the release of these prototypes, it is tested and changes are made to develop a new and improved prototype. These models are not discussed in detail, but are summarised in Table 10.

Table 10: Systems engineering methodologies not used in the development of the model

Systems Engineering Methodology	Description
Prototyping	The Prototyping Model evolved from the Waterfall Model. It differs from the waterfall model in the way that it has an iterative framework. The concept behind this model is that the developer builds a prototype, presents it to the customer for consideration and then makes changes as required (Green & DiCaterino, 1988).
Incremental	The framework type of the Incremental Model is a combination of linear and iterative system development. The project is divided up into smaller increments, and each increment acts as a mini-Waterfall process (CMS, 2008). The primary objectives of the incremental model are to reduce inherent project risks, provide faster results, and to offer greater flexibility (Green & DiCaterino, 1988)
Spiral	The Spiral Model evolved from the Waterfall and Prototyping models, in order to include the best features of both. The framework type of the Spiral Model is a combination of linear and iterative. Risk assessment and the minimisation of project risks are the focus of this model (CMS, 2008). This is achieved by breaking the project into smaller segments, which offers flexibility during the developmental process, as well as the opportunity to assess risks throughout the life cycle of the system (CMS, 2008).
Rapid Application Development	The key objective of the Rapid Application Development (RAD) approach is to deliver high quality systems, with fast development and delivery times, at low costs (Beynon-Davies & Holmes, 2002). It compresses the traditional step-by-step development approach into an iterative process. Another aspect of the RAD approach is to reduce inherent project risks. This is accomplished by breaking the project into smaller segments and providing more ease-of-change during the developmental process. This is similar to the Incremental and Spiral models
Concurrent Engineering	Concurrent Engineering (CE) is defined by INCOSE (2007) as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. The aim of this engineering process is to improve quality and to reduce costs and the lead time of the project, which is more or less the same as with the RAD model.

4.4 Chapter Conclusion

Approaches and methodologies that are used in SE were investigated in this chapter. The aim of this investigation was to determine which methodologies may be helpful, and used, in the development of the model.

It is concluded that the model will mainly follow the Waterfall and V-model methodologies, due to the fact that it will be based on large scale projects. These methodologies have an orderly sequence of development steps and strict controls that ensure that each project phase are tested and reviewed. Changes and risks are reduced if development occurs in this manner. The iterative nature of the Shigley model in the first two phases of a project is also an advantage, and will be used in the model.

It is concluded that the development approaches of the other methodologies will not be used in the model. These approaches are more focused on the development of software that uses iterative development. This includes the building and quick release of prototypes. After releasing these prototypes it is tested and changes are made to develop a new and improved prototype.

5. Systems Engineering Strategies

5.1 Chapter Introduction

Various approaches, methodologies and strategies exist to develop a system. These approaches and methodologies can be seen as concrete models used to develop a system. The strategies used in systems engineering (SE) can be seen as procedures that are applicable to any approach or methodology. In this chapter these strategies, that may be helpful in the development of the project management (PM) model, are investigated.

5.2 Requirements Engineering

5.2.1 Background

Poorly defined requirements were identified in Subsection 2.4.4 as one of the main risks that causes project failure. The main reason behind this is that the set of requirements do not represent the needs of the user. If this would occur the project team will be led down the wrong development path. It is stated by Lawrence *et al.* (2001) that the whole point of requirements engineering is to steer your development toward producing the correct deliverable. It was seen from the literature review on risks, in Subsection 2.4.4, that several factors led to inadequate requirements. Leishman & Cook (2002) identified strategies to mitigate these requirement risks.

The first of these strategies is to develop and follow sound processes and procedures. Consistency is very important, because the lack of it will lead to confusion, misunderstandings, development delays, and cost overruns (Leishman & Cook, 2002). It is also important to have proper documentation systems in place in order to reach a common understanding of requirements between the key project stakeholders (Leishman & Cook, 2002). Formal reviews should be conducted on requirements, because it can greatly improve the quality of requirement documents (Leishman & Cook, 2002). The aim of this is to reduce errors, inconsistencies, ambiguities, and confusion.

Secondly, users should be more involved in identifying requirements. It is stated by Leishman & Cook (2002) that the involvement of users in the requirements process greatly reduces the risk of identifying inadequate requirements. This strategy will be discussed in more detail in Subsection 5.3.1: Joint Application Development. This is a process that ensures that users are more involved in a project.

These identified strategies are discussed in more detail in the following sections. These discussions will focus more on the procedures in order to execute and satisfy these strategies.

5.2.2 Scoping the Project

Scoping is done to provide direction, and therefore it must be carried out before the project starts. The scoping of a project involves the following aspects that have to be identified and stated:

- Vision: the need(s) to develop a product
- Goals and objectives of the customer and organisation developing the product
- Missions or business cases
- Assumptions and constraints regarding the project
- Project risks
- Choosing the correct technical approach/methodology to develop the product

The first aspect, vision, is the statement made at the start of a project that drives everything else. It is generally a short statement that is related to the business or strategic plan of the organisation. This vision for the project should not change much over time and everything else done in the project must trace back to it.

The goals and objectives flow down from the project need(s). The goal is the fundamental aim behind the need, and the objectives expand on how the goals will be met. The objectives relate to what the product will do and how it will be developed.

The mission of the project addresses how the end deliverable will accomplish the objectives of the project. After the mission is stated a business case is prepared. This is an analysis of potential solutions that are available, which includes documentation of potential benefits, risks, and issues. A recommended solution with a generic implementation plan is then presented.

The above three aspects of scoping the project requires creativity from the project team. This will allow them to come up with solutions to particular problems. Ways in generating these ideas are discussed in Subsection 5.2.3 below.

The fourth aspect is the identification and documentation of assumptions and constraints, regarding the proposed solution. Any assumptions and constraints must be documented and validated early. Constraints can be anything that restricts a project with reference to its goal. Examples of them are: budgets, schedules, expertise, technology, political, ethical, etc.

The next step is to identify, assess, respond to, and document risks in accordance with the risk management process discussed in Section 2.4. Risks may be related to business, schedule or the technical side of the project.

The last step in the scoping of the project is to choose the correct technical approach or methodology to develop the end deliverable. Examples of these approaches were discussed in Chapter 4. It is the responsibility of the project manager to choose one, or combine several, of these models in the way she/he thinks will best suit the project.

5.2.3 Idea Generation via Lateral Thinking

Ideas can be generated in many ways. Edward de Bono suggests that lateral thinking is a good way to generate ideas to solve problems. Lateral thinking can be seen as creative thinking technique. It differs from logical ('vertical') thinking in the way that it tries to solve a problem by looking at it from different angles, rather than head-on. Logical thinking carries a chosen idea forward, while lateral thinking provokes fresh ideas. De Bono (2005) identified three lateral thinking techniques that can help with idea generation: 1) Provocation, 2) Random Input and 3) The Concept Fan.

5.2.3.1 Provocation

The process behind provocation is to deliberately make stupid statements. In a sense it is more or less the same as a hypothesis. The difference between a hypothesis and provocation is that a hypothesis tries to be reasonable, whereas a provocation tries to be "unreasonable" (De Bono, 2005). The reason for this is to develop statements that will shock our minds out of its usual way of thinking. Once a provocative statement is made, judgment is suspended and the statement is used to generate ideas. These statements are a good starting point for creative thinking.

De Bono (2005) identified five techniques to set up a provocative statement. These techniques are shown in Table 11 on the next page. Each technique is shortly described and an example is also given. Each provocative example given is preceded by "Po", as seen in Table 11. This is a term that De Bono invented to indicate that a statement is intended as a provocation and not as a serious suggestion.

Table 11: Techniques to set up provocative statements

Technique	Description	Example
The Escape Method	• We take for granted that … • Can never put down a problem, a complaint, or a negative feature as a "take-for-granted" item • Next step is to "escape" by cancelling, negating, dropping, removing, or denying the item taken for granted	• We take for granted that restaurants have menus • Po – Restaurants do not have menus
The Stepping-Stone Method	• Method is a good test to see whether your provocations are provocative enough • If all of your provocations can be used, be suspicious … • Use reversal, exaggeration, wishful thinking or distortion to make your statement more provocative • These four ways of creating stepping stone is considered next	
Reversal	• Go in the opposite or reverse direction than the normal • Make a reverse statement	• I drive the car to work • Po - The car drives me to work
Exaggeration	• Method is directly related to measurements and dimensions (e.g. number, frequency, volume, etc.) • Exaggeration means suggesting that a measurement falls far outside the normal range	• 90% of South Africans has access to a cell phone • Po – All South Africans owns a smart phone
Distortion	• In any situation there is normal relationship between parties, a normal time sequence of action exists • This method distorts these normal relationships by changing them to obtain a distorted provocation	• Turn on the alarm before leaving the house • Turn on the alarm after leaving the house
Wishful Thinking	• Put forward a fantasy wish knowing that it is impossible to achieve • Make sure that it is a fantasy, because a "weaker" desire, objective or task will not work • Start with "Wouldn't it be nice if …"	• Wouldn't it be nice if electricity were free

5.2.3.2 The Concept Fan

The concept fan is defined by De Bono (2005) as an achievement technique. It is used to find different approaches when all other solutions have been rejected. Therefore, you start with your purpose or objective of thinking and then take steps to ultimately obtain an idea to achieve the objective, as seen in Figure 21 on the next page. The process shown in Figure 21 will be explained with the use of an example.

As stated earlier, you start with your purpose or objective and move backwards to the broad concepts or "directions" that would lead back to the objective. For example, if the objective is "coping with water shortage" then the directions might be: reduce consumption, increase supply or do without it. The next step is to move a step back from each of these directions to find alternative "concepts", which are general methods or ways of doing something (De Bono, 2005). From Figure 21 it can be seen that a new concept level is created to the left of the directions. Each one of the new concepts is a way of achieving either one of the directions. For the example given, concepts for "reduce consumption" might be: increased efficiency of use, less wastage or discourage use. This is then carried out for each one of the directions. The last step is to find "ideas" to achieve either one of the concepts. These ideas are specific concrete ways of putting a concept to work (De Bono, 2005). For the example, ideas for "discourage use" might be: charge more for the water, only water at certain times, threaten to ration water, etc. This is then carried out for each one of the concepts.

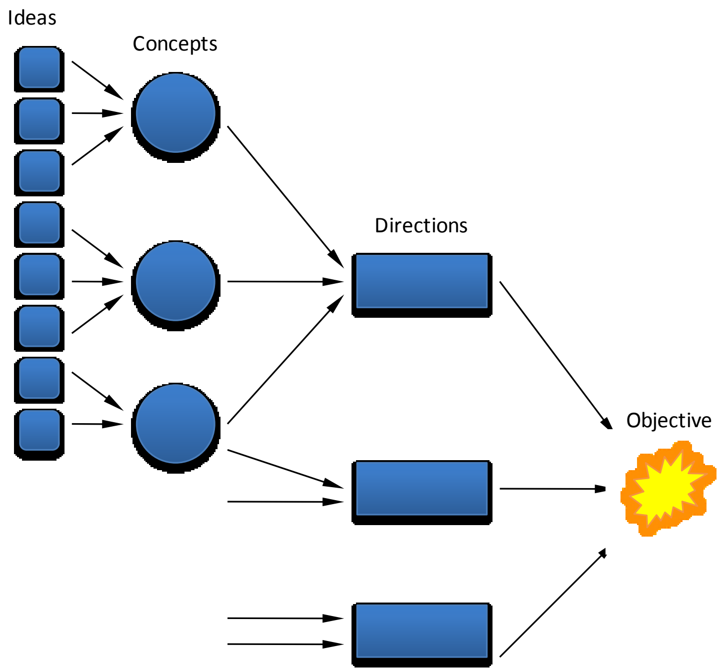


Figure 21: The Concept Fan (Redrawn from De Bono, 2005)

5.2.3.3 The Random Input

The random input technique is the simplest of all creative techniques, because the provocation is easily obtained and do not have to be "constructed" (De Bono, 2005). The technique works on the fact that a random entry point cannot really be chosen, it must be obtained by chance to obtain a provocation. Several practical ways exist to obtain words by chance. Two examples are given:

- Take a dictionary and think of a page number and the position of the word on the page, e.g. 5 rows down. If this word is a noun it can be used, otherwise just carry on in the same manner until a noun is found.
- With eyes closed randomly point with a finger, or pencil, on a newspaper or book. Again, if the word is a noun it can be used.

The random input process is as follow (examples are also given):

1. A certain situation or objective came to light (Example: Cigarettes are bad).
2. Get a random word, by means of the two examples above, which has no connection with the situation or objective (Example: Traffic light).
3. Hold the two together to obtain a provocative statement (Example: Cigarettes are bad *po* traffic light).
4. Generate ideas from the statement (Example: An idea may be to print a red band, which serves as a danger zone, some way from the butt end. If the smoker goes beyond the band, then smoking is more dangerous).

5.2.4 Needs Assessment and Validation

Ideas (customer needs) that are generated have to be assessed and validated before further progress can be made in the project. The main reason for this is to ensure that the product of the project is focused on the needs of the customers. This part of requirements engineering should be done among the entire development team to ensure they develop a common understanding of the customers' needs. The needs must also be documented as soon as they are identified by the team members. By doing this the team members can iterate and ensure that no critical customer need is missed or forgotten.

A good technique to assess and validate needs is to use the six thinking hats method highlighted by De Bono (2005). This excellent thinking technique forces a project team to think in certain ways to increase productivity during meetings. The six thinking hats are described in Table 12, on the next page.

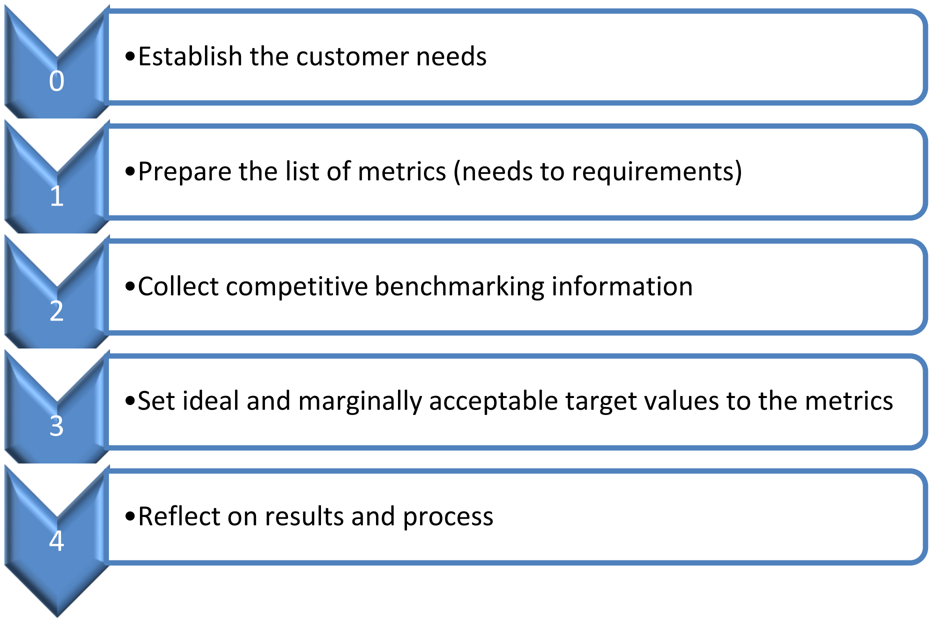
Table 12: The six thinking hats

	White Hat •During white hat thinking the team only focuses on the information and data that is available. •The Information is analysed to see what can be learned from it, what is needed, and how more information might be obtained.
	Red Hat •With red hat thinking you look at problems using feeling, intuition, hunches, and emotions. •This thinking hat gives people permission to put forward their feelings and intuitions without apology, without explanation, and without any need to justify them
	Black Hat •During black hat thinking logic and negative judgment is applied to look at a plan defensively and cautiously to identify flaws, risks or barriers. •With the weak points identified the team can eliminate them, alter them, or prepare contingency plans to counter them
	Yellow Hat •Yellow hat thinking allows the team to apply logic and positive judgement to identify benifits of the plan and the value in it. •Feasibility and how the plan can be executed are also looked at when using this thinking hat
	Green Hat •When green hat thinking is used the team is forced to be creative. •New creative ideas and solutions to a current problem are developed when using this thinking hat. •The idea generation techniques discussed earlier can be used here.
	Blue Hat •The blue hat stands for process control and is mostly used by the person chairing the meeting, but other participants can put forward suggestions. •The blue hat is for organising and controlling the thinking process so that it becomes more productive (e.g. if ideas are running dry direct thinking to the green hat).

5.2.5 From Needs to Specifications

The last step in requirements engineering is to move from the needs to specifications. This process involves 4 steps, as shown in Table 13 on the next page. Step zero in the table is not part of the process, because the customer needs were already identified and documented in the previous steps of requirements engineering.

Table 13: Moving from needs to specifications



The first step in moving from needs to specifications is to prepare a list of metrics (requirements). It is important that the metrics completely address the needs of the customer. Metrics can be seen as performance measures or output variables. It should also be practical in order to test its compliance within the budget and timeframe.

The second step, shown in Table 13, is the collection of benchmarking information. This is done to compare your product with that of suppliers to see where the product should be improved. Customer perceptions are also very important, because ultimately they will buy the product that suits them the best.

As soon as the metrics are identified, ideal and marginal ranges can be established for each one, as shown in Table 13 as step 3. In this step the development team establishes what the acceptable ranges are for each requirement. It is important for the team to remember not to set these ranges too narrow just for the sake of being "precise".

The final step in the needs to specifications is to reflect on the process and results. The reason behind this is to determine if any specifications are missing and if they reflect the characteristics that will dictate project success.

The process described above is very important in ensuring that a project is successful. A sound technique exists to ensure that this process is not neglected. This technique is called quality function deployment (QFD). QFD is a methodology, used in Systems Engineering, to translate customer needs into specific system or product characteristics, and then specifying the processes and tasks needed to produce that system or product (Nicholas & Steyn, 2008). Advantages of this methodology are that it yields end-item results in less time and lower cost (Nicholas & Steyn, 2008). QFD operations are performed by using a planning matrix called the House of Quality (HOQ). The HOQ facilitates group decision making by providing team members with a structured framework and an organised approach to improve the end-item quality (Trappey, Trappey, & Hwang, 1996). The basic structure of the HOQ is illustrated in Figure 22.

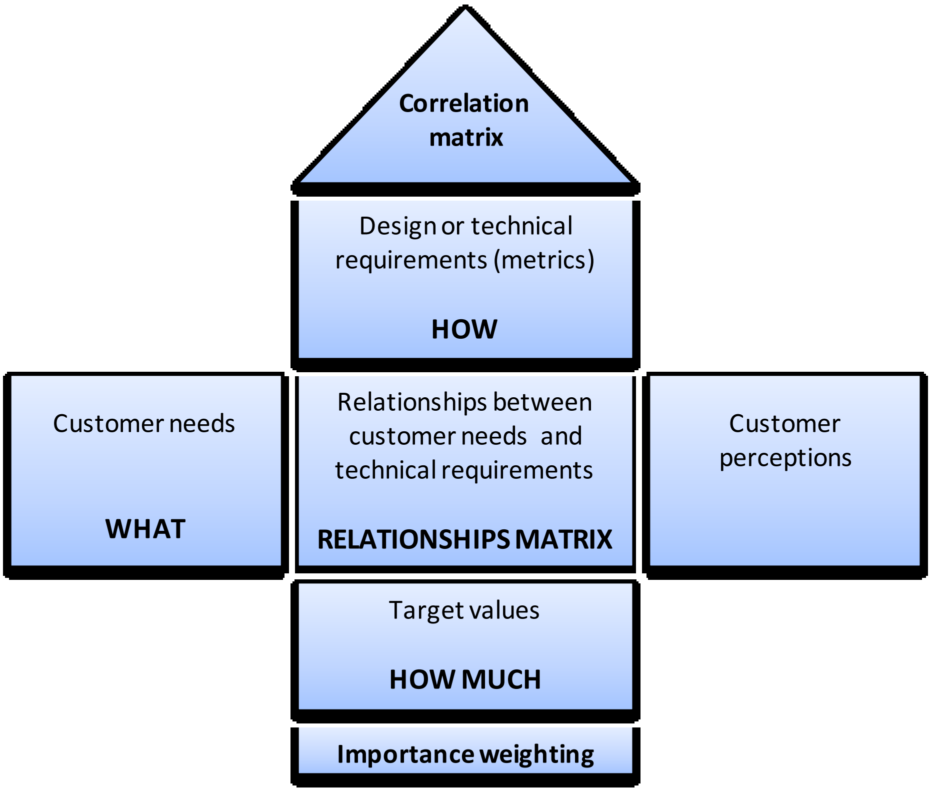


Figure 22: Structure of the house of quality (Adapted from Nicholas & Steyn, 2008)

Six basic steps are followed to complete the HOQ. They are:

1. The left hand side lists “what” the customer feel is important about the project (customer needs).
2. The top of the HOQ represents the “hows”. These are attributes about the product or service that tell you “how” it can meet customer requirements, which are the technical requirements of the product.
3. The third step is to relate the “whats” with the “hows” in a relationship matrix. The team uses this matrix to determine the relationship between customer needs and the ability to meet those needs.
4. A correlation matrix is the roof of the HOQ. In this step team members specify the interactions between the “hows” in this matrix.

5. The fifth step is to determine "how much". This is the establishment of target values for each of the "hows".
6. The last step is to rank the "hows" with respect to their technical importance. This ranking gives you an idea which technical aspects of the product matters most to the customer.

5.3 Agile Development

Agile development is a conceptual framework for undertaking software engineering projects, with the goal to minimise risk by developing software in short timeboxes, called iterations (Software Development Methodologies, 2012). It is based on the philosophy that modern business requirements change quickly and frequently (Visser, 2012). Various methodologies exist, and they are discussed in the subsections that follow. These methods emphasises real-time communication, preferably face-to-face (Software Development Methodologies, 2012).

5.3.1 Joint Application Development

Joint Application Development (JAD) is a requirements-definition and user-interface design methodology, where stakeholders get together in a room to discuss the problem or project (Software Development Methodologies, 2012). The goal of this method is to turn meetings into workshops (called JAD sessions), which are less frequent, well structured, and more productive (Abbot & Abbot). The typical participants of a JAD session include the project sponsor, project lead, facilitator, scribe, end users, developers, observers and subject matter experts (Abbot & Abbot).

The main focus of JAD is the business problem, and methods to shorten the elapsed time to gather the requirements of a system. An advantage of this methodology is the improvement in gathering requirements, which leads to a reduction in the number of costly, downstream requirements changes (Software Development Methodologies, 2012).

5.3.2 Scrum

Scrum is an iterative and incremental methodology with the goal to dramatically improve productivity in teams to deliver the highest business value in the shortest time (Software Development Methodologies, 2012). Furthermore, it also allows for rapid and repeated inspection of actual working software (Visser, 2012).

Projects using scrum make progress through a series of meetings, called "sprints". The typical length of sprints is two to four weeks and the people in attendance are the product owner, scrum master and project team. The scrum master is the facilitator and ensures team productivity by removing impediments, enabling close cooperation across all roles and functions, and shielding the team from external interferences (Visser, 2012). Features of the product for each sprint are defined by the product owner. Another responsibility of the product owner is to accept or reject work results (Visser, 2012). Visser (2012) stated the team, which normally consists of five to nine members, is always cross-functional and should be employed on a full-time basis.

After the completion of a sprint, a sprint review meeting is held. In this meeting the team presents what they accomplished during the sprint (Visser, 2012). This is usually an informal meeting attended by the whole team, product owner and customers.

5.3.3 Extreme Programming

Extreme Programming (XP) is a methodology used to create software within very unstable environments (Software Development Methodologies, 2012). Due to this products are frequently released in short development cycles, called timeboxes. These timeboxes act as checkpoints where new customer requirements can be adopted. The main goals of XP are to improve productivity and to lower the cost of changing customer requirements (Software Development Methodologies, 2012).

The core practices of XP can be summarised into five areas. Firstly, is feedback on a fine scale, where developers work in pairs in a test driven development environment. The aim of working in pairs is to check on each other's work, and providing the support to always do a good job (Visser, 2012). The second practice of XP is that it is a continuous process rather than batch. Work is integrated into the entire program as soon as it is completed (Visser, 2012). The third practice is to ensure that programmers have a shared understanding of the entire system. This is achieved by allowing developers to work on all areas of the system (Visser, 2012). The fourth practice is to ensure the welfare of developers, which is achieved by not overworking them (Visser, 2012). The last practice is to ensure customer involvement during coding. A representative of the customer should always be available to the XP team.

5.3.4 Crystal Clear

The focuses of the crystal clear methodology are on people and their interactions, skills, talents, and communications, with the belief that these factors have the largest effect on performance (Software Development Methodologies, 2012). For that reason, crystal clear uses the philosophy that each team has a different set of talents and skills, which requires uniquely tailored processes for a specific team (Software Development Methodologies, 2012).

Properties that are required by this method are that usable code should be frequently available to users and that reflective improvement should be carried out. Again, this method highlights the importance of customer involvement.

5.3.5 Feature Driven Development

Feature driven development (FDD) is an iterative and incremental software development process that focuses on having just enough processes to ensure scalability and repeatability (Software Development Methodologies, 2012). These processes are industry-recognised best practices that are driven from a client-valued functionality perspective. Software Development Methodologies (2012) states that FDD emphasises the use of a simple, well-defined, iterative processes for the building of a system. These process steps should be logical and their worth immediately obvious to each team member (Software Development Methodologies, 2012).

The principles described above are addressed by the following generic process that should be followed for the development of any systems using the FDD methodology (Software Development Methodologies, 2012)

1. Develop an overall model
2. Build a features list
3. Plan by feature
4. Design by feature
5. Build by feature

5.3.6 Dynamic Systems Development

Dynamic systems development (DSDM) evolved from the rapid application development (RAD) methodology. DSDM focus on the belief that nothing is built perfectly the first time (Software Development Methodologies, 2012). Nine generic principles of DSDM exist. They are (Software Development Methodologies, 2012):

1. Active user involvement;
2. Empowered teams that have the authority to make decisions;
3. A focus on delivering products frequently;
4. Using the fitness for business purpose as the essential acceptance criterion of deliverables;

5. Development are iterative and incremental to ensure convergence on an accurate business solution;
6. Changes are reversible during development;
7. Definition of requirements are base lined at a high level;
8. Integrated testing is performed throughout the life cycle of the system; and
9. Collaboration and cooperation between all stakeholders are essential.

5.4 Chapter Conclusion

Strategies used in SE were investigated in this chapter. The aim of this investigation was to determine which of these strategies may be helpful, and used, in the development of the model.

Inadequate articulation of requirements, and transforming these requirements into specifications, is a very big risk in project management. The SE strategy investigated to reduce these risks was requirements engineering. The main purpose of requirements engineering is to develop and follow sound processes and procedures (e.g. formal documentation, reviews and the involvement of the customer). The generation of ideas is also very important during this phase of a project. The lateral thinking techniques investigated were very good and will be used in the model. The last important step in requirements engineering is to transform the requirements into specifications. A sound technique used in SE is QFD. QFD operations are performed by using a planning matrix called the House of Quality. This provides team members with a structured framework and an organised approach to improve the end-item quality. For that reason, it will be used in the model.

The next strategy used in SE is agile development, which is a conceptual framework for undertaking software engineering projects. Several agile development methodologies were investigated, although it is mainly based on software. The reason for this is that these strategies hold benefits. It is concluded from this investigation that customer involvement is very important, because of the emphasis laid on communication by all of the methodologies. This principle will be used in the development of the model. The other principles were not really relevant to project management as a whole. They are more focused on the development of software, and therefore will not be used in the model.

6. Model Development

6.1 Chapter Introduction

A model that illustrates the integration of systems engineering (SE) into project management (PM) was developed as a tool that can be used by project managers and their teams. It is a generic tool that can be used for any project. Parts and procedures from various process models are integrated into one model. The aim of this is to use those processes, applicable to reducing risks in project management, in the model.

In order to develop a model that could be used in practice, the researcher had to first gain a thorough understanding of SE, PM and project related risks. This was achieved by doing a literature study on them to obtain insight into their methodologies. Secondly, SE approaches and strategies were investigated to see what principles can be used in the development of the model. Lastly, further insight to what risks has the highest priority in PM are investigated. The aim of this investigation is to identify those with the highest priority so that they can be reduced with the use of the model. These high priority risks are identified and verified by means of a questionnaire. The data collected from this questionnaire is presented and discussed in this chapter.

After the collection and discussion of data, the model requirements and parameters are determined. Following this, the research model is developed. This model will also be explained in detail later in this chapter.

6.2 Project Management Risks

Various PM risks were identified and discussed in Chapter 2 of this document. It is essential that risks are managed properly in order to complete projects successfully within the three goals of PM. Those risks are summarised for each phase of PM, and is shown in Table 14 on the next page. These are the most important risks, and will be used in the questionnaire that will be explained in Section 6.3.

Table 14: Summarised project management risks

Phase	Risks
Conception	• Poor definition of requirements ➢ Due to lack of customer involvement, and ➢ Poor communication with customer • Unclear definition of project objectives ➢ Leads to poorly defined deliverables, ➢ Inaccurate estimates, and ➢ Unrealistic timelines and budgets • No feasibility study ➢ Project executed with infeasible solution
Definition	• Poor specifications ➢ Due to inexperienced project team, and ➢ No formal process or procedure followed • Hasty planning ➢ Leads to unclear statement of work
Execution	• Poor communication between team members • Lack of change management ➢ Leads to scope creep, and ➢ Projects longer and more costly • Inadequate resources ➢ Leads to milestones missed • Poor/no risk management • Poor/no control systems
Closure	• Inadequate planning for termination ➢ Do not know when to terminate project ➢ Work orders stay open and project lose money • Poor end-item quality ➢ Leads to cash flow problems, and ➢ Unhappy customer

6.3 Data Collection and Analysis

The identified risks in Table 14 above are the basis of the PM risks questionnaire, which can be seen in Appendix A: Project Management Risks Questionnaire. The purpose of the research reported in this document is to reduce risks inherent to the first two phases of project management. This was stated in the Problem Statement in Chapter 3. One external risk, change in environment, were included in the questionnaire to see if the participants think this external risk is more important than process related risks. The questionnaire was designed to collect some relevant views of those in the industry to assess the importance and validity of the identified PM risks. The participants were asked to rate five of the identified risks in order of importance, from 1 to 5 (1 being the most important and 5 the least). Furthermore, they were asked if the identified risks are valid and if any other risks should be identified. The last question of the questionnaire was if there are any other recommendations.

The questionnaire was sent to thirty-three professionals in the industry. Thirteen responses were obtained from this pool. It would have been good to receive more responses, as this would increase the statistical confidence of the research. However, many people (20) opted not to take part in the survey. This was unexpected due to the fact that it was a small survey with few questions. The main reasons why only a small sample group was chosen are that they are known professionals and it was a small survey. More responses were certainly expected. A reminder was sent after the survey deadline. Only 3 more participants took part after the reminder, which gave a total of 13 responses. The responses of the participants can be seen in Appendix B: Risk Questionnaire Answer Sheets. The field of management of the participants is distributed as follow:

Civil (Construction) Engineering:	7 Participants
Multi-Disciplinary (Consulting):	5 Participants
Food Industry:	1 Participant

6.3.1 Risk Importance

The overall number of ratings each identified risk obtained are illustrated in Table 15 on page 86. The goal of this is to illustrate which of the risks obtained the most ratings, irrespective of their importance. Risk importance will be discussed later in this subsection.

It can be seen from Table 15 that poorly defined requirements and poor communication obtained the most ratings, 13 (20% of the total) and 12 (18% of the total) respectively. This conforms to the arguments made in Subsection 2.4.4 that they are very important risks in PM. The risks that obtained the third and fourth most ratings were the lack of customer involvement and poor risk management, which were 7 (11% of the total) for both. Again, this conforms to the arguments made.

The percentages of the total ratings for the remaining risks are all equal or below 9%. This illustrates that these risks pose threats to the success of a project, but not as much as the four discussed in the previous paragraph. Only one risk did not get a rating, which is "Scheduling: too tight, unrealistic or overly optimistic". The reasoning behind this is that it may be related to other risks or the participants just did not see it as important.

For each risk importance category, 1 to 5, a total of thirteen ratings was given, due to the fact that there were thirteen participants. A scoring system is used to determine the five most important risks from the survey, also illustrated in Table 15. Points are allocated to each vote as follow:

- Five points to a vote in risk important category 1
- Four points to a vote in risk importance category 2
- Three points to a vote in risk importance category 3
- Two points to a vote in risk importance category 4
- One point to a vote in risk importance category 5

The scores obtained by each risk, in their respective importance category, are aggregated to obtain a total score for that particular risk. The risk that obtain the highest number of points are the most important, second highest number of points are second most important, etc. From Table 5 it is evident that the following five risks are the most important:

1. Poorly defined requirements with 52 points
2. Poor communication with 41 points
3. Poor risk management with 23 points
4. Lack of customer involvement with 15 points
5. Poor quality control with 14 points

This strengthens the arguments made that requirements, communication, risk management and customer involvement plays an important role in the successful completion of a project. Quality control is a very important process during the third phase of a project (execution). However, as stated in the research problem, the research conducted in this thesis mainly considers the first two phases of PM. For this reason the risk with the most points, associated with the first two phases, substitutes poor quality control. This risk is inaccurate estimates with 12 points. Furthermore, it can be seen from Table 15 that inaccurate estimates received three votes in risk importance category 3, whereas poor quality control received two. The vote received for poor quality control in risk importance category 1 was from the participant from the food industry. Quality control is of utmost importance in the food industry, and is therefore the primary process for them, which was not the same for the other participants. This rating in the first category also boosted the amount of points poor quality control received, which would have been less if it received a vote in the lower categories. These arguments also support the decision made to substitute poor quality control with inaccurate estimates.

It can also be seen that the risk change in environment received 10 points. This is less than the top five process related risks, and therefore the assumption made that major process related risks are more important than this external risk.

Table 15: Total number of ratings and points per identified risk

Risk Importance	Points Allocation	Poor Communication	Poorly Defined Requirements	Lack of Change Management	Unclear Project Objectives	Poor Risk Management	Inadequate Resources	Poorly Defined Deliverables	Poor Testing	Change in Environment	Inaccurate Estimates	Lack of Customer Involvement	Scope Creep	Poor Quality Control	Scheduling: too tight, unrealistic or overly optimistic
1	**5**	3	6	-	-	1	1	-	-	-	-	-	1	1	-
2	**4**	3	3	1	-	3	-	-	1	1	-	1	-	-	-
3	**3**	4	3	-	-	-	-	-	-	-	3	1	-	2	-
4	**2**	-	-	1	1	3	-	1	-	2	-	3	1	1	-
5	**1**	2	1	1	-	-	-	-	-	2	3	2	1	1	-
Total		12	13	3	1	7	1	1	1	5	6	7	3	5	0
Percentage		18%	20%	5%	2%	11%	2%	2%	2%	8%	9%	11%	5%	8%	0%
Total Points		41	52	7	2	23	5	2	4	10	12	15	8	14	0

6.3.2 Extra Questions

The participants were asked to answer three extra questions. They were:

1. Are these identified risks valid?
2. Are there any other important risks that should be identified?
3. Is there any other comments?

Question 1

All of the participants agreed that the identified risks are valid. Comments were made about some of the risks that are related. One of the participants commented that poorly defined requirements and deliverables are related to poor communication. Another commented that poor communication and lack of customer involvement are related and have an impact on poorly defined requirements. This confirms that these risks are related and very important in PM.

Question 2

A few risks, not provided in Table 14 earlier, were identified by the participants. They were:

- External risks (e.g. political, legal, economical and site conditions)
- Mistakes in design and the omission of important aspects (especially safety)
- Worker safety – this should be identified during risk management.
- Contractor lack of experience
- Inexperienced and ill-informed clients

External risks are always a factor in PM. This was not identified, because the goal of the risk investigation was to determine which processes in PM pose the highest risk. Mistakes in design and the omission of important aspects must be addressed during the planning and definition phase of PM. Worker safety must be ensured by doing proper risk management. Contractor lack of experience poses a risk in construction projects. However, this must be avoided by the project manager. Inexperienced and ill-informed clients should be addressed by getting them more involved in projects, as discussed in Subsection 2.4.4 and Section 5.3.

6.3.3 Conclusion

As stated earlier the goal of this investigation was to collect expert opinions to assess the importance and validity of identified process related project management risks. It is concluded from the discussions above that the five most important risks are:

1. Poorly defined requirements;

2. Poor communication;
3. Poor risk management;
4. Lack of customer involvement; and
5. Inaccurate estimates.

These are the most risky processes in PM, according to the survey. The model that was developed addresses these risks by integrating principles of SE into PM.

6.4 Model Requirements

The core of the findings of the literature study are summarised in this section in order to formulate the model parameters.

6.4.1 Model Requirements based on Literature Study

Many projects fail to meet the three goals of PM, which is meeting the budget, schedule and performance requirements. Risk management is essential in projects to meet those three goals. Risk is a measure of probability and impact, i.e. the probability that some problematic event will occur and the impact it has on the project. Risk management consists of five phases, namely:

- Risk Management Planning
- Risk Identification
- Risk Assessment
- Risk Response Planning
- Risk Monitoring and Control

PM and SE are two tightly intertwined domains. However, differences and similarities do exist between them. The main similarities between PM and SE are that both plan for producing a product or service, and both conduct stakeholder analyses. The main differences between the two disciplines are that PM is accountable for the success of the entire program and all aspects of it, whereas SE is responsible for the technical success of the program. Two processes that are used more in SE are requirements management and customer involvement. It was proved in previous discussions that these two processes are very important to the success of a project.

6.4.2 Model Requirements based on Systems Engineering Investigation

Several SE approaches and methodologies were investigated in Chapter 4. The model that was developed is intended for large scale projects. Large projects require orderly development steps and strict controls to ensure that each project phase is tested and reviewed. Changes and risks are reduced if development occurs in this manner. The Waterfall and V-model provide these principles, and therefore the model will mainly be based on them. Iterative development, especially during the first two phases of a project, may also prove to be an advantage, which is illustrated by the Shigley model.

Strategies used in SE were investigated in Chapter 5 of this thesis. The adequate articulation of requirements is very important to the success of a project. Requirements engineering is a very good process to ensure this. The first purpose of this process is to develop and follow sound processes and procedures to acquire the correct requirements. The second is to transform the requirements into specifications. Two processes used in requirements engineering that addresses these were identified, namely:

- Idea generation via lateral thinking; and
- Quality function deployment (QFD) (House of Quality (HOQ)).

Two other SE principles that lead to successful SE projects are customer involvement and communication. Agile development addresses these principles.

6.4.3 Model Requirements based on Risk Investigation

Risks have adverse impacts on projects. Several risks were identified in the literature study. These risks were used in a questionnaire to collect relevant views of industry experts on their importance and validity. The five most important project management risks are:

1. Poorly defined requirements;
2. Poor communication;
3. Poor risk management;
4. Lack of customer involvement; and
5. Inaccurate estimates.

The model will aim to reduce these five important risks.

6.5 Model Parameters

The model requirements can be summarised into the model parameters given in this section. The following four attributes have the highest priority:

- The model should be based on large scale projects.
- A comprehensive risk management plan must be prepared before the project starts.
- The model should aim to reduce the top five identified risks.

- To reduce these risks, principles of SE should be used.

SE principles that will be used in the model are:

- Orderly development steps to ensure each development step is reviewed.
- Iterative development, mainly for the first two phases of a project.
- Requirements engineering to ensure the adequate articulation of requirements, and the transformation of them into specifications.
- Customer involvement and communication.

The following are other attributes of the model:

- It must be simple and generic.
- It should act as a guide to the project manager and team.
- The steps in each project management phase should be clearly laid out.
- Model instructions must be clear.
- Templates will be used to guide the project manager and team through the various steps of the model.

6.6 Model Development Discussion

The development of the model is discussed in this section. This model should be seen as a tool that illustrates the researched PM, SE and risk management principles, and that they are integrated. At first the model outline is discussed, then more detail is given on each phase, and lastly the templates used in the model are discussed. The model was developed in Microsoft Office Excel®, and can be seen on the CD that accompanies this thesis, under the folder named "Model". To open the model click on the Macro-Enabled worksheet named "Project Management Integrated with Systems Engineering Principles Model". Macros are used to navigate through the model, whereas hyperlinks are used to open the templates and guides. The templates and guides used in the model can also be seen on the CD that accompanies the thesis. The instructions on how to use the model is provided later in this section.

6.6.1 Model Outline

The model is named "Project Management Integrated with Systems Engineering Principles Model". This name is given to highlight the fact that SE principles will be used in the model. The PM framework is used as the basis for the model, as seen in Figure 23 on the next page. This figure shows that the life cycle of a project has four generic phases; 1) Conception, 2) Definition,

3) Execution, and 4) Completion (Termination). These four phases were discussed in detail in Chapter 2 of this thesis. This framework was chosen to ensure that an orderly sequence of development steps is followed, due to the fact that it will be based on large scale projects. From the conclusions drawn in Chapter 4 this framework is based on the Waterfall and V-model. These SE methodologies ensure that each phase of the project is tested and reviewed, which is essential in large projects.

Two alterations are made to the basic framework. The first is; it is recommended by this model that the Risk Management Plan must be completed before any work on the project begins. The reason for this is to ensure that the importance of project risks is highlighted from the beginning of the project, and therefore addresses the identified risk: Poor Risk Management. Figure 23 shows that the Risk Management Plan is linked to all four phases. This is done to ensure that risks are managed throughout the entire project. It will be seen in the discussion of the phases, Subsection 6.6.2, that a risk management step is inserted in each phase.

The second alteration is to include the Project Master Plan. This was done to highlight its importance. This plan must be thoroughly completed before work can begin on the third phase, as illustrated in Figure 23. It can also be seen that if any changes do occur during phase three, the Project Master Plan must be updated.

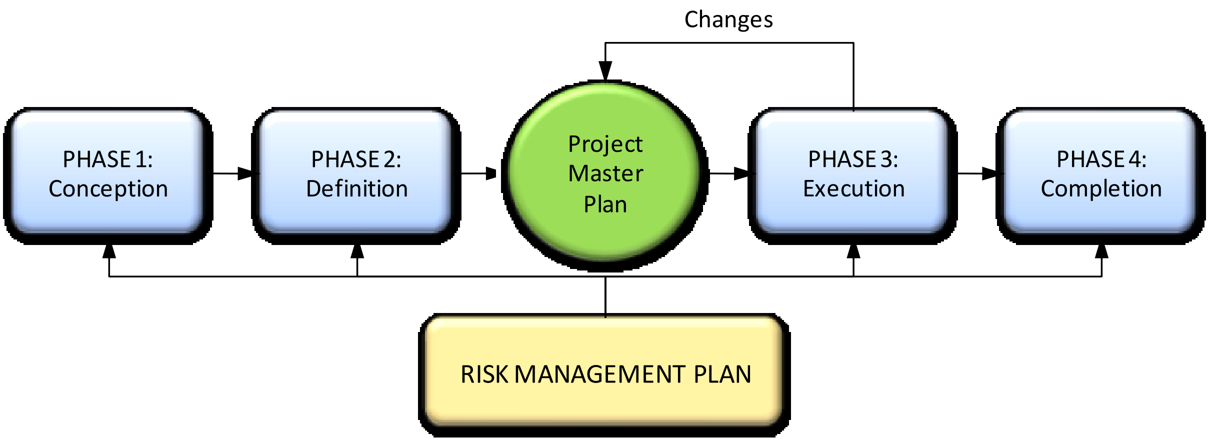


Figure 23: Model outline

6.6.2 Model Phases

Each of the model phases, shown in Figure 23, are discussed in detail in this subsection. The Risk management Plan is seen as a phase on its own. The Project Master Plan is included in Phase 2: Definition.

6.6.2.1 Risk Management Plan

As stated earlier, the Risk Management Plan is created before any planning goes into the project. The process to manage risks is illustrated in Figure 24.

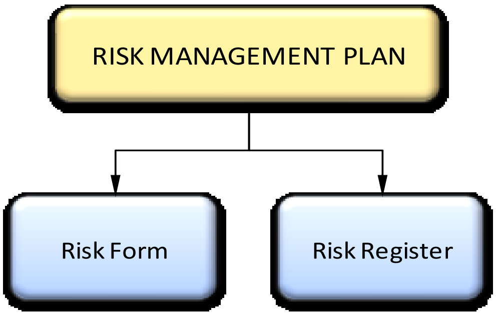


Figure 24: Risk Management Process

The risk management plan outlines the strategy to identify sources of risk, assess their probability, impact and priority, determine appropriate response planning, and to monitor and control them. This plan is given as a guide, which explains how all the processes works. The processes that are followed were discussed in Section 2.4 of this document. Two other templates are given as part of the risk management process. They are the risk form and risk register. Identified risks are documented in Risk Forms to gain approval from the project manager. After approval the risks are documented in the Risk Register.

6.6.2.2 Phase 1: Conception

The first phase in this model is project conception. The development of the concept is normally based on a perceived problem, opportunity, or need. All the steps of this phase are illustrated in Figure 25, and discussed below. The phase starts with the Project Idea and Definition and ends with the Phase Review.

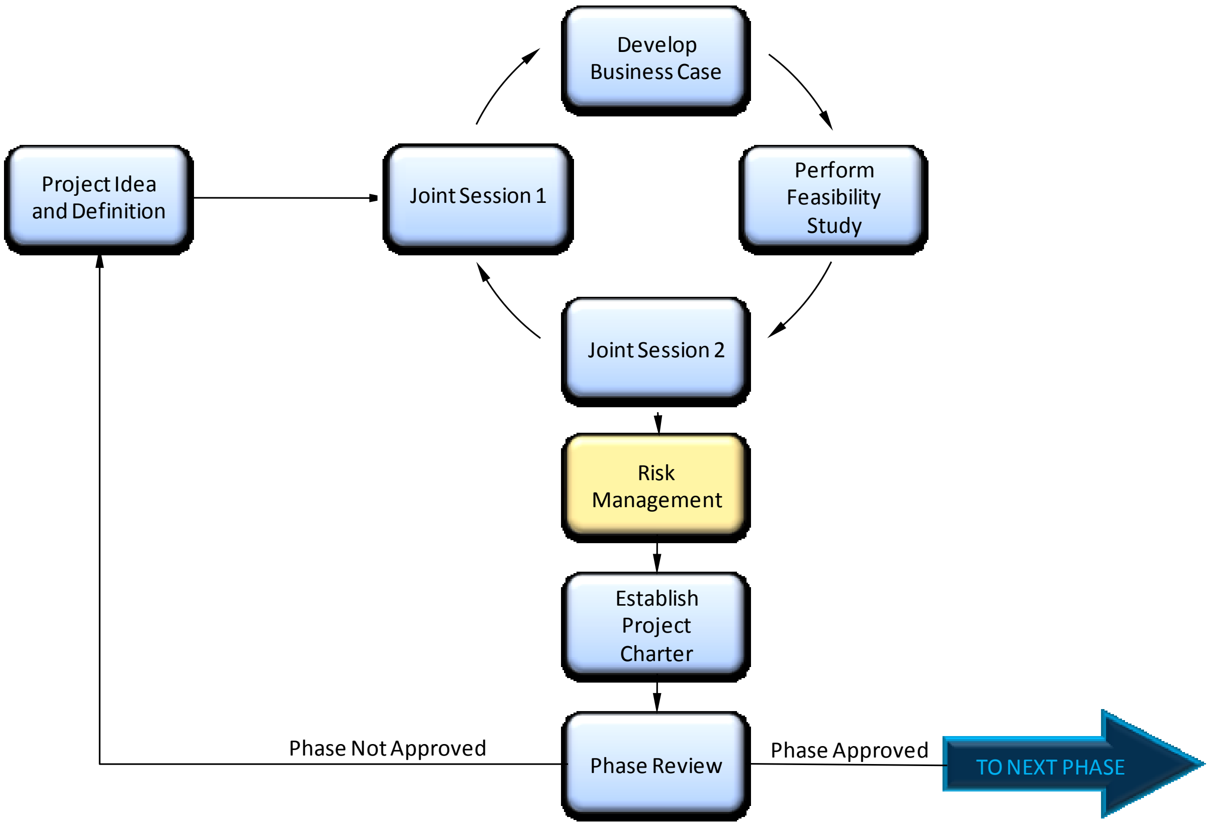


Figure 25: Phase 1 steps

The first step, Project Idea and Definition, has two purposes. Firstly, the project idea is described and various project details are documented, which includes the project name and owner or sponsor. The second purpose is to define the project. This includes the project vision, objectives, estimated duration, likely technologies and development strategies that will be used, and the marketing and sales strategies.

After the project is defined, development moves into iterative development to obtain the best solution to the project idea. This involves four steps (discussed below); 1) Joint Session 1, 2) Developing a Business Case, 3) Performing a feasibility study, and 4) A second joint session.

These iterative steps incorporate two SE principles. Firstly is iterative development and secondly customer involvement, which addresses the identified risk: Lack of Customer Involvement. One can only move on to the next step, “Risk Management”, if both the customer and project manager agree on the recommended solution after Joint Session 2. If not, the process must start at Joint Session 1 again, and all the respective documentation must be updated.

The first Joint Session is based on the Joint Application Development (JAD) Methodology, which is used in Systems Engineering. JAD is a requirements-definition and user-interface design methodology in which end-users (customers), executives, and developers attend intense off-site meetings to work out the system's details. The JAD methodology aims to involve the client in the design and development of the project deliverables. This joint session is performed to ensure that the needs of the customer are well understood. It is also used to obtain ideas or solutions, in collaboration with the customer, for the particular business problem. This addresses the identified risks: Poor Communication and Lack of Customer Involvement. The SE idea generation techniques, discussed in Subsection 5.2.3, are used in this joint session.

The business case is developed after the first joint session. Three aspects are looked at during this development. Firstly, is the problem statement that describes the main characteristics of the business environment that led to the need for the project (business problem and/or opportunity). The second aspect is a description of the solutions identified during the first joint session and a recommendation to which option is preferred. The last aspect is the implementation strategy that will be followed for the recommended solution.

After the business case is developed, a feasibility study is performed to investigate the potential solution, as well as the recommended solution. Project requirements and possible benefits are identified during this study. The study includes an assessment of the solutions, and finally a comparison between them to recommend a feasible solution that will satisfy the customer requirements.

The second joint session is held after the feasibility study is completed. This joint session is performed to ensure that the customer agrees with the project requirements and recommended solution obtained. This addresses the identified risks: Poorly Defined Requirements and Poor Communication. A decision criterion is provided at the end of the joint session. Two options are given; either the recommended solution will be used or an alternative solution. If it is decided on the recommended solution one can move on to the next step of the phase, “Risk Management”. If an alternative solution is decided upon, the process must start at Joint Session 1 again.

After deciding on the recommended solution the project team must perform the risk management process, as described earlier.

The next step in this phase is the establishment of the Project Charter. The Project Charter explores several aspects of the project. The first is a description of the project organisation that identifies customers and the relevant stakeholders. Secondly, is a description of the project, which includes the main project objectives and deliverables. The third aspect looked at is the estimated schedule. Important project dates, milestones and high-level activities are identified.

The fourth aspect is an estimated total cost for expense items (estimated budget). Lastly, other project considerations are explored. This includes project risks, issues, assumptions and constraints.

The final step of the first phase is a review, which includes a revision of several project aspects to date. This includes the project schedule, budget, deliverables, risks, issues, and changes made. A decision criterion is provided at the end of the review. Two options are given; either the phase is approved or not. If the phase is approved proceed to the next phase of the model (Phase 2), otherwise start again at the beginning of the phase. If the latter is decided upon, the steps shown in Figure 25 must be followed from the start.

6.6.2.3 Phase 2: Definition

The second phase in this model is definition. In this phase the product is designed, the build-method outlined, and detailed schedules and plans are developed to make or implement the product. All the steps of this phase are illustrated in Figure 26 on the next page. The phase starts with QFD and ends with the Phase Review.

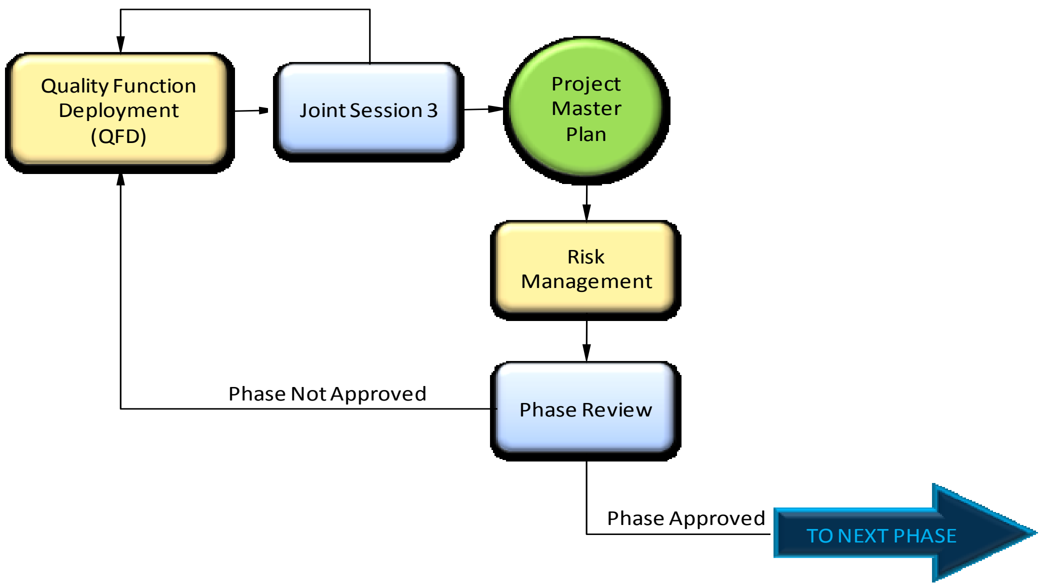


Figure 26: Phase 2 steps

The first step, QFD, is a methodology, used in SE, to translate customer needs and requirements into specific system or product characteristics, and then specifying the processes and tasks needed to produce that system or product. The HOQ, as discussed in Subsection 5.2.5, is used to do this. This SE principle addresses the identified risks: Poorly Defined Requirements and Inaccurate Estimates.

After the specifications of the project are determined a third joint session is held, to ensure that the customer agrees with the determined specifications. This addresses the identified risks: Poorly Defined Requirements, Lack of Customer Involvement and Inaccurate Estimates. A decision criterion is provided at the end of the joint session. Two options are given; either the specifications are accepted or there were new/changed specifications. If it is decided on the first option, move on to the next step of the phase (Project Management Plan), otherwise move back to the previous step (QFD). This process is repeated until the project team and customer agrees on the specifications.

After the project specifications are decided upon, the project team can start to prepare the Project Master Plan. The purpose of the Project Master Plan is to work out the details that will guide the project team throughout the execution of the project. This plan will ultimately be used in Phase 3 to execute the project. The typical contents of a Project Master Plan are shown in Table 16 on the next page. A short description of the content is also given. The contents of the Project Master Plan vary depending on the size, complexity, and nature of the project. Depending on the client or type of project contract, some plans require additional and special items that are not outlined here.

After the Project Master Plan is completed, the project team must perform the risk management process, as described earlier.

The final step of the second phase is a review, which includes a revision of several project aspects to date. This includes the project schedule, budget, deliverables, risks, issues, and changes made. A decision criterion is provided at the end of the review. Two options are given; either the phase is approved or not. If the phase is approved, proceed to the next phase of the model (Phase 3), otherwise start again at the beginning of the phase. If the latter is decided upon, the steps shown in Figure 26 must be followed from the start.

Table 16: Project Master Plan contents (Adapted from Nicholas & Steyn, 2008)

Content	Description
Project Scope	Overview of the project oriented towards management, customer, and stakeholders. Includes a brief description of the project, objectives, overall requirements, constraints, risks, problem areas, and solutions.
Management and Organisation Section	Description of the project organisation, management, and personnel requirements, which consist of the following: • Project Management and Organisation: key personnel and authority relationships. • Manpower: workforce requirements estimates - skills, expertise, and strategies for locating and recruiting qualified people. • Training and Development: executive development and personnel training necessary to support the project.
Technical Section	This section includes major project activities, timing, and cost.
User and System Requirements	Includes a list and description of the User and System Requirements. This is acquired from the step at the start of Phase 2.
Project Action Plan	Shows the arranged project activities in successively finer detail.
Work Breakdown Structure	Consists of the work packages (project activities) and a detailed description of each, including resources, costs, schedules, and risks.
Project Schedule	Generalised project and task schedules showing major events, milestones, and points of critical action or decision.
Responsibility Assignments	List of key personnel and their responsibilities for work packages (project activities) and other areas of the project.
Budget and Cost	Budget, cost accounts, and sources of financial support. This includes estimates and timing of all capital and development expenses.
Quality Plan	Measures for monitoring quality and accepting results for individual work tasks, components, and end-item assemblies.
Risk Management Plan	Risk strategies, contingency and mitigation plans for areas posing greatest risk. The Risk Management Plan is prepared at the beginning of the model.
Communication Plan	Types of information to be distributed, the methods of distributing information to stakeholders, and the frequency of distribution and responsibilities of each person in the project team for distributing information regularly to stakeholders. This addresses the risk: Poor Communication
Work Review Plan	Procedures for periodic review of work. This includes what is to be done, by whom, when, and according to what standards.

Table 16: Continued

Content	Description
Change Control Plan	Procedures for review and handling of requests for changes or de facto changes to any respect of the project.
Procurement Plan	The policy, budget, schedule, plan, and controls for all goods, work, and services to be procured externally.
Documentation Plan	List of all documents to be produced, format, timing, and how they will be organised and maintained.
Implementation Plan	The procedures to guide customer conversion to or adoption of project deliverables

6.6.2.4 Phase 3: Execution

The third phase of the model is execution. In this phase the project is implemented and controlled as per the Project Master Plan developed in Phase 2. All the steps of this phase are illustrated in Figure 27 on the next page. The phase starts with the Project Action Plan and ends with the Phase Review

The Project Action Plan is developed as part of the Project Master Plan in the previous phase, and acts as the basis for the execution of the project. It brings four different planning activities together, namely:

1. Work Breakdown Structure;
2. Scheduling;
3. Responsibility Assignments; and
4. Financial Planning.

Before the deliverables are built, the project team must perform the risk management process that was described earlier. This is the second step in Phase 3 of the model.

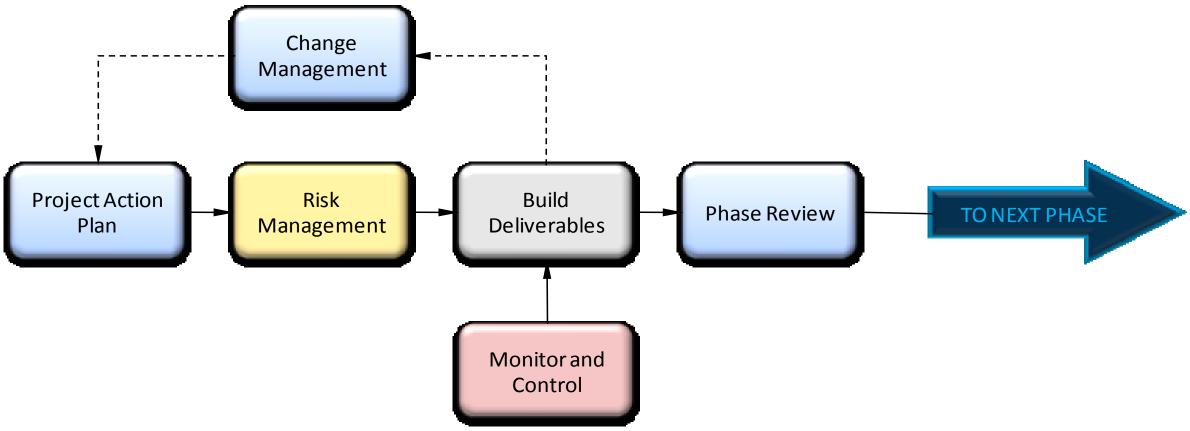


Figure 27: Phase 3 steps

After the identification and mitigation of risks, the team can start to build the deliverables. A range of management processes, developed during Phase 2, is implemented by the project manager to monitor and control the project. These processes were discussed in Chapter 2 under Subsection 2.2.2 and are not repeated here. Table 17 below only lists the processes. Additional information provided are the documents that are used during the respective monitoring and control process. All of these documents are given as templates with the model.

Table 17: Monitor and Control processes

Process	Documents Used
Cost Management	• Expense Form • Expense Register
Time Management	• Timesheet Form • Timesheet Register
Quality Management	• Quality Review Form • Quality Register
Acceptance Management	• Acceptance Form • Acceptance Register
Change Management	• Change Request Form • Change Register
Procurement Management	• Purchase Order Form • Procurement Register
Work Review Management	• Project Status Report

It can be seen that the change management process is included in Figure 27. This is done to highlight the importance, and the link to the project action plan, of this process. When changes do occur, a change request form has to be completed by the person requesting the change. The project manager then reviews it to decide if the change should be implemented or not. If it is implemented, the project action plan must be updated. It is also the task of the project manager to document all changes in the change register.

The final step of the second phase is a review, which includes a revision of several project aspects to date. This includes the project schedule, budget, deliverables, risks, issues, and changes made. No decision criteria are provided for this review. There is no turning back on completion of this phase. The customer will be unhappy if deliverables were not built according to the specifications, and for that reason the project can be seen as a failure.

6.6.2.5 Phase 4: Completion

The final phase of the model is termination and completion. In this phase it is confirmed that the project has been implemented or built to the design specifications. Two activities are performed during this phase, which is illustrated in Figure 28 below.

The first step is completing the project closure report. This report documents three important aspects of the project. The first is to determine whether all the project completion criteria have been satisfied. Secondly, all outstanding issues are documented, and actions are provided in order to resolve them. The last aspect is the identification of actions required to close the project. These required actions are:

- To hand over project deliverables and documentation to the customer;
- To terminate all contracts with suppliers;
- To release all project resources; and
- To communicate project closure to the relevant stakeholders.

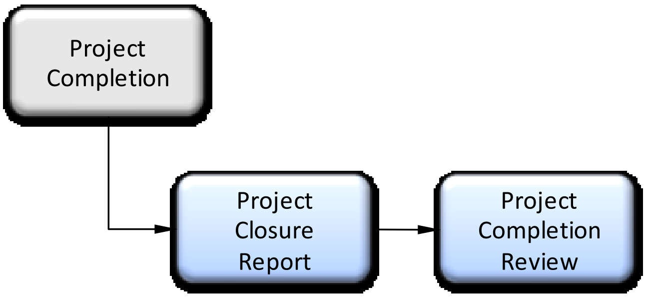


Figure 28: Phase 4 steps

The second step of this phase is the project review. Five project characteristics are reviewed during this step. The first is project performance regarding goals and objectives, benefits, scope, milestones and deliverables, expenses, and resources. The second is a review of the project achievements. All the major achievements are listed with the positive effects it had on the business. Project failures and lessons learned are the third and fourth characteristics reviewed, respectively.

The last characteristic is a review of the different project management processes. This review is performed in contradiction to their plans developed in Phase 2. For each process it is determined to what extent those plans were met. The processes reviewed are:

- Risk Management
- Resource Management
- Time Management
- Cost Management
- Communication Management
- Quality Management
- Work Review Management
- Change Control Management
- Procurement Management
- Implementation Management

6.7 Model Usage

The model is developed as a Microsoft Office Excel® Macro-Enabled Worksheet. Macros are used to automate repetitive tasks. The macros created in the model are mainly used to navigate through the model. In order to do this, macros are assigned to objects, called “buttons”, throughout the model. This allows the user to navigate through the model, by clicking on these buttons. The discussions that follow entails a description of the model worksheets, instructions and the templates used throughout the model.

6.7.1 Model Worksheets

The Excel worksheets used in this model are discussed in this subsection. Screenshots of these worksheets were taken and they are shown in Appendix C: Model Worksheets. However, macros must be enabled in order for the program to function. This is done in the following manner:

1. Open the file Project Management Integrated with Systems Engineering Principles Model.xlsm.
2. When the file is open a security warning, “Macros have been disabled”, will be displayed.
3. Click on “Options” and select “Enable this content”.
4. Click “OK”.

The macros will now be enabled and the program will function properly. Each of the model worksheets will now be discussed.

The model starts with a welcome page, as illustrated in Appendix C Figure 1. To start using the model the user must click on the “start” button. The second worksheet, illustrated in Appendix C Figure 2, is the instructions page. This provides all the instructions necessary to navigate through the model, how to open templates, and how to use the templates. These instructions are provided in Subsection 6.7.2. The third worksheet, model outline, is illustrated in Appendix C Figure 3.

The five model phases, as described under Subsection 6.6.2, start with the risk management plan on the fourth worksheet. This is illustrated in Appendix C Figure 4. The fifth worksheet is named Phase 1 and is shown in Appendix C Figure 5. This sheet portrays all the steps, as discussed in Subsection 6.6.2, of Phase 1. Phase 2, illustrated in Appendix C Figure 6, is the sixth worksheet of the model. Again, the steps discussed earlier are shown on this sheet. The difference is a green button that is added to move on to the project master plan, which is the seventh sheet. This worksheet is illustrated in Appendix C Figure 7. It can be seen from this figure that a button, “Back to Phase 2”, is added. This allows the user to move back to Phase 2 after the project master plan is completed. After the completion of the project master plan, the last steps of Phase 2 must be attended to. The eighth worksheet is Phase 3, and is illustrated in Appendix C Figure 8. The steps of this phase were also discussed in Subsection 6.6.2. An extra button, “Monitor and Control”, is added. This is done to navigate the user to the Monitor and control worksheet, which is illustrated in Appendix C Figure 9. It can be seen from this figure that a button, “Back to Phase 3”, is added. This allows the user to move back to Phase 3, after the project has been successfully monitored and controlled. The final worksheet is Phase 4, which is illustrated in Appendix C Figure 10. The steps of this phase were also discussed in Subsection 6.6.2.

6.7.2 Model Instructions

An instructional worksheet is provided with the model. This worksheet also acts as the home screen of the model. The model instructions are divided into two sections; 1) Navigational and 2) Opening of templates.

Model Navigation Instructions

1. The figures presented in Appendix C illustrate how to navigate through the model.
2. The panel on the left-hand side of these screenshots, with blue buttons, is used to navigate through the model.
3. Click on any one of the buttons to go to that respective worksheet.
4. The '**NEXT**' and '**BACK**' buttons, on each page, can also be used to navigate through the model.
    - If you click on '**NEXT**', the program will proceed to the next step in the model.
    - If you click on '**BACK**', the program will revert to the previous step in the model.
    - The '**INSTRUCTIONS**' worksheet, Appendix C Figure 2, acts as the home screen.
        - An extra button, '**HOME**', is added to the panel on the worksheets that follows the home screen.
        - If you click on '**HOME**', the program will return to this page

Opening Templates

1. The model is broken up into steps, as discussed earlier, which are presented in shapes that look like buttons. This is illustrated by the figures in Appendix C.
2. Blue buttons represents templates and gold buttons guides. Grey buttons are only used as a heading.
3. If the user moves over it with the mouse pointer, a command will appear that says 'Open …. Template' or 'Open .... Guide'.
4. The corresponding template will open by left-clicking on that button.

6.7.3 Model Templates

Various templates and guides are provided with the model. The instructions on how to use these templates are as follow:

1. A number of different text styles are used within the templates.
    - Text in *italics* is intended to provide a guide to the kind of information that can be included in a section.
    - Text in normal font is intended as examples.

- Text enclosed in *<angle brackets>* is intended to be replaced to whatever it is describing.

2. Upon completing the templates the user must make sure to remove all instructional text.

An example of a template, the communications plan, is provided in Appendix D. The three different text styles are illustrated in this example. The purpose of this subsection is to make the reader aware of all the templates and guides in the model. It can be seen below that the list is divided up into five sections; Risk Management, Phase 1, Phase 2, Phase 3 and Phase 4. The names of each document that can be found in each of these sections are given. Furthermore, it is shown whether it is a template or guide. This list is also provided with the model to ensure that confusion, as to where each template or guide belongs in the model, is avoided.

Risk Management

- Risk Management Plan - Guide
- Risk Form - Template
- Risk Register - Template

Phase 1

- Project Idea and definition - Template
- Joint Session 1 - Template
- Business Case - Template
- Feasibility Study - Template
- Joint Session 2 - Template
- Project Charter - Template
- Phase Review - Template

Phase 2

- Quality Function Deployment - Guide
- Joint Session 3 - Template
- Project Master Plan - Template
    - House of Quality - Template
    - Project Action Plan - Guide
        - Work Breakdown Structure - Template
        - Project Schedule - Template
        - Responsibility Assignments - Guide
        - Responsibility Matrix - Template
        - Financial Plan - Template
    - Quality Plan - Template
    - Communications Plan - Template
    - Work Review Plan - Template
    - Change Control Plan - Template

  - Procurement Plan - Template
  - Documentation Policy/Plan - Template
  - Implementation Plan - Template
- Phase Review - Template

Phase 3

- Change Management Plan - Template
- Monitor and Control
  - Expense Form - Template
  - Expense Register - Template
  - Timesheet Form - Template
  - Timesheet Register - Template
  - Quality Review Form - Template
  - Quality Register - Template
  - Acceptance Form - Template
  - Acceptance Register - Template
  - Change Request Form - Template
  - Change Register - Template
  - Purchase Order Form - Template
  - Procurement Register - Template
  - Project Status Report - Template
- Phase Review - Template

Phase 4

- Project Closure Report - Template
- Project Completion Review - Template

6.8 Chapter Conclusion

In this chapter, the PM model integrated with SE principles that was developed as part of this thesis was examined. This model was developed as a tool that can be used by engineers and their teams. Furthermore, the model is not intended to be the end product of the thesis, but rather a medium that illustrates the use of SE principles in PM, with the intent to reduce risks. In order to develop a model that integrates these principles, a thorough understanding of SE and project management risks were needed. For this purpose, the researcher undertook an investigation of several SE methodologies and strategies (Chapters 4 and 5 respectively) as well as a questionnaire regarding PM risks. In this chapter the data collected, and the results of the research, were analysed and discussed.

Several model parameters were identified in Section 6.5. The research and discussions provided in the previous sections addresses these parameters and are summarised below.

Large scale projects normally require an orderly development steps to ensure that testing and reviews are performed. The model was mainly based on the SE waterfall methodology that allows for testing and reviews. From the discussion in Section 6.6 it was seen that reviews are performed after each phase of the model. Orderly development also makes the model simpler.

Risk management is a very important aspect in the success of projects. This can only be achieved by preparing a comprehensive risk management plan. The model suggests that the risk management plan is linked to all four phases and that it must be prepared before any work on a project starts. It should be done in this manner to highlight its importance and to ensure that risk management is performed throughout the entire project.

Five important risks were identified in Section 6.3. The model aims to address them by using principles of SE. The most important risk was poorly defined requirements, as well as inaccurate estimates (fifth most important risk), are addressed by using the QFD strategy discussed in Section 5.2. The second and fourth identified risks, poor communication and lack of customer involvement, respectively, are closely related. These two risks were addressed by preparing a communications plan and involving the customers in the first two phases, by using the JAD strategy discussed in Subsection 5.3.1. Customer involvement also address the poorly defined requirements and inaccurate estimates risks, due to the second joint session performed that ensures the customer agrees with the project requirements and recommended solutions. The third most important risk, poor risk management, was addressed through proper risk management. Iterative development was also used in the first two phases. Poorly defined requirements and inaccurate estimates were addressed by using this SE development strategy.

The model was not aimed at a specific profession, which makes it generic. Two other parameters that were addressed are that the model steps in each phase are clearly laid out and the instructions are clear. Templates were used to guide the project manager and team through the various steps of the model. These templates were discussed in Subsections 6.6.2 and 6.7.3.

7. Model Validation

7.1 Chapter Introduction

The validation of the model that was developed as part of this thesis is based on expert opinion. This is performed by experts in the project management industry. They will go through the model, test it, and complete a review questionnaire. The purpose of this validation is to see if the objectives of the research were met, and if the model is valid in the sense of ease of use and usefulness. The final objective of the validation process is to determine if the integration of systems engineering (SE) principles into project management (PM) were successful, and if it will reduce risks in large scale projects.

7.2 Model Testing by Professionals

The completed model, as discussed in Chapter 6, was evaluated by experts in the project management community. Several project managers offered to participate in the validation process of the model. The researcher gave them the model and a review questionnaire, which can be seen in Appendix E: Model Review Questionnaire. All the model instructions were included in the file Project Management Integrated with Systems Engineering Model.xlsm, which is a Microsoft Office Excel file. The instructions on how to conduct the review were given with the review questionnaire. This review questionnaire contained the following questions:

1. Were the instructions provided clear and unambiguous, so that it was easy to use?
2. Was the model easily understood (i.e. the different processes within the phases)?
3. Did you find the various templates and guides practical?
4. Will you be able to use the various templates and guides?
5. Would you make use of the model?
6. Did you notice that principles of Systems Engineering were being used?
7. Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?
8. Do you think this model will reduce risks in large scale projects?
9. What is your overall impression of the model?
10. What recommendations do you have that would enhance the model?

Each reviewer was asked to give a rating between 1 and 5 for each question, where 1 meant *'not at all'*, 2 meant *'no'*, 3 meant *'sometimes'*, 4 meant *'yes'* and 5 meant *'definitely'*. The reviewer was also encouraged to comment on each question. These comments are discussed under

Section 7.3. Furthermore, the reviewers were also asked to list any recommendations that could enhance the model.

A total of seven responses were obtained for the validation of the model. The completed review questionnaires are attached to this document and can be seen in Appendix F: Review Questionnaire Answer Sheets. The field of management and qualifications of the reviewers are illustrated in Table 18.

Table 18: Field of management and qualifications of reviewers

Reviewer	Field of Management	Qualifications
1	Civil (Construction)	M.Sc Engineering (Engineering Management)
2	CEO – Food industry	M.Sc Chemical Engineering
3	Project Manager - Consulting	Pr.Eng, Pr. CPM, C.Eng
4	Project Manager – Machine Construction	Pr.Eng
5	Engineering Manager – Food Industry	B.Eng
6	CEO – Machine Construction	Pr.Eng
7	Project Manager – Machine Construction	B.Sc (Mechanical Engineering), M.Sc Industrial Engineering

7.3 Feedback and Validation

7.3.1 Rating Review

The feedback ratings from the reviewers are given in Table 19 on the next page. This table contains the ratings they gave for each question, as well as the mean, standard deviation, and variance for each question, sample group and the overall data. The mean is the average or expected value of a data set. Standard deviation is defined as the measure of how widely values are dispersed from the mean. The variance is an indicator of how far the ratings are placed from the mean, and therefore it is a parameter that gives an indication of the distribution of the ratings in the sample.

Table 19: Model validation data

Question	Reviewers							Overall	Mean (x)	Standard Deviation (s)	Variance (s^2)
	1	2	3	4	5	6	7				
1	4	3	3	4	5	4	5		4.00	0.82	0.67
2	5	5	4	4	5	4	5		4.57	0.53	0.29
3	4	4	3	5	4	4	4		4.00	0.58	0.33
4	3	5	3	5	4	4	4		4.00	0.82	0.67
5	4	4	2	3	3	3	3		3.14	0.69	0.48
6	4	4	4	4	3	4	3		3.71	0.49	0.24
7	4	5	5	5	4	4	5		4.57	0.53	0.29
8	4	5	2	5	4	5	5		4.29	1.11	1.24
9	4	5	-	4		4	5		4.40	0.55	0.30
								Overall			
Mean (x)	4.00	4.44	3.25	4.33	4.00	4.00	4.33	**4.07**			
Standard Deviation (s)	0.50	0.73	1.04	0.71	0.76	0.50	0.87	**0.79**			
Variance (s^2)	0.25	0.53	1.07	0.50	0.57	0.25	0.75	**0.63**			

It can be seen from Table 19 that the mean for most of the questions are higher than four. This indicates that the reviewers are in agreement that they are satisfied with those aspects of the model. Question five obtained the lowest mean, 3.14. This indicates that the reviewers will sometimes make use of the model. The reason behind this is that most companies have set procedures on how to do their projects. The standard deviation and variance of most of the questions, except question eight, is below one. This indicates that the reviewers were in agreement for most of the questions.

The mean, standard deviation and variance were also calculated for each reviewer (sample group). It can be seen from Table 19 that 6 out of the seven reviewers obtained a mean greater than four. This gives an indication that the model satisfied the objectives tested through this review for the individual reviewers. Reviewer three has a mean of 3.25. This indicates that the model sometimes satisfies its objective for this particular reviewer. The standard deviation and variance for each reviewer is less than or very close to one, which indicates that the reviewers were in agreement.

The mean, standard deviation and variance were also calculated for the overall data. Table 19 shows that the overall mean is equal to 4.07, which indicates that the model more than satisfies the objectives tested through this review. The overall standard deviation and variance of the entire sample group are less than one. This suggests that all of the reviewers were in agreement.

The first objective of the validation process was to determine if the model is easy to use and understand. Questions 1 and 2 measure the ease of which the model can be used. It is shown in Table 20 that the mean of these two questions is 4.29. A rating of 4 means "yes", which indicates that the reviewers found it easy to use and understand the model. The standard deviation and variance are below one for questions 1 and 2, which suggest that the reviewers were in agreement that the model is easy to use and understand.

Table 20: Ratings of certain questions

	Ease of Use Questions 1-2	**Useful / Practical** Questions 3-5	**Successful Integration** Questions 6-7	**Risk Reduction** Question 8
Mean (x)	4.29	3.71	4.14	4.29
Standard Deviation (s)	0.73	0.78	0.66	1.11
Variance (s^2)	0.53	0.61	0.44	1.24

The second objective of the validation process was to determine if the model is practical and useful. Questions 3, 4 and 5 measure the practicality and usefulness of the model. Table 20 shows that the mean for these questions is 3.71. A rating of 3 means “sometimes” and 4 means “yes”. This value of 3.71 therefore indicates that the reviewers found the model to be practical and useful. The standard deviation and variance are below one for these questions, which suggest that the reviewers were in agreement that the model is practical and useful.

The final objective of the validation process was to determine if the integration of SE principles into PM were successful, and if it will reduce risks in large scale projects. Questions 6 and 7 measure the successfulness of the integration. Table 20 shows that the mean for these questions is 4.14, which indicates that the principles of SE were successfully integrated into PM. The standard deviation and variance are below one for these questions, which also suggest that the reviewers were in agreement that the principles were successfully integrated. Question 8 measure if the integration of these principles will reduce risks. Table 20 shows that the mean for this question is 4.29, which indicates that the reviewers believe that risks will be reduced in large scale projects. The standard deviation and variance were above one. The reason for this is the low rating that the question obtained by the third reviewer.

7.3.2 Feedback and Recommendations

The participants that took part in the review of this model were encouraged to give comments on the various questions asked. This feedback is summarised in Table 21 below. It can be seen from this table that most of the comments made were positive in nature. This gives one an indication that the reviewers were satisfied with the model and that it achieved its objectives.

Table 21: Feedback from reviewers

Question	Feedback
1. Were the instructions provided clear and unambiguous, so that it was easy to use?	• The instructions were clear • Yes • In general, yes
2. Was the model easily understood (i.e. the different processes within the phases)?	• Yes • The logic was easy to follow
3. Did you find the various templates and guides practical?	• Good quality, well explained and practical • Yes. In industry, some training would usually be required to implement something like this • The size of the project determines just how much • A bit superficial and too time consuming, but ok

Table 21: Continued

Question	Feedback
4. Will you be able to use the various templates and guides?	• Our company has its own templates, but these templates are definitely well thought through and could be useful • Yes • When the project warrants it • I'd be inclined to use them as a check list
5. Would you make use of the model?	• A model like this would be useful • If a project needs to be well documented, e.g. if it will be used to secure further funding or register patents, it would be appropriate. Most projects I deal with do not and this would be seen as unnecessary paperwork • Depends on the scope. • But one is inclined after many years to get slack • We perform several projects and mini-projects at any given time. Very simple, small, low cost and complexity projects would not require the time and effort of going through the process envisaged herein
6. Did you notice that principles of Systems Engineering were being used?	• I don't know much about systems engineering • 30 years since I looked at "academic" industrial engineering • I am not familiar with any of the formal systems of project management. However, having dealt with formal project managers in the past, some of their processes were evident
7. Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	• Excellent idea • I'd say there are many appropriate applications of SE in PM • Anything that imposes systematic rational thought onto the process of mismanaging a project by the method of "didn't think of that"
8. Do you think this model will reduce risks in large scale projects?	• Could be very valuable in large scale projects • Yes – it forces methodical & logical thinking • Managing your projects through this process could definitely benefit the project • The model is a means of formalising procedures to ensure that steps are not missed, and that the all-important buy-in from ALL departments/divisions is obtained
9. What is your overall impression of the model?	• Very well thought through, applicable templates and practical. I like that the process is an integrated system • Very good • The rating scale does not respond to this question • Seems well thought out and makes it easy to access many templates from a simple hub • Easy to use, implement and check. Well presented • It would be a good model to give project engineers, combined with the instruction that they have to tick off each aspect that they have "done" and justify why they have not done some of them. However, it is rather "long" for application to small projects being carried out by small time pressed team • It would appear to be a very useful tool to ensure that processes followed in complex project management are formalised, documented, and recorded

The reviewers were also requested to list any recommendations they may have that would enhance the model. The recommendations given by them are:

1. As with the Risk Management Plan, the Project Master Plan and Quality Plan should run parallel with the project.
2. The model should account for the fact that Project Design, Planning and Management are iterative processes. They run in loops and are not linear.
3. A more comprehensive introduction to what the tool does, and why, could be useful.
4. An interactive feedback mechanism could be included to control the proper use of the model, for instance:
    a. A description of the project that includes scores on some of the variables, which will allow the model to highlight stages or steps that really needs to be done for that particular project.
    b. By filling in responses in some areas the model could demand responses to logically connect other areas, or hide areas that are not actually needed.
5. Develop a less involved model in order to deal with less complex projects. In that way the model could become the standard for future project management for all projects. The principle focus is on the management of risks, which are applicable to both simple and complex systems. However, the complexity of this model would make it unattractive to simpler projects which would then lose the benefit of the risk focus.

7.4 Chapter Conclusion

In this chapter the model was validated to see whether the objectives of the research were met. The three objectives of the validation process were:

1. Determine the validation of the model in the sense of ease of use and usefulness.
2. To determine if the integration of SE principles into PM were successful.
3. To determine if the use of SE principles will reduce risks in large scale projects.

From the discussions in the previous sections it can be concluded that the validation process did meet the three objectives listed above. Feedback from the reviewers was also mainly positive, which indicates that that the reviewers were satisfied with the model and that it achieved its objectives. The reviewers were also asked to list recommendations that may enhance the model. They listed several recommendations, as discussed in subsection 7.3.2, that may lead to future studies.

8. Conclusions and Recommendations

8.1 Thesis Conclusions

8.1.1 Processes and Principles

The first objective of the thesis was to understand the processes and principles of project management (PM), systems engineering (SE) and risk management. These processes and principles were researched and discussed in the literature review.

It is concluded from this research that many projects fail to meet the three goals of PM, and therefore a need exist for improved PM. This failure is mainly due to the complexity of modern projects, poor risk management, inadequate articulation of requirements and inadequate technical skills.

It is also concluded from the research reported in the literature study that SE allows for a more holistic and systematic approach. These characteristics were found to be beneficial in the improvement of PM if the disciplines are integrated. Various SE approaches and strategies were investigated in Chapters 4 and 5. It is concluded from the investigation in Chapter 4 that the model mainly follows the Waterfall, V-model and Shigley methodologies. These methodologies are based on large projects. They have an orderly sequence of development steps, iterative development and strict controls that ensure testing and revision of each project phase. It is concluded that these characteristics are beneficial to the improvement of PM, and therefore it was used in the development of the model.

The final process that was researched in the literature study is risk management. The aim of this investigation was to determine whether risk management is essential to the success of a project. It was concluded from this investigation that formal and effective risk management processes plays an important role in the success of a project, and therefore it was used in the model. Another important aspect of risk management was that it should be implemented throughout the entire life cycle of a project.

8.1.2 Project Management Risks

The second objective of the thesis was to identify areas of greater risk within the management of projects. It is concluded from the survey that the following five risks poses the biggest threat to the success of a project (in order of importance):

1. Poorly defined requirements;

2. Poor communication;
3. Poor risk management;
4. Lack of customer involvement; and
5. Inaccurate estimates.

8.1.3 Model

The final objective of this research was to develop an effective generic model, by integrating the principles of SE into PM. The goal of this model was to reduce the five identified risks. This model was intended to be a tool that illustrated the researched PM, SE and risk management principles, as well as the fact that they are integrated. The model also demonstrated the use of orderly development steps, which ensures that testing and reviews are performed after each phase of the project. It was also not aimed at a specific profession, which makes it generic. Risk management was applied throughout the entire model. It was seen that the risk management plan is linked to all four phases and that it must be prepared and completed before any work on a project starts.

It is concluded from the discussions on the model that the identified risks were successfully addressed with the use of SE principles, namely:

- Poor risk management was addressed by following proper risk management processes. This process flow concurrent to the project and therefore utilises the concurrent engineering principle of SE.
- Poorly defined requirements and inaccurate estimates were addressed by using the requirements engineering strategy.
- Poor communication and lack of customer involvement were addressed by preparing a communications plan and using the joint application development (JAD) SE methodology.
- The involvement of the customer subsequently addressed the poorly defined requirements and inaccurate estimates risks.
- Iterative development was used in the first two phases to address the risks poorly defined requirements and inaccurate estimates.

It is concluded that the model successfully illustrate the integration of SE into PM, to reduce the five identified risks. Furthermore, based on the validation of the model, it can also be concluded that the model satisfies its objectives.

8.2 Proof of Hypothesis

The research conducted in this thesis, the literature study and investigations into SE and PM risks, gave the author a good understanding of PM, SE principles and risk management. It was concluded that SE allows for a more systematic approach than PM. Furthermore, various principles of SE were successfully integrated into PM. For these reasons the first hypothesis made, “The application of SE principles in PM will result in a more systematic approach”, is true.

The model that was created illustrated the integration of SE principles into PM and the importance of risk management. It was concluded that the SE principles that were used in the model addressed the five identified risks. This was also confirmed during the validation of the model. For these reasons the second hypothesis made, “The integration of systems engineering principles into project management will reduce risks in large scale projects”, is true.

8.3 Recommendations and Future Studies

The research reported on the principles and processes of PM, SE and risk management and to integrate the principles of SE into PM could have been improved in various ways. These recommendations and future studies are discussed below.

From the discussions in the thesis it was apparent that communication is a very important factor in successful projects. For this reason, it will be appropriate to look into the impact that communication has on projects. Future studies may include the use of case studies on communication, in the management of projects.

SE principles that were integrated into PM were mainly used in the first two phases of the model that was developed. Further investigation into the use of SE principles in phase three may be researched. It is recommended that the use of customer involvement may be used in this phase when changes occur. For this reason, future studies may include investigation of the impact the customer has on project changes and the change management process.

The model was only reviewed by experts in the project management industry. Future studies may include testing of the model on an active project. The problem with this is that it would be difficult, due to the fact that it is based on large scale projects. However, a study of this measure will greatly improve the validity of the model.

Several recommendations were made by the reviewers during the validation of the model. The main recommendations that could lead to future studies are:

1. As with the Risk Management Plan, the Project Master Plan and Quality Plan should run parallel with the project. Future studies may include the investigation of this, so that it can be used in the model
2. An interactive feedback mechanism could be included to control the proper use of the model, for instance:
   a. A description of the project that includes scores on some of the variables, which will allow the model to highlight stages or steps that really needs to be done for that particular project.
   b. By filling in responses in some areas the model could demand responses to logically connect other areas, or hide areas that are not actually needed.
3. Develop a less involved model in order to deal with less complex projects. In this way the model could become the standard for future project management for all projects. The principle focus is on management of risks which are applicable to both simple and complex systems. However, the complexity of this model would make it unattractive to simpler projects which would then lose the benefit of the risk focus. Future studies may include trade-off studies between a more and less complex model. This would be beneficial in the sense where and when each model could be used.

9. References

Abbot, K., & Abbot, R. (n.d.). *Joint Application Development.* Retrieved April 20, 2012, from University of Maryland: userpages.umbc.edu/~cseaman/ifsm698/spr01/JAD.ppt

Baldwin, C. (2010). *Project Management and its Relation to Systems Engineering.* Retrieved April 20, 2012, from INCOSE: http://www.incose.org/delvalley/baldwin_11_18_03.pdf

Beynon-Davies, P., & Holmes, S. (2002). Design breakdowns, scenarios and rapid application development. *Information and Software Technology* , 579–592.

Boehm, B. W. (1988). *A Spiral Model of Software Development and Enhancement.* TRW Defence Systems Group.

Boehm, B., Koolmanojwong, S., Lanea, J., & Turner, R. (2012). Principles for Successful Systems Engineering. *Procedia Computer Science* , 297 – 302.

Bruzelius, N., Flyvbjerg, B., & Rothengatter, W. (2002). Big decisions, big risk. Improving accountability in mega projects. *Transport Policy* , 143-154.

Bucanac, C. (1999, January 4). *The V-Model.* Retrieved June 02, 2012

Burke, R. (2006). *Project Management: Planning & Control Techniques* (5th ed.). England: Burke Publishing.

Calleam Consulting Ltd. (2012). Retrieved June 02, 2012, from Why Technology Projects Fail: A resource center for advanced learning: http://calleam.com/WTPF/?page_id=1445

CASEMaker Inc. (2000). Retrieved June 02, 2012, from What is Rapid Application Development?: http://www.casemaker.com/download/products/totem/rad_wp.pdf

Centerline Solutions. (2005, February 18). Retrieved March 16, 2012, from 10 Major Causes of Project Failure: www.gtislig.org

CMS. (2008). *Selecting a Development Approach.* Centers for Medicare and Medicaid Services (CMS), Department of Health and Human Services, USA.

Coley Consulting. (2012). Retrieved March 16, 2012, from Why do projects fail?: http://www.coleyconsulting.co.uk/failure.htm

De Bakker, K., Boonstra, A., & Wortmann, H. (2010). Does risk management contribute to IT project success? A meta-analysis of empirical evidence. *International Journal of Project Management* , 493–503.

De Bono, E. (2005). *Serious Creativity: Using the Power of Lateral Thinking to Create New Ideas.* Zondervan.

Denscombe, M. (2010). *The Good Research Guide: for small-scale social research projects* (4th ed.). Maidenhead: Open University Press.

Dinsmore, P. C., & Cabanis-Brewin, J. (2006). *The AMA Hanbook of Project Management.* USA: AMACOM.

DoD-USA. (2001, January). *Systems Engineering Fundamentals.* Retrieved October 15, 2011, from http://www.dau.mil/pubs/pdf/SEFGuide%2001-01.pdf

Dorsey, P. (2005). *Top 10 Reasons Why Systems Projects Fail.* Retrieved April 20, 2012, from www.hks.harvard.edu

Eisner, H. (2002). *Essentials of Project and Systems Engineering Management* (2 ed.). New York: John Wiley & Sons, Inc.

Ferreira, S., & Faezipour, M. (2012). An Analysis of Processes, Risks, and Best Practices for Use in Developing Systems Engineering Process Simulators. *Procedia Computer Science* , 87 – 92.

Flores, J. A., Salcedo, O. H., Pineda, R., & Nava, P. (2012). Senior Project Design Success and Quality: A Systems Engineering Approach. *Procedia Computer Science* , 452 – 460.

Fourie, C. J. (2011). A Modular Course in Project Management. *(15th ed.)* . University of Stellenbosch: Department of Industrial Engineering.

Frank, M. (2012). Engineering Systems Thinking: Cognitive Competencies of Successful Systems Engineers. *Procedia Computer Science* , 273 – 278.

Frederick, C., & Sauser, B. (2007). Studies on Systems Engineering Benefits. *Conference on Systems Engineering Research* (pp. 1-10). Hoboken, NJ , USA: Stevens Institute of Technology.

Frigenti, E., & Comninos, D. (2002). *The Practice of Project Management: A Guide to the business-focused Approach.* London: Kogan Page.

G2SEBoK. (2004). *INCOSE - Guide to the Systems Engineering Body of Knowledge*. Retrieved April 9, 2012, from http://g2sebok.incose.org/

Green, D., & DiCaterino, A. (1988). *A Survey of System Development Process Models.* Retrieved May 30, 2012, from Center for Technology in Government: www.ctg.albany.edu/publications/reports/survey_of_sysdef

Hauser, J. R., & Clausing, D. (1988). The House of Quality. *The Harvard Business Review* , 63-73.

Hoyle, D. (2007). *Quality Management Essentials.* Oxford: Elsevier Ltd.

IEEE. (2005). *IEEE Standard for Application and Management of the Systems Engineering Process.* New York: The Institute of Electrical and Electronics Engineers, Inc.

INCOSE. (2007). *Systems Engineering Handbook* (Vol. 3.1). International Council on Systems Enginering.

Industries, C. (2011). *Quality Function Deployment.* Retrieved June 2, 2012, from http://www.ciri.org.nz/downloads/Quality%20Function%20Deployment.pdf

Kapsali, M. (2011). Systems thinking in innovation project management: A match that works. *International Journal of Project Management* , 396–407.

Kerzner, H. (2009). *Project Management: A Systems Approach to Planning, Scheduling and Controlling.* John Wiley & Sons.

Königs, S. F., Beier, G., Figge, A., & Stark, R. (2012). Traceability in Systems Engineering – Review of industrial practices, state-of-the-art technologies and new research solutions. *Advanced Engineering Informatics* , 924–940.

Kossiakoff, A., Sweet, W. N., Seymour, S. J., & Biemer, S. M. (2011). *Systems Engineering: Principles and Practice* (2 ed.). New Jersey: John Wiley & Sons, Inc.

Lawrence, B., Wiegers, K., & Ebert, C. (2001). The Top Risks of Requirements Engineering. *The Atlantinc Systems Guild* , 62-63.

Leishman, T. R., & Cook, D. A. (2002, April). *CrossTalk: The Journal of Defence Software Engineering.* Retrieved June 02, 2012, from Requirements Risks Can Drown Software Projects : http://www.stsc.hill.af.mil/crosstalk/2002/04/leishman.html

Loch, C. H., DeMeyer, A., & Pich, M. T. (2006). *Managing the Unknown: A New Approach to Managing High Uncertainty and Risks in Projects.* USA: John Wiley & Sons, Inc.

Meredith, J. R., & Mantel, S. J. (2006). *Project Management: A Managerial Approach* (6th ed.). Asia: John Wiley & Sons, Inc.

Method123. (2003). *Project Management Guidebook.* Retrieved February 2012, from Method123: www.method123.com

Nicholas, J. M., & Steyn, H. (2008). *Project Management for Business, Engineering, and Technology: Principles and Practice* (3rd ed.). Oxford: Butterworth-Heinemann.

Ören, T., & Yilmaz, L. (2012). Synergies of simulation, agents, and systems engineering. *Expert Systems with Applications* , 81–88.

Parnell, G. S., Driscoll, P. J., & Henderson, D. L. (2008). *Decision Making in Systems Engineering and Management.* New Jersey: John Wiley & Sons, Inc.

PMI. (2008). *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* Project Management Institute.

Prasanta, K. D. (2002). Project Risk Management: A Combined Analytic Hierarchy Process and decision Tree Approach. *Cost Engineering , vol. 44, no. 3*, 13-26.

Raspotnig, C., & Opdahl, A. (2013). Comparing risk identification techniques for safety and security requirements. *The Journal of Systems and Software* , In press: http://dx.doi.org/10.1016/j.jss.2012.12.002.

Reilly, N. B. (1993). *Successful Systems Engineering for Engineers and Managers.* New York: Van Nostrand Reinhold.

SANS. (2009). Standard South African National Standard. *ISO 31000:2009/SANS 31000:2009 - Risk Management - Principles and Guidelines* . SABS Standards Division.

Sauser, B. J., Reilly, R. R., & Shenhar, A. J. (2009). Why projects fail? How contingency theory can provide new insights – A comparative analysis of NASA's Mars Climate Orbiter loss. *International Journal of Project Management* , 665–679.

Sharon, A., de Weck, O. L., & Dori, D. (2011). Project Management vs. Systems Engineering Management: A Practitioners' View on Integrating the Project and Product Domains. *Wiley Periodicals, Inc.* , 1-14.

Shigley, J. E., Miscke, C. R., & Budynas, R. G. (2004). *Mechanical Engineering Design* (7th ed.). New York: McGraw-Hill.

Software Development Methodologies. (2012). Retrieved April 20, 2012, from IT Knowledge Info: http://www.itinfo.am/eng/software-development-methodologies

Stashevsky, S., & Elizur, D. (2000). The effect of quality management and participation in decision-making on individual performance. *Journal of Quality Management* , 53-65.

Stem, D. E., Boito, M., Younossi, & Obaid. (2006). *RAND.* Retrieved October 15, 2011, from Systems engineering and program management trends and costs for aircraft and guided weapons programs: http://www.rand.org/pubs/monographs/2006/RAND_MG413.pdf

Stewart, R. W., & Fortune, J. (1995). Application of systems thinking to the identification, avoidance and prevention of risk. *International Joumal of Project Management* , 279-286.

Thomas, J., & Mengel, T. (2008). Preparing project managers to deal with complexity – Advanced project management education. *International Journal of Project Management* , 304-315.

Trappey, C. V., Trappey, A. J., & Hwang, S.-J. (1996). A Computerized Quality Function Deployment Approach for Retail Services. *Computers Industrial Engineering* , 611-622.

Visser, W. (2012). *Software Engineering: a brief introduction.* Stellenbosch University, Faculty of Science, Stellenbosch.

Vose, D. (2008). *Risk Analysis: A Quantitative Guide.* England: John Wiley & Sons, Ltd.

Wysocki, R. K. (2007). *Effective Project Management* (4th ed.). USA: Wiley Publishing, Inc.

Zipes, L. F. (n.d.). *Program Management vs Systems Engineering.* Retrieved April 20, 2012, from http://www.dtic.mil/ndia/2007systems/Wednesday/AM/Track3/5381.pdf

10. Appendices

10.1 Appendix A: Project Management Risks Questionnaire

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Identified Risks:

1. Poorly defined requirements
2. Scheduling: too tight, unrealistic or overly optimistic
3. Change in environment
4. Poor risk management
5. Inadequate resources
6. Poorly defined deliverables
7. Poor testing
8. Communication
9. Unclear project objectives
10. Lack of change management
11. Inaccurate estimates
12. Lack of customer involvement
13. Scope creep
14. Quality Control

List in Order of Importance:
(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) -

2) -

3) -

4) -

5) -

Questions:

Are these risks valid?

Are there any other risks that should be identified?

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

10.2 Appendix B: Risk Questionnaire Answer Sheets

Participant 1:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Multi-disciplinary projects

Identified Risks:

8. Poorly defined requirements
9. Scheduling: too tight, unrealistic or overly optimistic
10. Change in environment
11. Poor risk management
12. Inadequate resources
13. Poorly defined deliverables
14. Poor testing
15. Communication
16. Unclear project objectives
17. Lack of change management
18. Inaccurate estimates
19. Lack of customer involvement
20. Scope creep
21. Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 1

2) - 4

3) - 8

4) - 10

5) - 12

Questions:

Are these risks valid?

Yes

Are there any other risks that should be identified?

Control systems should be in place to ensure successful projects

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 2:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Construction

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 4

2) - 8

3) - 1

4) - 9

5) - 11

Questions:

Are these risks valid?

Yes

Are there any other risks that should be identified?

Poor specifications, however it is directly related to poorly defined requirements and unclear project objectives

Any other comments?

None

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 3:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Civil engineering

Identified Risks:

. Poorly defined requirements
. Scheduling: too tight, unrealistic or overly optimistic
. Change in environment
. Poor risk management
. Inadequate resources
. Poorly defined deliverables
. Poor testing
. Communication
. Unclear project objectives
. Lack of change management
. Inaccurate estimates
. Lack of customer involvement
. Scope creep
. Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 1

2) - 4

3) - 8

4) - 12

5) - 3

Questions:

Are these risks valid?

Yes

Are there any other risks that should be identified?

Inadequate monitoring

Any other comments?

None

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 4:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Consulting (multi-disciplinary projects)

Identified Risks:

. Poorly defined requirements
. Scheduling: too tight, unrealistic or overly optimistic
. Change in environment
. Poor risk management
. Inadequate resources
. Poorly defined deliverables
. Poor testing
. Communication
. Unclear project objectives
. Lack of change management
. Inaccurate estimates
. Lack of customer involvement
. Scope creep
. Quality Control

List in Order of Importance:
(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 8

2) - 12

3) - 1

4) - 4

5) - 11

Questions:

Are these risks valid?

Yes. However, 8 and 12 are related and have an impact on 1. But all three are important.

Are there any other risks that should be identified?

External risks (e.g. political and legal)

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 5:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Consulting on multi-disciplinary projects (range from IT to construction)

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 1

2) - 10

3) - 8

4) - 4

5) - 13

Questions:

Are these risks valid?

Yes. Poorly defined requirements, lack of user involvement and communication are related, but all three are important. Risk management is always important in projects. Scope creep is also a risk, which is related to lack of change management, poorly defined deliverables and unclear project objectives.

Are there any other risks that should be identified?

Economic risks

Any other comments?

None

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 6:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Machine construction

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 1

2) - 7

3) - 11

4) - 14

5) - 8

Questions:

Are these risks valid?

Yes.

Are there any other risks that should be identified?

Mistakes in design and the omission of important aspects

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 7:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Food industry

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 14

2) - 3

3) - 11

4) - 12

5) - 1

Questions:

Are these risks valid?

Yes. Quality control is very important in the food industry.

Are there any other risks that should be identified?

Worker safety – this should be identified during risk management.

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 8:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Civil Engineering

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 5

2) - 1

3) - 12

4) - 4

5) - 8

Questions:

Are these risks valid?

Yes

Are there any other risks that should be identified?

In construction one of our biggest risks are site conditions.
Also the contractor's lack of experience could be a major risk.
Quality control (In construction, that's more important than testing)
Lack of feasibility studies (in construction that includes site investigations, geotechnical studies,
Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 9:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Civil engineering

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - Communication

2) - Poorly defined requirements

3) - Inaccurate estimates

4) - Scope creep

5) - Change in environment

Questions:

Are these risks valid?

Yes. However, project risk profile will depend on the project type, scope, size, complexity, etc. After 25 years of working with projects, I have learnt that communication is the biggest project risk there is. Furthermore, there is a direct relationship between this risk and the complexity of the project.

Are there any other important risks that should be identified?

Stakeholder Management. This is however related to communication. Other than that, the list is pretty complete.

Any other comments?

None

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 10:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Consulting Civil Engineer

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) 1

2) 8

3) 14

4) 12

5) 11

Questions:

Are these risks valid?

Yes

Are there any other important risks that should be identified?

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 11:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Civil/ structural engineering

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - Poorly defined requirements

2) - Communication

3) - Quality Control

4) - Change in environment

5) - Lack of customer involvement

Questions:

Are these risks valid?

Y, but should be limited through effective project management

Are there any other important risks that should be identified?

Any other comments?

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 12:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Management of multi-disciplinary projects (not in the Building sector), esp for feasibility studies, concentrating on the waste, environmental and water infrastructure sectors.

Identified Risks:

- Poorly defined requirements
- Scheduling: too tight, unrealistic or overly optimistic
- Change in environment
- Poor risk management
- Inadequate resources
- Poorly defined deliverables
- Poor testing
- Communication
- Unclear project objectives
- Lack of change management
- Inaccurate estimates
- Lack of customer involvement
- Scope creep
- Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) 13 Scope creep

2) 1 Poorly defined requirements

3) 8 Communication

4) 6 Poorly defined deliverables

5) 10 Lack of change management

Questions:

Are these risks valid?

Yes

Are there any other important risks that should be identified?

Inexperienced and ill informed clients

Clients not understanding that in investigative studies, one does not know what one will find. If we knew what the findings would be at the start, there would be no need for the stud! The procurement rules are too inflexible to allow changes in scope, which may become necessary, only after the work has progressed somewhat.

Any other comments?

The most sophisticated approach risk management that I have encountered is as practiced by Transnet Capital Projects (Francois.Joubert@ transnet.net) Please don't bother him unnecessarily.

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

Participant 13:

Project Management Risks

Note: All the answers can be typed and answered on the document.

Project Management Field:

(Please state the field of your work)

Civil engineering

Identified Risks:

. Poorly defined requirements
. Scheduling: too tight, unrealistic or overly optimistic
. Change in environment
. Poor risk management
. Inadequate resources
. Poorly defined deliverables
. Poor testing
. Communication
0. Unclear project objectives
1. Lack of change management
2. Inaccurate estimates
3. Lack of customer involvement
4. Scope creep
5. Quality Control

List in Order of Importance:

(Please rate five of the identified risks in order of importance; from 1 to 5.)

1) - 8

2) - 4

3) - 1

4) - 3

5) - 14

Questions:

Are these risks valid?

Yes, 1, 6 and 9 are all related to 8(communication)

2 and 5 should be addressed before the “project management” stage of a project

7 and 14 very much the same thing

Are there any other important risks that should be identified?

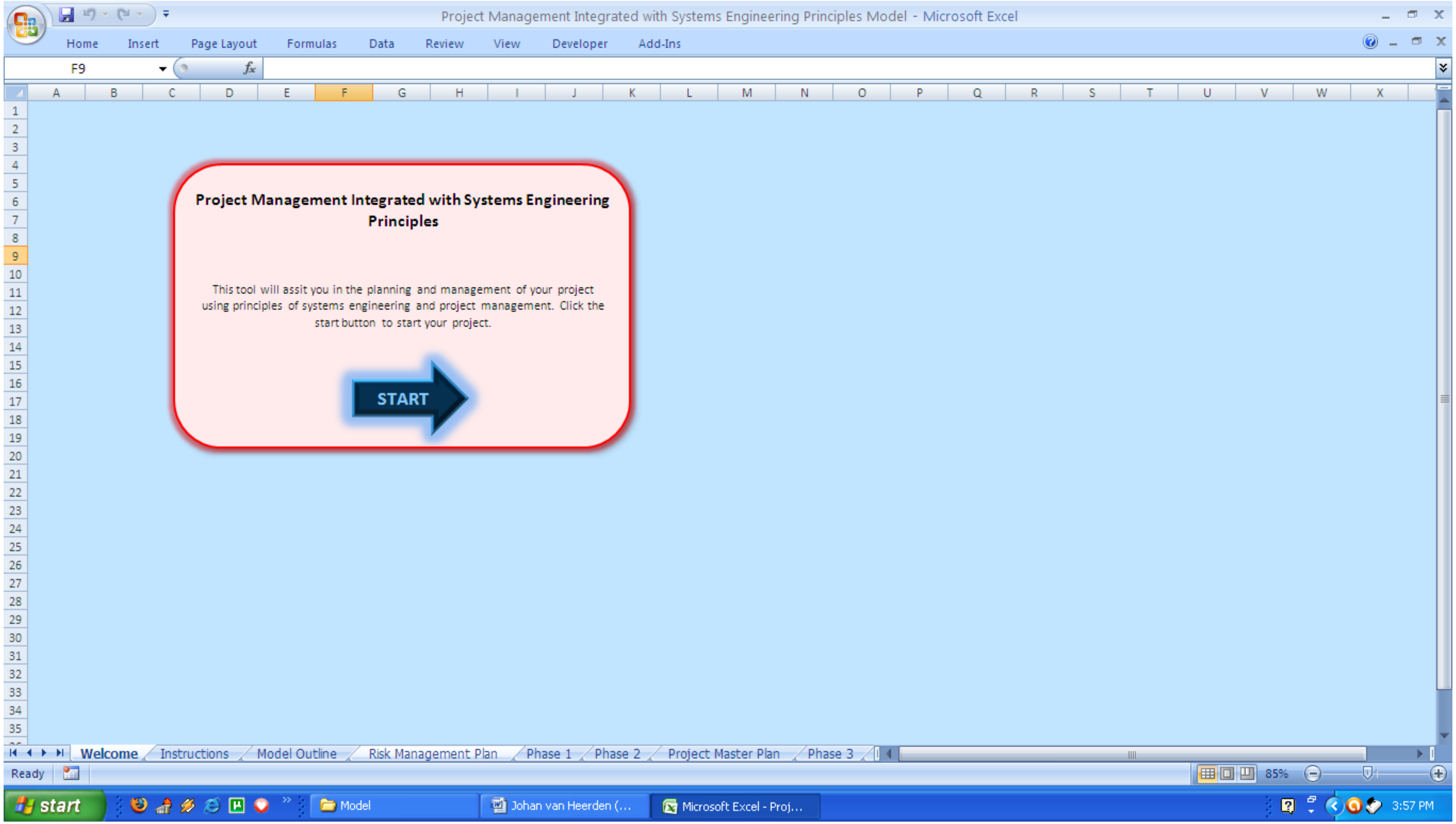
Inadequate programming and monitoring

Any other comments?

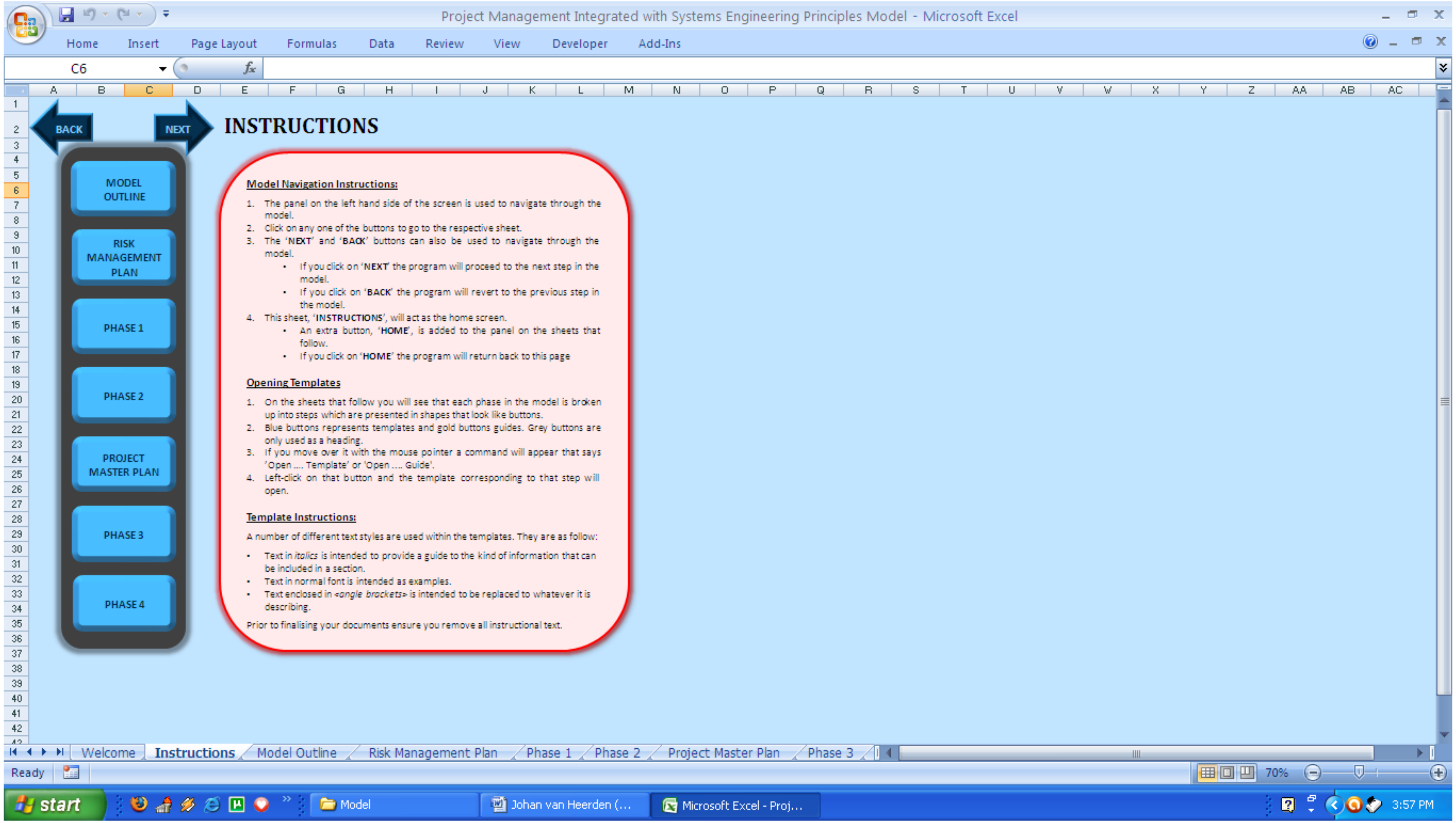
Project management must address cost, time and resources (CTR)

THANK YOU FOR TAKING THE TIME TO COMPLETE THE QUESTIONNAIRE

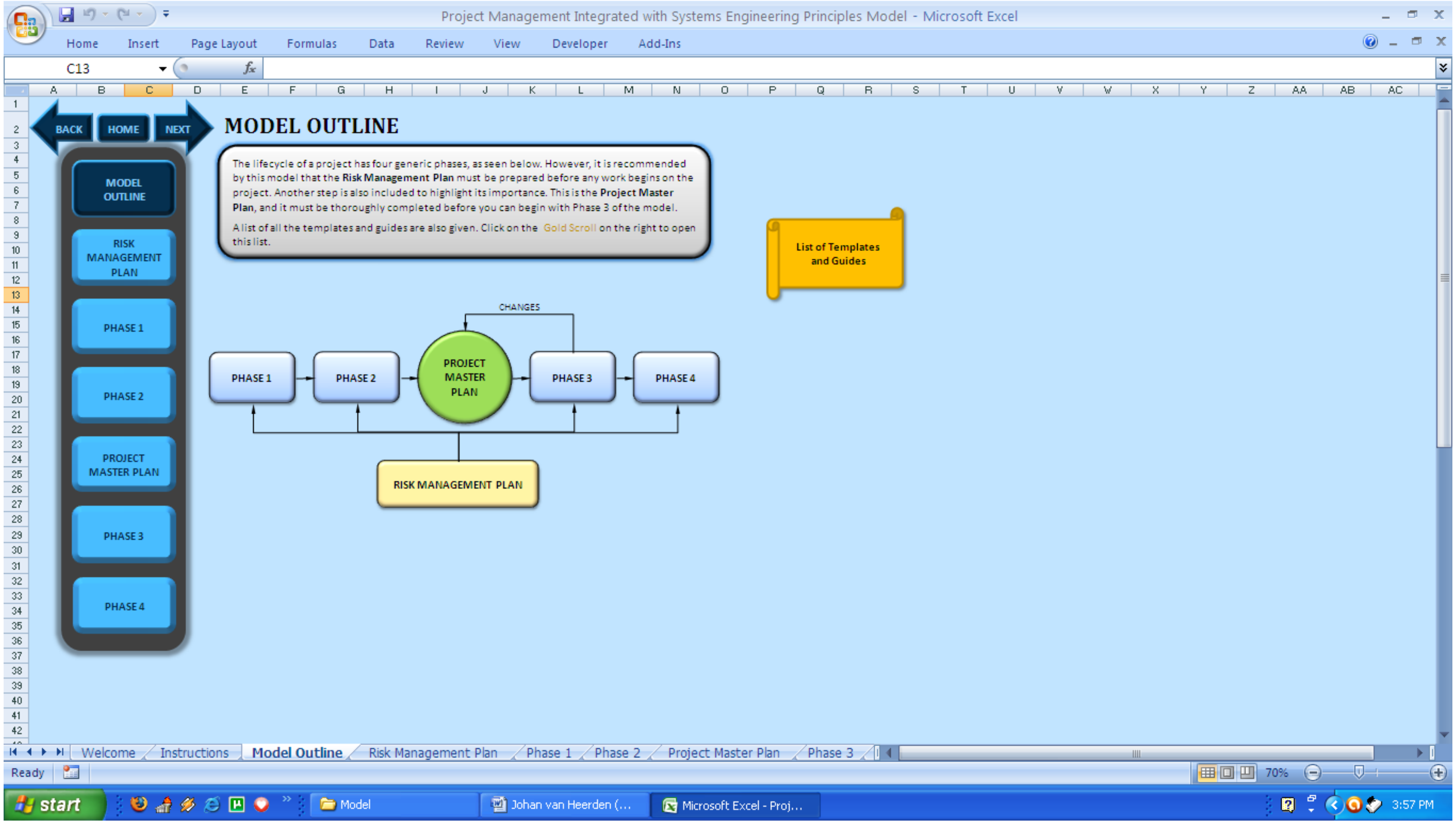
10.3 Appendix C: Model Worksheets



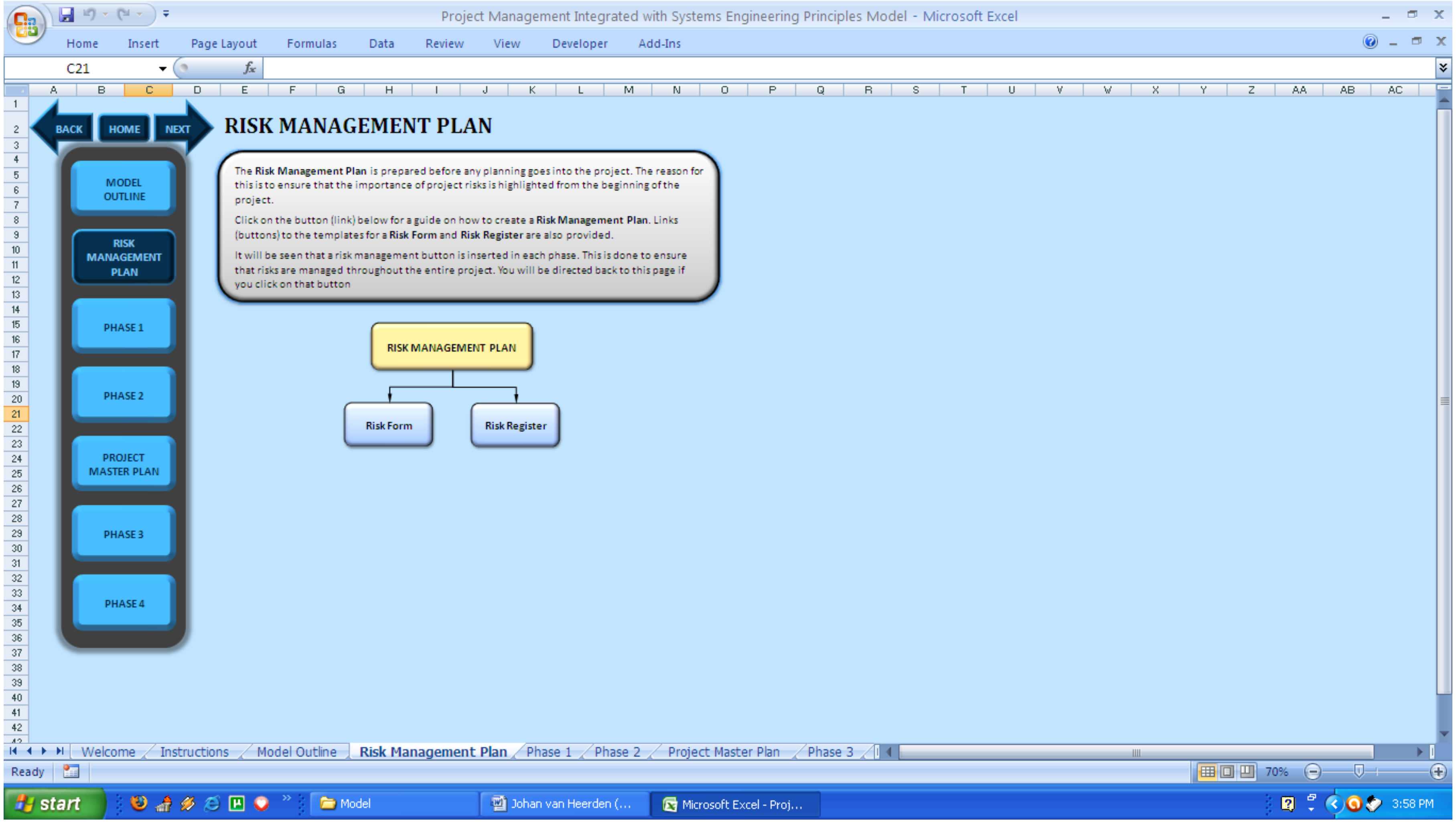
Appendix C Figure 1: Welcome Page



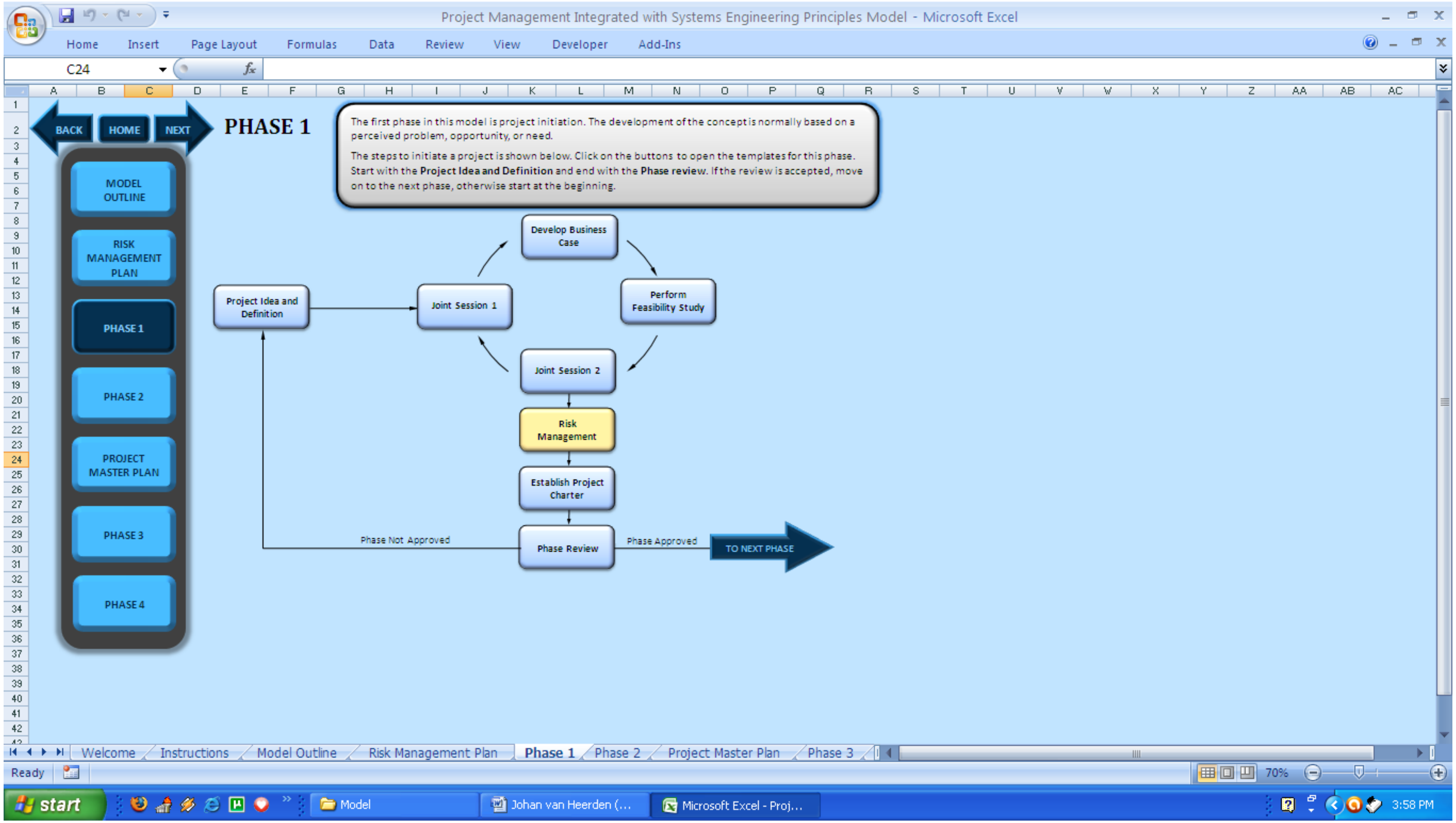
Appendix C Figure 2: Instructions



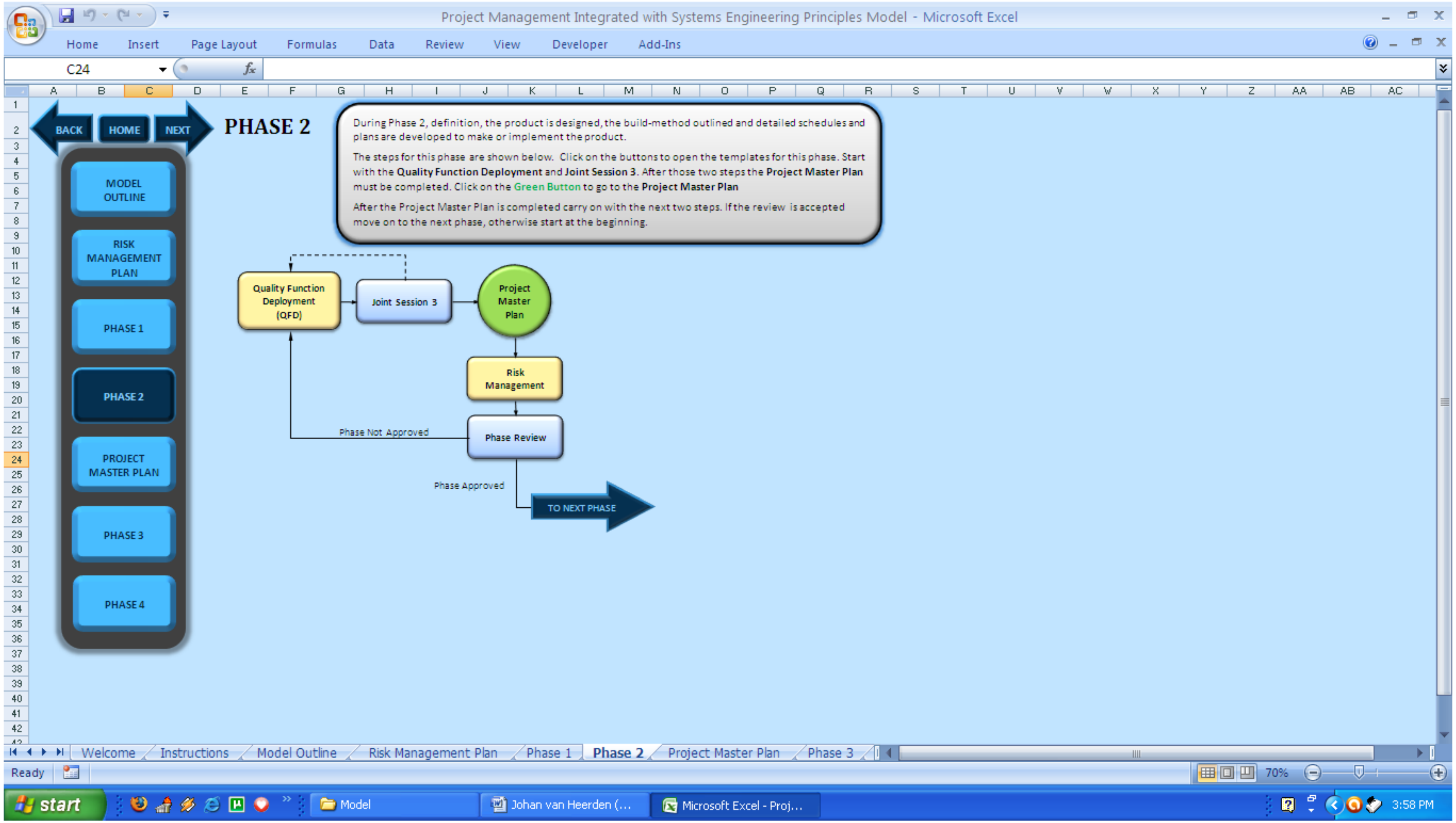
Appendix C Figure 3: Model Outline



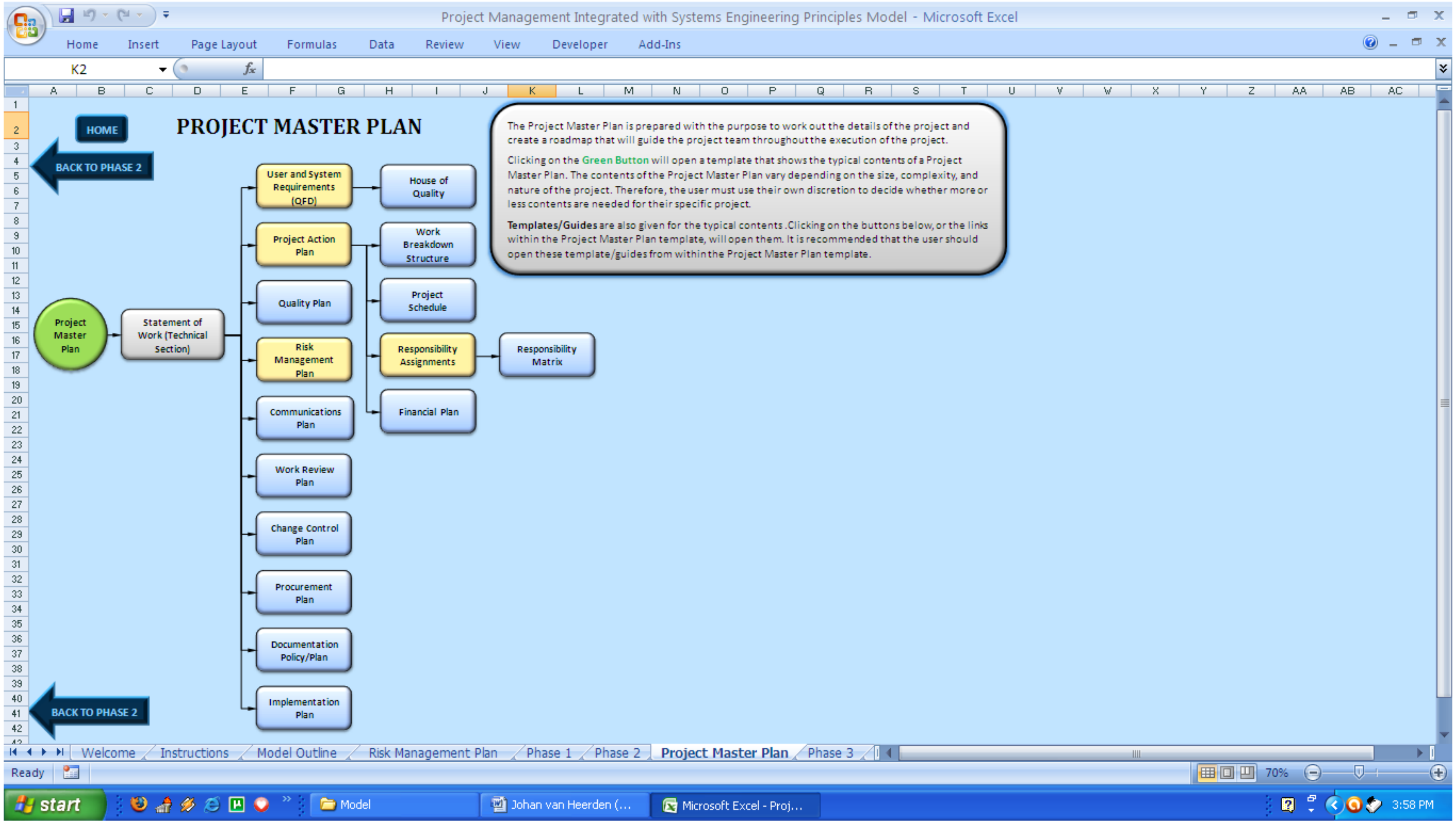
Appendix C Figure 4: Risk Management Plan



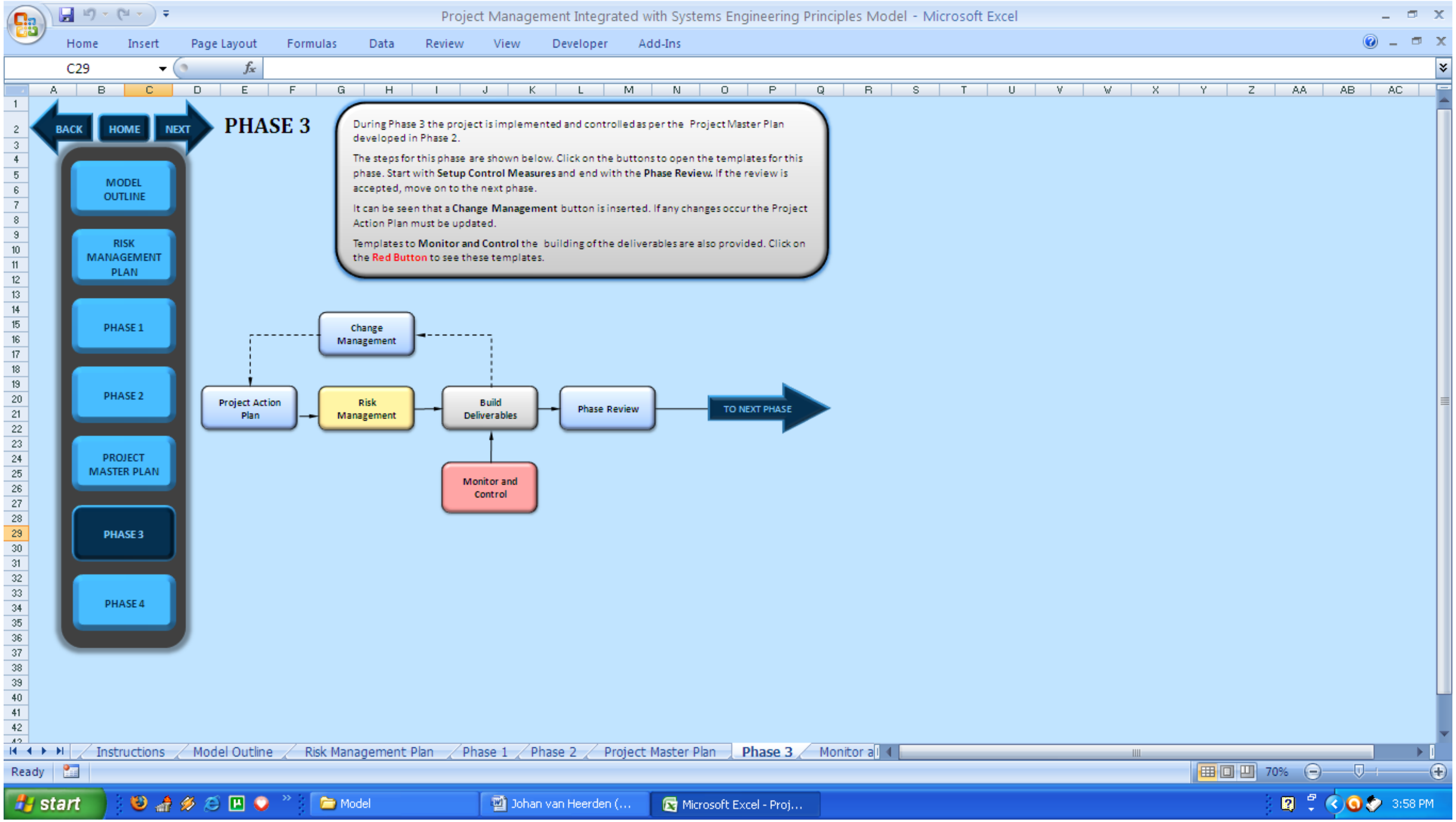
Appendix C Figure 5: Phase 1



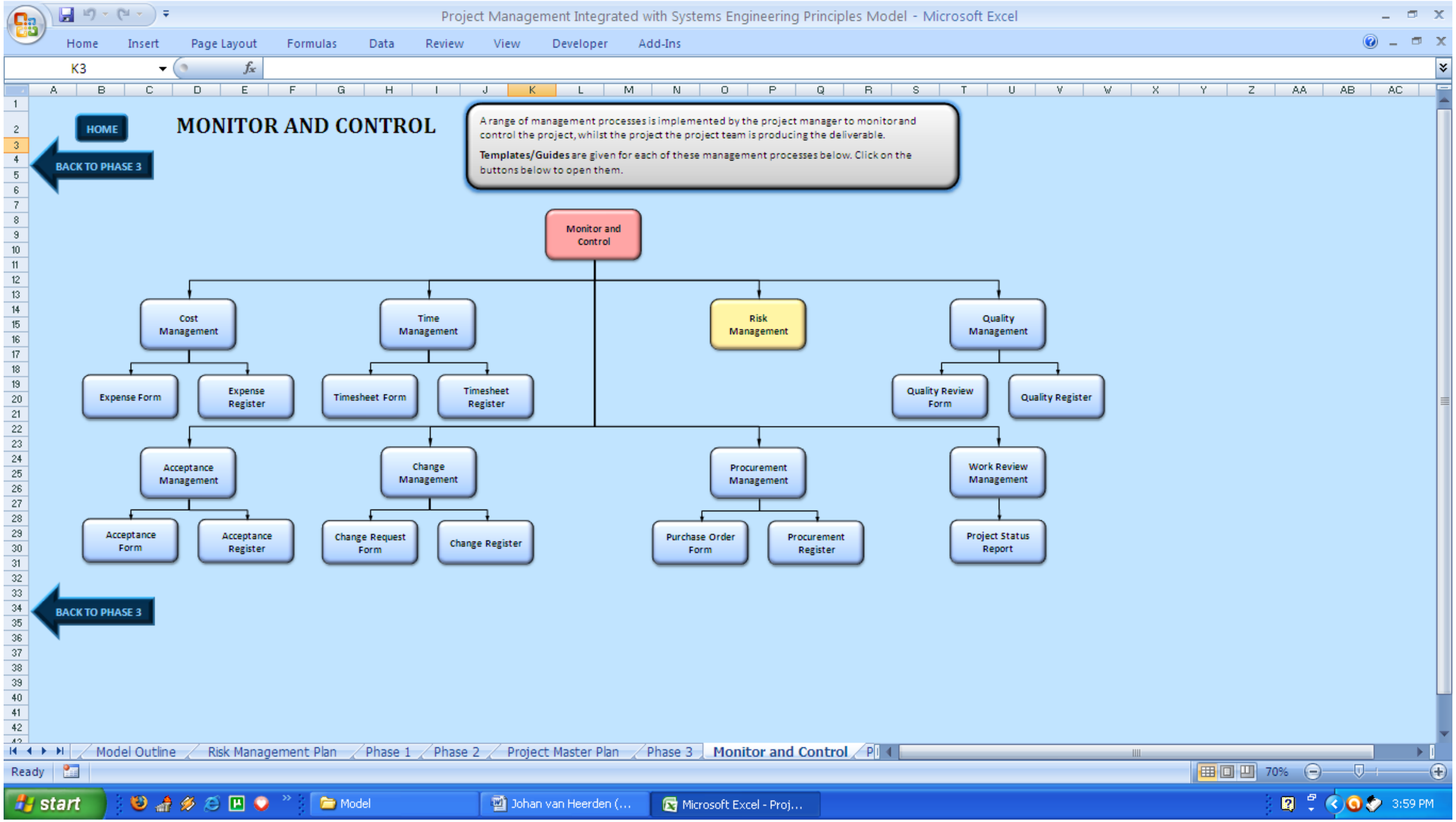
Appendix C Figure 6: Phase 2



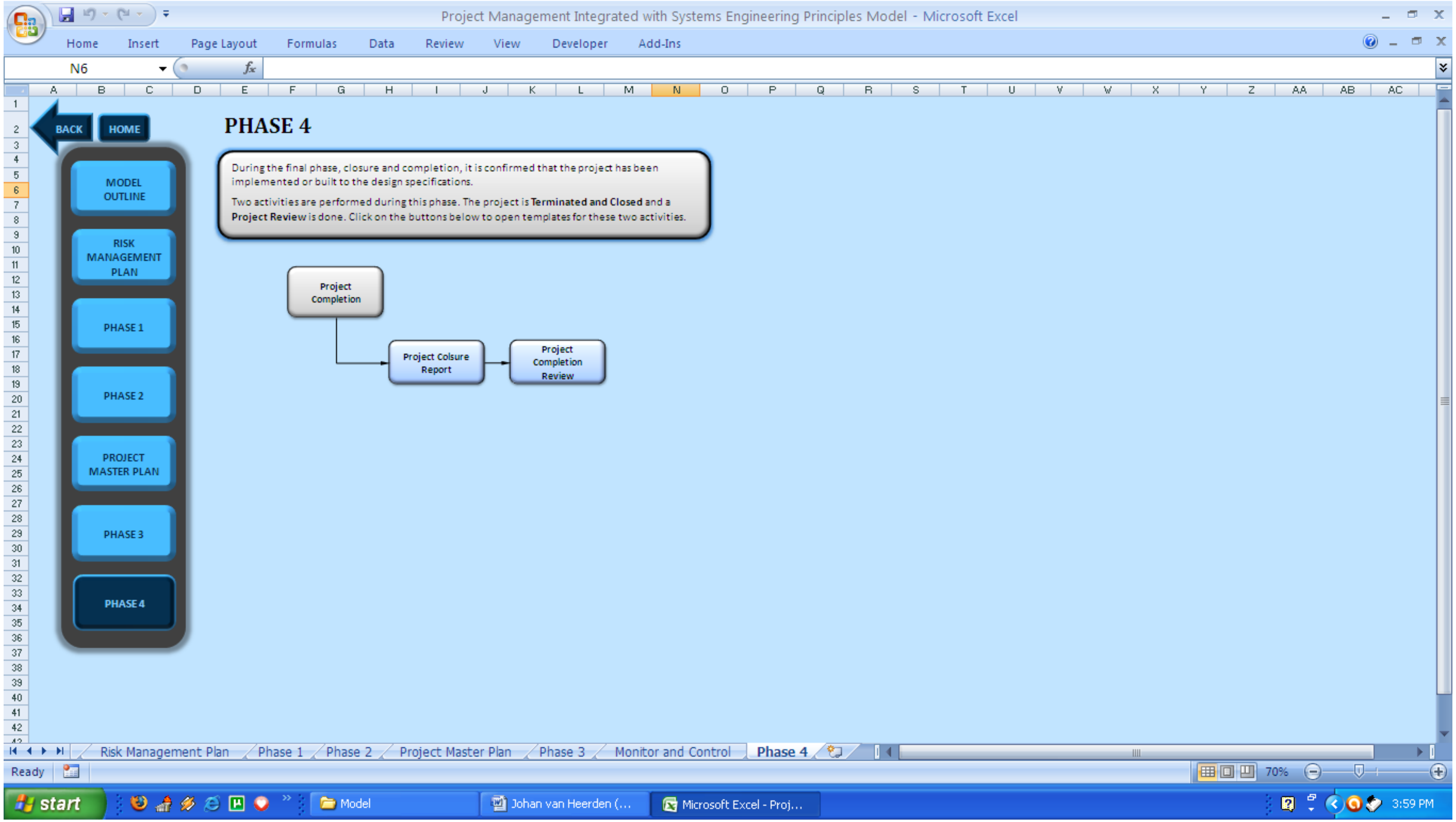
Appendix C Figure 7: Project Master Plan



Appendix C Figure 8: Phase 3



Appendix C Figure 9: Monitor and Control



Appendix C Figure 10: Phase 4

10.4 Appendix D: Template Example

COMMUNICATION PLAN

PROJECT DETAILS

Project Name: *Name of the Project*

Project Manager: *Name of the Project Manager*

STAKEHOLDERS IDENTIFICATION

Provide a list of the stakeholders vested in the project. This list include stakeholders' role in the project, name, title (e.g. manager) and contact details. (Add rows as needed)

Name	Title	Contact Details	Role	Comments

COMMUNICATION DELIVERY METHODS IDENTIFICATION

<Provide a list of the different types of communications that will be used in the project (e.g. emails, team meetings, events, conference calls, etc.).>

COMMUNICATIONS PLAN

The communication plan is a detailed list of the communication types to whom they are communicated (audience), the items to be communicated (deliverables), and the frequency of communication. Also indicated on the plan are a brief description of the deliverable, the delivery method (as identified in the previous step) and the person who is responsible for the communication (the owner). If any other communication types are identified, just add it in its respective column. Two examples are given. (Add rows as needed)

Communication Type	Deliverable	Description	Delivery Method	Frequency	Owner	Audience
Reports	Project status report	Regular update on critical project issues	Email	Weekly	Project manager	Project Manager, Project Sponsor, Project Team
Presentations	Project review	Project status update	Meeting	Monthly	Project Manager	Project Manager, Project Sponsor, Project Team
Project Announcements						

Reviews and Meetings						
Team Morale						

10.5 Appendix E: Model Review Questionnaire

Review Questions

- Please be sure to answer all the questions provided.
- In the *Rating* column, please enter the appropriate value between 1 and 5 (where 1 = ‘Not at all’, 2 = ‘No’, 3 = ‘Sometimes’, 4 = ’Yes’, 5 = ’Definitely’)
- Your opinion is valued and any comments/suggestions made will be considered in the finalisation of the tool.

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that it was easy to use?		
2	Was the model easily understood (i.e. the different processes within the phases)?		
3	Did you find the various templates and guides practical?		
4	Will you be able to use the various templates and guides?		
5	Would you make use of the model?		
6	Did you notice that principles of Systems Engineering were being used?		
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?		
8	Do you think this model will reduce risks in large scale projects?		
9	What is your overall impression of the model?		

10	What recommendations do you have that would enhance the model?

10.6 Appendix F: Review Questionnaire Answer Sheets

Reviewer 1:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that it was easy to use?	4	
2	Were the model easily understood (i.e. the different processes within the phases)?	5	
3	Did you find the various templates and guides practical?	4	
4	Will you be able to use the various templates and guides?	3	Our company has its own templates, but these templates are definitely well thought through and could be useful.
5	Would you make use of the model?	4	A model like this would be useful
6	Did you notice that principles of Systems Engineering were being used?	4	
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	4	
8	Do you think this model will reduce risks in large scale projects?	4	Managing your projects through this process could definitely benefit the project.
9	What is your overall impression of the model?	4	Very well thought through, applicable templates and practical. I like that the process is an integrated system.

	What recommendations do you have that would enhance the model?
10	The links to the forms do not stay there when you email the Model. Perhaps inform the user to save that folder in a standard place so as to keep the link.

Reviewer 2:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that the model was easy to use?	3	The instructions were clear
2	Was the model easily understood (i.e. the different processes within the phases)?	5	
3	Did you find the various templates and guides practical?	4	Good quality , well explained & practical
4	Will you be able to use the various templates and guides?	5	Yes
5	Would you make use of the model?	4	yes
6	Did you notice that principles of Systems Engineering were being used?	4	
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	5	Excellent idea
8	Do you think this model will reduce risks in large scale projects?	5	Yes – it forces methodical & logical thinking
9	What is your overall impression of the model?	5	Very good

10	What recommendations do you have that would enhance the model?
	I don't know if the problems are experienced in 'saving' and accessing the templates was due to my system or generic. Examine the cause (if others had similar experience) and correct accordingly.

Reviewer 3:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that it was easy to use?	3	
2	Was the model easily understood (i.e. the different processes within the phases)?	4	
3	Did you find the various templates and guides practical?	3	
4	Will you be able to use the various templates and guides?	3	
5	Would you make use of the model?	2	
6	Did you notice that principles of Systems Engineering were being used?	4	
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	5	
8	Do you think this model will reduce risks in large scale projects?	2	
9	What is your overall impression of the model?		The rating scale does not respond to this question.

10	What recommendations do you have that would enhance the model?
	Start with the basics, such as correct English grammar. Errors occur in both the questionnaire (highlighted) and the model. The model needs much more thought. You can't have the Project Master plan only after Phase 2. The Quality Plan and the Project Plan needs to run parallel with the project, as does the Project Risk Plan in your model. Project Design, Project Planning and Project Management are all iterative processes ie they run in loops. They are not linear processes. Your model needs to account for this.

Reviewer 4:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that the model was easy to use?	4	Yes
2	Was the model easily understood (i.e. the different processes within the phases)?	4	Yes
3	Did you find the various templates and guides practical?	5	Yes. In industry, some training would usually be required to implement something like this.
4	Will you be able to use the various templates and guides?	5	
5	Would you make use of the model?	3	If a project needs to be well documented, e.g. if it will be used to secure further funding or register patents, it would be appropriate. Most projects I deal with do not and this would be seen as unnecessary paperwork.
6	Did you notice that principles of Systems Engineering were being used?	4	I don't know much about systems engineering.
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	5	I'd say there are many appropriate applications of SE in PM.
8	Do you think this model will reduce risks in large scale projects?	5	Yes
9	What is your overall impression of the model?	4	Seems well thought out and makes it easy to access many templates from a simple hub.

10	What recommendations do you have that would enhance the model?
	An introduction to what the tool does and why would be good. Pushing NEXT to scroll through the blue buttons skips PROJECT MASTER PLAN. Minor grammatical errors.

Reviewer 5:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that the model was easy to use?	5	
2	Was the model easily understood (i.e. the different processes within the phases)?	5	
3	Did you find the various templates and guides practical?	4	
4	Will you be able to use the various templates and guides?	4	
5	Would you make use of the model?	3	We perform several projects and mini-projects at any given time. Very simple, small, low cost and complexity projects would not require the time and effort of going through the process as envisaged herein.
6	Did you notice that principles of Systems Engineering were being used?	3	I am not familiar with any formal systems of project management. However, having dealt with formal project managers in the past, some of their processes were evident.
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	4	
8	Do you think this model will reduce risks in large scale projects?	4	The model is a means of formalising procedures to ensure steps are not missed, and that the all-important buy-in from ALL departments/divisions is obtained.
9	What is your overall impression of the model?		It would appear to be a very useful tool to ensure that the processes followed in complex project management are formalised, documented, and recorded

10	What recommendations do you have that would enhance the model?
	One recommendation that I could possibly make is that there is maybe a second, less involved model that is developed in order to deal with less complex projects – in that way the model could become the standard for future project management for all projects. The principle focus is on management of risks which are applicable to both simple and complex projects, however, the complexity of this model would make it unattractive to simpler projects which would then lose the benefit of the risk focus.

Reviewer 6:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that the model was easy to use?	4	In general, yes
2	Was the model easily understood (i.e. the different processes within the phases)?	4	The logic was easy to follow
3	Did you find the various templates and guides practical?	4	The size of the project determines just how much
4	Will you be able to use the various templates and guides?	4	When the project warrants it
5	Would you make use of the model?	3	Depends on the scope.
6	Did you notice that principles of Systems Engineering were being used?	4	
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	4	
8	Do you think this model will reduce risks in large scale projects?	5	Could be very valuable in large scale projects
9	What is your overall impression of the model?	4	Easy to use implement and check. Well presented.

10	What recommendations do you have that would enhance the model?
	A simplified model for smaller scale projects could, in our case ,be useful.

Reviewer 7:

	QUESTION	RATING	COMMENTS
1	Were the instructions provided clear and unambiguous, so that the model was easy to use?	5	
2	Was the model easily understood (i.e. the different processes within the phases)?	5	
3	Did you find the various templates and guides practical?	4	A bit superficial and too time consuming but ok.
4	Will you be able to use the various templates and guides?	4	I'd be inclined to use them as a check list
5	Would you make use of the model?	3	But one is inclined after many years to get slack.
6	Did you notice that principles of Systems Engineering were being used?	3	30 years since I looked at "academic" industrial engineering.
7	Do you think it is a good idea to integrate the principles of Systems Engineering into Project Management?	5	Anything that imposes systematic rational thought onto the process of mismanaging a project by the method of "didn't think of that"
8	Do you think this model will reduce risks in large scale projects?	5	
9	What is your overall impression of the model?	5	It would be a good model to give project engineers, combined with the instruction that they have to tick off each aspect that they have "done" and justify why they have not done some of them.... However it is rather "long" for application to small projects being carried out by small time pressed team

10	What recommendations do you have that would enhance the model?
	Just a thought. The reason projects get mismanaged is that everybody "Hasn't got time for all that", so actually the steps get skipped or ignored or glossed over in a hurry. There should be an interactive feedback mechanism to control the proper use of the model(1) you have to input a description of the project including scores on some of the variables (2) The model then highlights stages / steps that really need to be done /ticked / scored/// (3) There could be an interactive system so that as one filled in responses in some areas the model would demand responses to logically connected other areas, or hide areas that are not actually needed. Then the model can score the user of the model for his own benefit, or the benefit of his manager.