Theory of optimisation for projects: A licensing plan for nuclear energy in South Africa as a case study

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Declaration

I, Randall Ruben Lavelot, declare that the PhD thesis entitled "***Theory of optimisation for projects: A licensing plan for nuclear energy in South Africa as a case study***", applied for the South African nuclear energy industry is entirely my own original work and is no more than 34,507 words exclusive of figures, tables, footnotes, references and appendices. I am the sole author and all sources applied have been acknowledged by way of reference. This PhD thesis was not previously submitted at North–West University or any another educational institution.

21st February 2018

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Signature Date

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On a more general note, I would like to most importantly thank OR-AS (Operations Research - Applications and Solutions) who provide me with the scheduling simulation software ProTrack 3.0 license for the duration of my PhD Thesis.

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Abstract

Theory of optimisation for projects: A licensing plan for nuclear energy in South Africa as a case study

Scope

This research case study focused on identifying the benefits of introducing the criticality index concept for selection of the critical chain project management (CCPM) using Monte-Carlo simulation, i.e. Improvements in the measurement of task time and the expected project time are addressed in preference to the accuracy of estimates.

This research contested the CCPM normally performed, by modelling the theory for optimisation of projects (TOP[1]) using nuclear case study projects of South Africa.

To support the identification of the benefits of introducing the criticality index concept for selection of the CCPM, the objectives of this study were (1) to present a TOP through simulation and (2) to validate the theory through an empirical study.

Approach

The experimental design was modelled on the Christensen theory–building process for development of Part 1 of the scoping review study. The theory development in Part 2 was modelled to Eisenhardt theory–building concept and validated using Pearson's Product-Moment, Spearman's Rank and Kendall's Tau Rank Correlation in the subsequent Part 3.

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[1] 6–step critical chain project scheduling process by Author

H_1: CCRCS[2] *task time* offers a longer *expected project time* than the methodology based on PERT[3]. **$H_{1.0}$** is stated as: *Task time* for CCRCS does not offer a longer *expected project time* than the methodology based on PERT.

H_2: Implementing a methodology based on TOP will reduce the risk of the *expected project time*; with corresponding **$H_{2.0}$** that implementing a methodology based on TOP will not reduce the risk of the *expected project time*. **H_2** appraises TOP by Monte-Carlo simulation and assays its effectiveness as a supporting tool for structuring nuclear projects.

The scoping review assessed the relationship between the CCRCS and PERT on the PM case study project. Inductive reasoning was achieved, and consolidated the *observations*, *categorisation* and *association* of the project management (PM) case study. The results deduct support for **H_1**.

The theory of optimisation for projects using simulation was developed, complying with seven basic requirements for building theory: (1) begin with a research question, (2) identify simple theory, (3) choose the simulation approach, (4) create computational representation, (5) verify computational representation, (6) experiment to build novel theory, and (7) validate with empirical data. The theory is also partly evaluated in terms of the requirements of **Figure 18 – Eisenhardt Theory–Building Process**.

The research was further supported by three measurements to validate the time sensitivity of tasks on the expected project time by correlation to evaluate the results from applying TOP to nuclear project B. The validation process was examined

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[2] Critical Chain Resource-Constrained-Scheduling (CCRCS) "largely concentrate on the generation of a precedence and resource feasible schedule that 'optimises' the scheduling objective (s) and that should serve as a baseline schedule for executing the project" (Penga & Huangb, 2013)

[3] Project Evaluation and Review Technique (PERT) "shows the time taken by each component of a project, and the total time required for its completion" – (http://www.businessdictionary.com/definition/program-evaluation-and-review-technique-PERT.html)

to determine whether the $\mathbf{H_2}$ theory–building results could be correctly represented in the real life practice. The results of the experiments were compared with the task time and expected project time by correlation. The validity of simulation results increases with a higher number of simulation runs. The simulated results ended with a predefined number of runs $(k = 100)$ due to lengthy computations. For Nuclear Project B, 100 simulation runs were performed by the researcher making the total of 900 simulations.

TOP

It is revealed that there is a lack of PM support to complete projects successfully in organizations. The shortcoming of project failures is problematic to the delivery of projects. The proposed TOP methodology presented in chapter 6 (**Figure 83 – Proposed Theory of Optimisation for Projects**), integrates different heterogeneous scenarios data sources to reduce the risk of the *expected project time*.

The researcher performed a search in EBSCOhost and established that the hypothetical connotation proposed by the researcher in terms of the TOP methodology: **If you can measure it, you can improve it** was reported across only 10 source types between 2000 and 2016. Nothing was obtained by the researcher across source type underlying the field in nuclear project management.

Potential Benefits from the TOP

The main benefits that the proposed TOP methodology can provide to the nuclear arena are the following: (1) delays are less likely when using the Criticality Index concept for selection of the critical chain using Monte-Carlo to manage highly uncertain tasks. The methodology will provide a unique, integrated and placid source of information, (2) complete view of heterogeneous critical task activities based on the array of information for validating the time sensitivity of tasks on the expected project time by correlation. The correlations display the degree of linear relationship between the task time and expected project time, (3) accurate information for project managers to make decisions. Using the TOP the nuclear area will be able to distinguish between the time sensitivity or insensitivity relationship between the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank that are not easily available with a simple system, and (4) ability to validate the time sensitivity of the task time on the expected project time by correlation using 50% sizing rule integrator for time sensitivity dimension. The validity of simulation results increases with a higher number of simulation runs.

Potential limitations

Though there are several positive facts to adopting the TOP methodology, there are also several shortcomings. These are related to the costs of the ProTrack software system including the costs of human capital. All the information might not always be understood by project manager for decision-making. Creating access and educating several projects managers is another cost drawback for adopting the TOP methodology. Another shortcoming is that the costs to produce project schedules in a timely manner may be too expensive.

The PM life cycle concept of this research study was adapted to Klein (2000). Klein's concept includes two additional phases (i.e. in which the project has to be **scheduled** is denoted by "**S**" and the project **controlled** is denoted by "**C**") (refer to **Figure 8**). The research study was mapped out of three (3) dimensions of scheduling dynamically, in particular: 1) **complexity** of project scheduling; 2) **uncertainty** of risk analysis; and 3) **project control**. When the level of uncertainty is high, the schedule of a project becomes more susceptible to change. The goal of project managers is to measure and cope with uncertainties and complexities of their projects. The current research study was further arranged around the classification of PERT/CPM, SRA, RCS and critical chain/buffer management.

Originality

The goal of the research described in this thesis was to propose a TOP through simulation to the nuclear project management arena in South Africa. The latest method of developing theory (through simulation) was adapted by the researcher (refer to **Figure 28 – Developing Theory Through Simulation Methods**). The major result the researcher presented in this research study is a revision of the critical chain project scheduling process model by Tukel et al. (2006). The development of the TOP is data oriented and is not requirements oriented. As a result of the proposed TOP, delays are less likely when managing highly uncertain tasks. The methodology will provide a unique, integrated and placid source of information. It may provide a complete view of heterogeneous critical task activities. Accurate information for project managers to make decisions. Ability to validate the time sensitivity of the task time on the expected project time using 50% sizing rule integrator for measuring time sensitivity dimension. Project managers may now be aided to resolve resource contentions by following the researcher's 6–step critical chain project scheduling process (**Figure 84 – Theory of Optimisation for Projects**) to reduce the risk of the *expected project time*.

Recommendations

The recommendations are related to the empirical findings and to the proposed TOP. Nuclear project management will gain benefits in their decision-making process if the methodology is implemented. To minimize several potential limitations, finalize the process of defining the cost of human capital. Based on the proposed TOP, the researcher suggests that access be created for users and for several users to be educated for adopting the model. The proposed model will, facilitate the decision-making process, by providing coherent data to the decision makers.

Other recommendations include the definition of the supporting tool for structuring nuclear projects to be implemented and designing the data model integration process to include the 50% sizing rule integrator.

Keywords: Nuclear project management, theory for optimisation of projects, expected project time, theory–building through simulation.

List of Acronyms

Acronym	Description
AFR	Away–From–Reactor
CCPM	Critical Chain Project Management
CCRCS	Critical Chain Resource-Constrained-Scheduling
CCS	Critical Chain Scheduling
CI	Criticality Index
CP	Critical Path
CRI	Crucially Index
DC	District Columbia
df	Degree of Freedom
EAF	Energy Availability Performance
EBSCO	Elton B. Stephens Co
EIA	Environmental Impact Report
EMEA	Europe, the Middle East, and Africa
EPRI	Electric Power Research Institute
EVM	Earned Value Management
FB	Feeder buffer
$H_{1(2)}$	Research Hypothesis
$H_{1.0(2.0)}$	Null Hypothesis
IAEA	International Atomic Energy Agency

IPPs	Independent Power Producers
KNPS	Koeberg Nuclear Power Station
MS	Microsoft
MW	Mega-watt
Necsa	South African Nuclear Energy Corporation
NIL	Nuclear Installation License
NNR	National Nuclear Regulator
NY	New York
OR-AS	Operations Research - Applications and Solutions
PERT	Program Evaluation and Review Technique
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
Pr	Probability
ProTrack	Project Tracking
PWRs	Pressurised Water Reactors
RCS	Resource-Constrained Scheduling
RSE	Root Square Error
SFPs	Spent Fuel Pools
SI	Significance Index
SNF	Spent Nuclear Fuel

SOC	State–Owned Company
SR	Scoping Review
SRA	Schedule Risk Analysis
SSI	Schedule Sensitivity index
tHM	Metric Tons of Heavy Metal
TOP	Theory of optimisation for projects
TWh	Two Thousand Terawatt–Hours
UCF	Unit Capability Performance
UK	United Kingdom
USA	United States of America
WNA	World Nuclear Association
ZA	Republic of South Africa
ρ	rho

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CHAPTER 1: INTRODUCTION

A broad overview of the research study process is depicted in **Figure 1**. An introduction to the management of nuclear projects and its importance of structuring work in provided, followed by an overview of the criterion and factors for project success. In this Chapter the research scope and problem statement is identified; the aim and objectives, hypothesis statements and original contribution are defined.

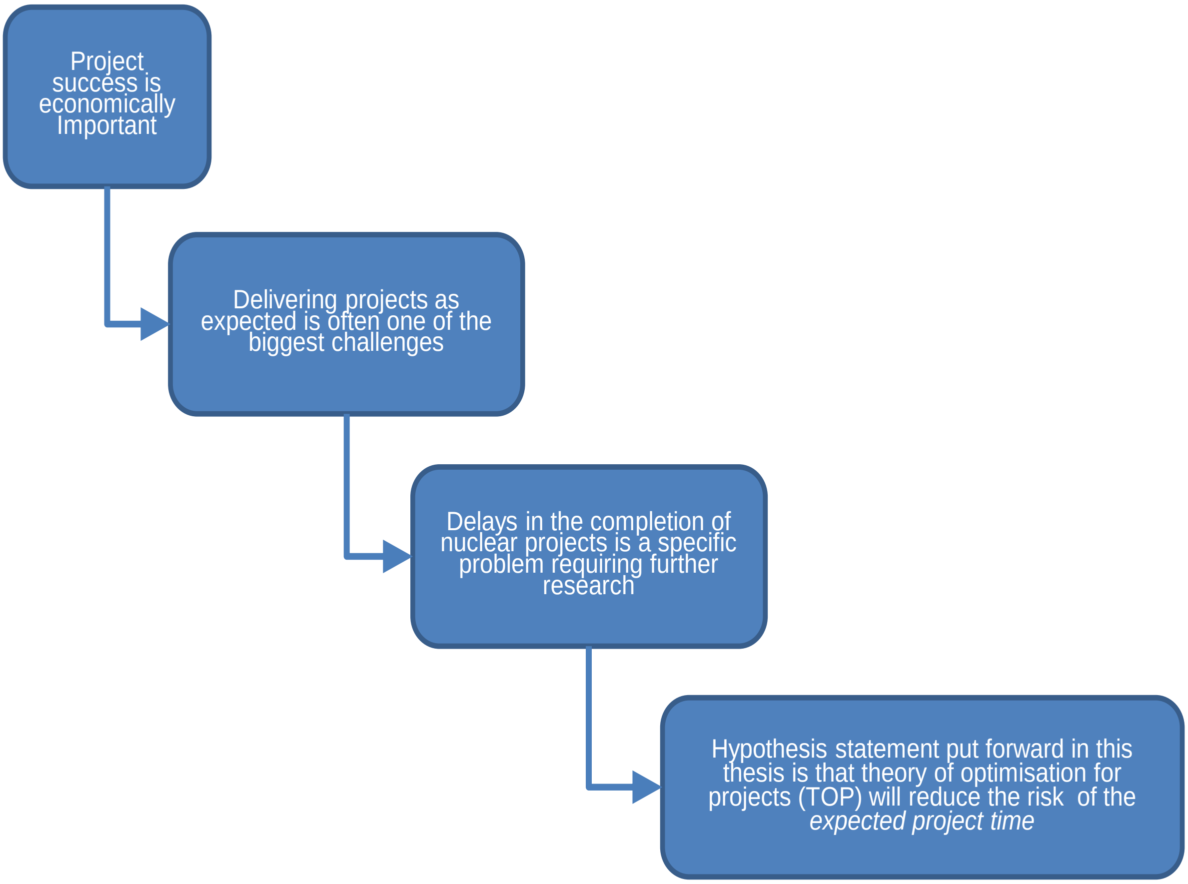


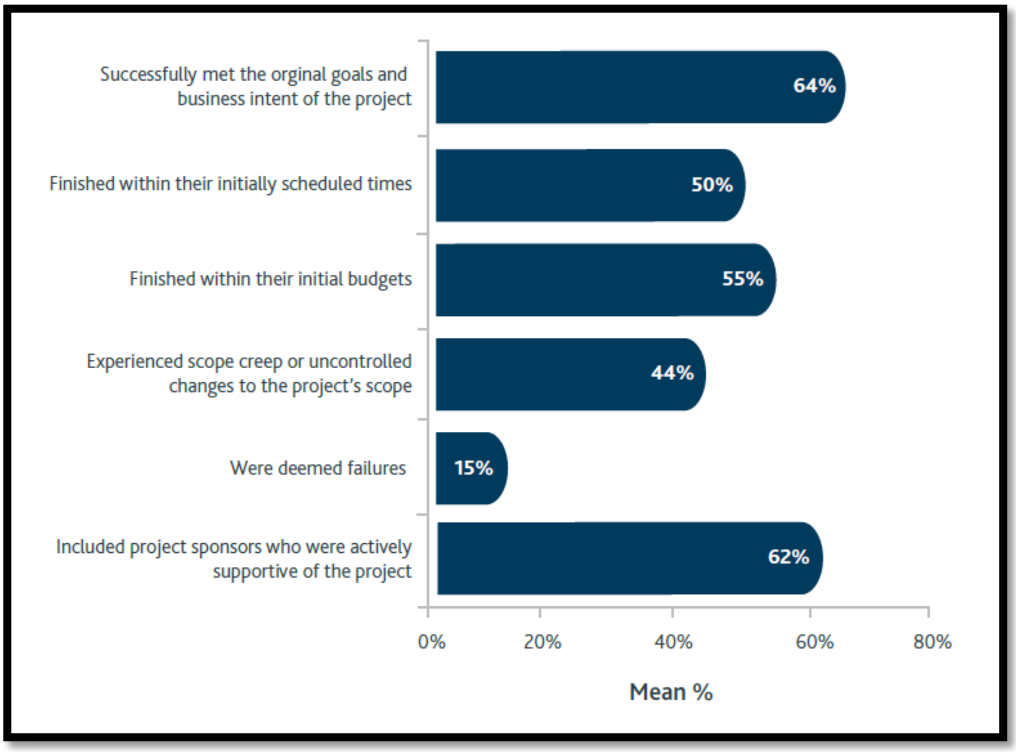
Figure 1 – Research Study Process

The management of projects has matured considerably due to its significant economic importance. Projects are constituted as one of the more effective ways of structuring work in most organisations (Svejvig & Andersen, 2015). Important efforts have been made by international project management (PM) practitioners and researchers to rethink project management, and disseminated findings among the PM community. Research papers published in the *International Journal of Project Management* over its first decade contributed to significant new tools and techniques of PM. The journal also indicates that there still is room for much needed improvements in the areas of theory formulation, theoretical concepts and for research collaboration between academia and industry (Kwak & Anbari, 2009).

'The iron triangle' approach represents the basis of the criteria for project success (Cserháti & Szabó, 2014). This approach easily assesses the critical criteria for the success of a project such as, the completion time, cost and performance specifications. Researchers have become more dependent on the aspect of measurement for success. While certain organisational studies have shown that environmental impact, technical success and effects on business operations as the most important criteria for project success.

Moreover, critical factors for project success could contribute to the failure of a project and would also require special attention. Earlier studies have revealed three critical factors for the success of projects or not fail is namely; schedule adherence, maintain high-levels of performance, and to keep costs within budget (Cserháti & Szabó, 2014).

The 2015 pulse found that many industries have continued to waste US$109 million for every US$1 billion invested in projects, while only 64% have successfully met their original goals and organisation intent of projects, where 15% were deemed as failures (refer to **Figure 2)**. The organisation with the high-level performance will meet their project goals 2½ times more frequently, and will waste thirteen times less on money than the low-level performing organisation. A number of critical project factors contribute to this success, including the focus on the basics such as, aligning projects to strategy (Project Management Institute, 2015).

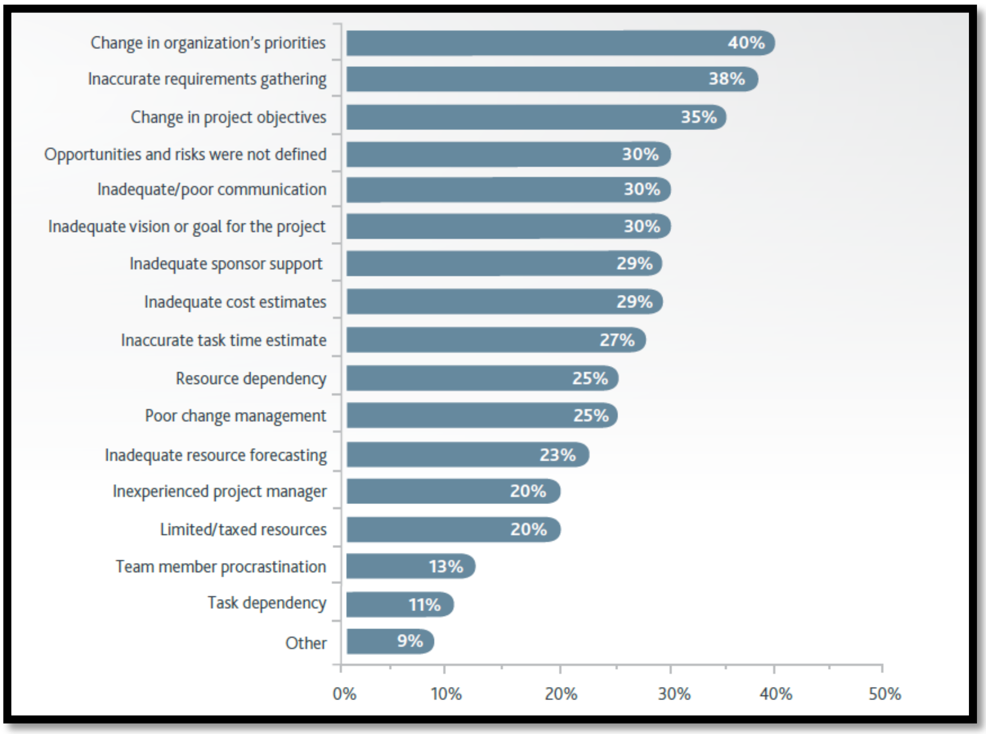


Source: Pulse of the Profession® (Project Management Institute, 2015)

Figure 2 – Projects Completed Across Countries over 12 months

The percentile of project failures and its causes over a 12 month period across North America, EMEA[4], Asia Pacific and Latin Pacific are depicted in **Figure 3**. It is shown that the common cause of project failures is due to inaccurate **task time** estimates, resource dependency, inaccurate resource forecasting, limited resources, team member procrastination and task dependency.

[4] Europe Middle East and Africa (EMEA) is "a classification of a specific international company's division that focuses its operations either in Europe, the Middle East, or in Africa and is typically operated by a specific separate company executive" – (http://www.investorwords.com/18135/Europe_Middle_East_and_Africa_EMEA.html#ixzz57pPm1dH5)



Source: Pulse of the Profession® (Project Management Institute, 2015)

Figure 3 – Projects deemed as failures over 12 months

In summary, it is revealed that there is a lack of PM support to complete projects successfully. The shortcoming of project failures is problematic to the delivery of projects, hence the need for further research.

1.1. Scope of research

This thesis is limited to the introduction of critical chain resource-constrained-scheduling (CCRCS) and Monte-Carlo simulation as suggested by Schuyler (2000); to be able to identify reliable task times using the criticality index (CI)[5] concept for selection of the critical chain using the Eskom Koeberg Nuclear Power Station and Sasol Secunda as research case studies. The case study projects utilised in this

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[5] Measures the probability of a task on the critical path by Monte-Carlo simulations

research were from an extract of Eskom's Koeberg spent fuel storage project and researcher's Masters Dissertation, in particular:

- Project A: Construction of a transient interim storage facility for the storage of casks, to whom the researcher is assigned to as the nuclear project manager (extract of baseline project schedule).

- Project B: A licensing plan for coupling a nuclear energy source to a chemical process plant – SASOL Secunda as a case study (extract of baseline project schedule) (Lavelot, 2014).

The simulated results are represented as a supporting tool for structuring work, and provides the nuclear industry in South Africa with a quantified assessment of its possible outcomes based on using the theory of optimisation for projects through simulation.

1.2. Identification of Research Problem

Worldwide, all spent nuclear fuel (SNF) discharged from nuclear fission reactors is commonly stored on–site. Forego of reprocessing facilities and delays with establishing a permanent repository have destined spent fuel to spent fuel dry storage facilities. The storage of the uranium spent fuel will endure until a repository facility is made available in countries such as South Africa. While several studies suggest it would be more coercing to establish an on–site (above ground) interim storage programs other than the immediate bulk storage of SNF, following the Fukushima accident (Davied, 2011).

During 2018, Koeberg's spent fuel wet storage will be expended with spent nuclear fuel assemblies, based on its latest 10 year production plan. An interim solution will be to reduce the existing spent fuel pools (SFPs) seismic mass and/or radioactive material for the nuclear power station to continue operating; otherwise

SNF may not be loaded or off–loaded from its nuclear fission reactors. This interim solution paved the way to the formulation of the Eskom's Koeberg spent fuel storage project strategy, which is being carried out over three distinct project phases, one being Project A of the case study. With no reprocessing, repository or interim spent fuel dry storage facilities for additional cask emplacement, Koeberg may be shut down pre–maturely (Eskom, 2014b) & (Eskom, 2015).

A rethink of PM methods were needed to successfully carry out the Koeberg spent fuel storage project strategy. One of these new methods is Critical Chain Project Management (CCPM), which was first presented by Goldratt at the Jonah International Conference in 1990. The principle of the Theory of Constraints PM was extended through publishing of the 'Critical Chain' in 1997. With regard to CCPM, the unique constraint is the longest activities chain in the project network in the project environments, taking into account critical chain (both resource dependencies and activity precedence). Critical Path[6] (CP) Method and Program Evaluation and Review Technique (PERT) project scheduling methods have remained relatively unchanged, while CCPM was considered as an innovative breakthrough (Ghaffari & Emsley, 2015).

The implementation of CCPM the traditional way is complex and challenging for larger projects. Considerable effort has been made to solve the problems on the research of resource-constrained scheduling (RCS). On the other hand, literature also reveals that minimal efforts were made on the research of optimisation methods for projects. Therefore, research is required to be able to schedule projects in an automated approach by using the theory of optimisation for projects (Penga & Huangb, 2013).

[6] Critical path is the longest sequence of activities in a project plan, which must be completed on time for the project to complete on due date – (www.businessdictionary.com/definition/critical-path)

1.3. Aim and Objectives of the Study

The thesis aim is to identify the benefits of introducing the Criticality Index concept for selection of the critical chain using Monte-Carlo simulation[7] automated approach (Ghaffari & Emsley, 2015).

For realising the aim of the research study, the following objectives must be met, using the PM case study:

1. To present a theory of optimisation for projects through simulation; and

2. To validate the theory through an empirical study.

This research case study focused on the optimisation methods for projects in the nuclear environment in South Africa. The motivation for the preference of introducing TOP is presented in Chapter 2 & 4.

1.4. Research hypothesis

The research design has addressed the following two hypotheses:

$\mathbf{H_1}$: CCRCS *task time* offers a longer *expected project time* than the methodology based on PERT. $\mathbf{H_{1.0}}$ is stated as: *Task time* for CCRCS does not offer a longer *expected project time* than the methodology based on PERT.

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[7] Monte-Carlo-method is a computation intensive forecasting technique applied where statistical analysis is extremely cumbersome due to the complexity of a problem (such as queuing or waiting line probabilities, or inventories involving millions of items) – (www.businessdictionary.com/definition/Monte-Carlo-method)

H_2: Implementing a methodology based on TOP will reduce the risk of the *expected project time*; with corresponding **$H_{2.0}$** that implementing a methodology based on TOP will not reduce the risk of the *expected project time*. **H_2** appraises TOP by Monte-Carlo simulation and assays its effectiveness as a supporting tool for structuring nuclear projects.

1.5. Original Contribution

Knowledge of the critical path and the degree of criticality and sensitivity of the task time is a specific problem requiring further research (referred to in Chapter 2 & 4). This research study makes that contribution to this knowledge gap of the nuclear industry in South Africa. Key is the contribution to the international project management community through the development of novel theory on the TOP within the South African context. Until now, there is no specific procedure to resolve resource contentions and general optimisation method due to its complexity (Herroelen, 2001) & (Penga & Huangb, 2013). The major result the researcher presented in this research study is a revision of the critical chain project scheduling process model by Tukel et al. (2006). The proposed TOP methodology presented in chapter 6 (**Figure 83 – Proposed Theory of Optimisation for Projects**) integrates different heterogeneous scenarios data sources to reduce the risk of the *expected project time*. The TOP is data oriented and is not requirements oriented. As a result of the proposed novel TOP, delays are less likely when managing highly uncertain tasks. The methodology will provide a unique, integrated and placid source of information. It may provide a complete view of heterogeneous critical task activities. Accurate information for project managers to make decisions. Ability to validate the time sensitivity of the task time on the expected project time using the researcher's 50% sizing rule integrator for measuring time sensitivity dimension. Project managers may now be aided to resolve resource contentions by following the researcher's 6–step critical chain project scheduling process (**Figure 84 – Theory of Optimisation for Projects**) to reduce the risk of the *expected project time.*

1.6. Chapter Division

The research study is reported over seven (7) chapters**.** Details on the content of the subsequent chapters are provided in the subsequent bullets.

Chapter 2 will highlight a summary of the literature study pertinent to the research study. It will be arranged by starting with an overview of the case study under investigation. The second section will then provide an overview on knowledge of PM theory. The final section will provide an overview on the PM schedule risk analysis for the research study.

Chapter 3 will focus on the empirical study of the research under investigation. It starts with the research design. The chapter will also provide an overview of the data gathering method through computation.

Chapter 4 will formally present the scoping review including the results, evaluation and analysis of $\mathbf{H_1}$. The goal in this chapter was to provide the reader with a preliminary study to evaluate whether CCRCS task time offers a longer expected project time than the methodology based on PERT.

Chapter 5 will formally present the TOP based on the principle of theory–building by PM case study. The chapter also provides specific deliverables by revisiting the aim and objectives of the research study. This Chapter systematically documents the author's original contribution to the knowledge gap of the nuclear industry in South Africa.

Chapter 6 will formally present a validation study utilising empirical research findings on the application of the theory. It further presents an extensive discussion on research rigour contributing to the validity of the research case study.

Chapter 7 will conclude with a summary of the discussion, conclusion and recommendations on the report offers advice to guide best practice on the theory for nuclear installations. The chapter also provides specific deliverables by revisiting the aim and objectives of the research study.

1.7. Summary

Chapter 1 provides a broad overview of the research study process. It highlighted the research scope and problem statement is identified; the aim and objectives, hypothesis statements and original contribution are defined. It had implicitly–illustrated the importance of project success. It provided an understanding of Koeberg's spent nuclear fuel storage project and its relationship to the research problem and requisite for the research study. Moreover, the research hypothesis statement, and original contribution by the author was provided for the research study.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

A broad overview of the research literature review is depicted in **Figure 4**. The chapter provides an overview of the case studies and covers the area of knowledge of PM theory underlying PERT/CPM and CCPM including the CCRCS, as it relates to the objective of the research study. The chapter will conclude with an overview on PM SRA to be able to establish the TOP using the research PM case studies.

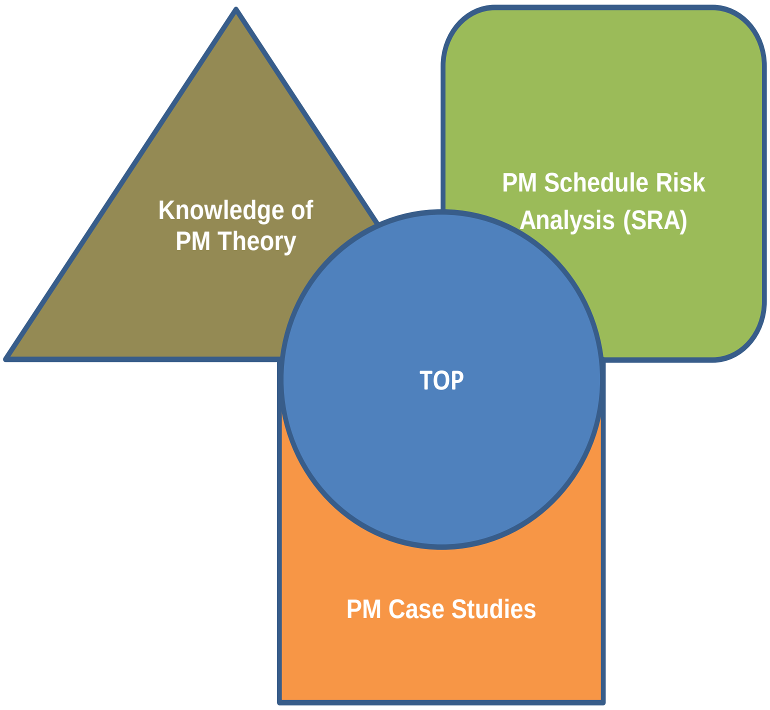

Figure 4 – Literature Framework Highlighted in Terms of Applicability

"When theorists build theory, they design, conduct, and interpret imaginary [thought] experiments" (Weick, 1989). Restated, this leads to a usable abstract definition that thought experiments commands theorists to design and conduct theory–building through imaginary. For the researcher to conform to the usable abstract definition, the subsequent sections supports the framework for the TOP; commencing with the understanding of the context for the research PM case studies.

2.2. PM Case Study Overview

Nuclear fission reactors have generated over two thousand terawatt–hours (TWh)[8] of nuclear energy worldwide, an unexpected increase after years of significant decline. Climate change and rising fossil–fuel costs commanded nuclear technology back into the race for base–load[9] electricity. When compared with other energy technologies, nuclear energy has been attested to reducing carbon emissions, unplanned outages and fatalities–unvarying after Japan's Fukushima Daiichi accident in March 2011 (IEA & Schneider, 2014).

More than three years later, 31 countries nonetheless operated nuclear fission reactors worldwide. These fission reactors generated 2,359 net TWh of nuclear energy, a marginal increase of circa *+0.5%* after 2 years of debility. South Africa's is one such country which generated 13.6 TWh of electricity during 2013 (IAEA, 2014a, pp. 18-19).

South Africa's recent agreement with Russia's state–owned nuclear company may infer more nuclear fission reactors being built, after an inter–governmental agreement was signed at the conference's 58th session of the International Atomic Energy Agency (IAEA).

> **"The agreement lays the foundation for the large–scale nuclear power plants procurement and development programme"** (Ginindza & Faku, 2014).

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[8] 1 terawatt-hour (TW·h) = 100 megawatt-hours (MW·h)

[9] Operation at steady full power

South Africa's state–owned utility Eskom (2014a) Holdings SOC Limited generates, transmits and distributes South Africa's electricity to commercial, industrial, agricultural, mining and residential consumers and subsequent municipal areas, who sequentially re–allocate electricity to households and businesses. It also procured electricity from independent power producers (IPPs) and electricity generation stations beyond its borders. Wholly, Eskom Holdings SOC Limited operates 27 power stations totalling *41,995 MW*, comprising of *thirty-five 726 MW* of coal–fired stations, *two 409 MW* of gas–fired, *two 000 MW* hydro and pumped-storage stations, *3 MW* wind and *one 860 MW* of nuclear energy at Koeberg's nuclear power station (KNPS). Eskom is the owner–operator of the only nuclear power station on the African continent.

Source: Electricity Supply Commission (Eskom, 2014a)

Figure 5 – Koeberg Nuclear Power Plant

Eskom has two French built fission reactors, each with a gross fission power output of *2,775 MW* thermal (refer to **Table 1**). It comprises of 2 three–loop pressurised water reactors (PWRs), turbine generators and associated plant. The Koeberg nuclear power plant is located on the site of Cape Farm number 1552 (also known as Duynefontyn) east of Cape Town within the Western Cape Province.

Koeberg's fission reactors begun commercial operation in 1984 and 1985 respectively, its units have been in operation for circa 30 years (Eskom, 2014a).

Table 1 – South Africa's Nuclear Fission Reactors

Reactor Code	**ZA-1**	**ZA-2**
Reactor Name	Koeberg Unit 1	Koeberg Unit 2
Type	PWR	PWR
Model	CPI	CPI
Thermal Capacity (MW)	2 775	2 775
Gross (MW)	970	970
Net (MW)	930	930
Reactor Operator	ESKOM	ESKOM
Supplier of Nuclear Steam Supply System	Framatome	Framatome
Construction Start[10]	July 1976	July 1976
Grid Connection[11]	April 1984	July 1985
Commercial Operation	July 1984	November 1985
EAF %[12]	75.8	84.1
UCF %[13]	76.2	84.9

Source: Nuclear Power Reactors in the World (IAEA, 2014a, p. 40)

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[10] Date of the first major placement of concrete, usually for the base mat of the reactor building (IAEA, 2014a)

[11] Date the plant is first connected to the electrical grid for the supply of power. After this date, the plant is considered to be in commercial operation (IAEA, 2014a)

[12] Energy availability performance factor (IAEA, 2014a)

[13] Unit capability performance factor (IAEA, 2014a)

Nuclear fission is the key process for generating nuclear energy at Koeberg. In tandem with light water reactors (LWRs), it yields spent nuclear fuel (SNF[14]) with high levels of radioactivity[15]. SNF subsists in the form of UO2[16] pellets and convene in zirconium–alloy tubes (known as uranium fuel cladding).

In the past, fresh uranium fuel was supplied by South African Nuclear Energy Corporation (Necsa), to operate Koeberg's LWRs from 1988 to 1994. This agreement discontinued when Necsa's operations became globally uncompetitive. At present, Toshiba's Westinghouse Electric Corp (US/Japan) and Areva (France) provisions 30 metric–tonnes of enriched uranium annually, to operate both Koeberg's fission reactors (Reuters, 2012).

Koeberg refuels each fission reactor, with fresh uranium fuel circa 16 months respectively. After refuelling and prior to being transported, the SNF (in the form of fuel assemblies similar to **Figure 6** are initially submerged–underwater for shielding against radioactivity and for cooling. SNF typically remain in the cooling pool(s) for 5 to 10 years before it is discharged at Koeberg. Spent uranium fuel may also be transported to be processed in a reprocessing facility. Fuel not destined for reprocessing may too be transported to a separate away–from–reactor (AFR)[17] spent fuel dry storage facility or repository (Dalnoki-Veress. F, 2013).

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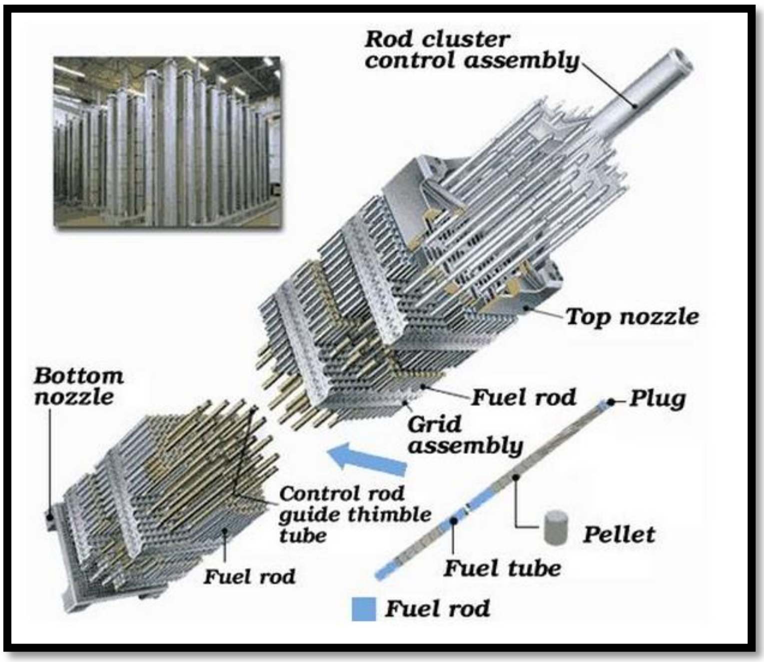
14 Spent Nuclear Fuel, also referred to as irradiated fuel or used nuclear fuel (EPRI, 2010)

15 Radioactivity is "[t]he phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation" (IAEA, 2007a)

16 Uranium oxide

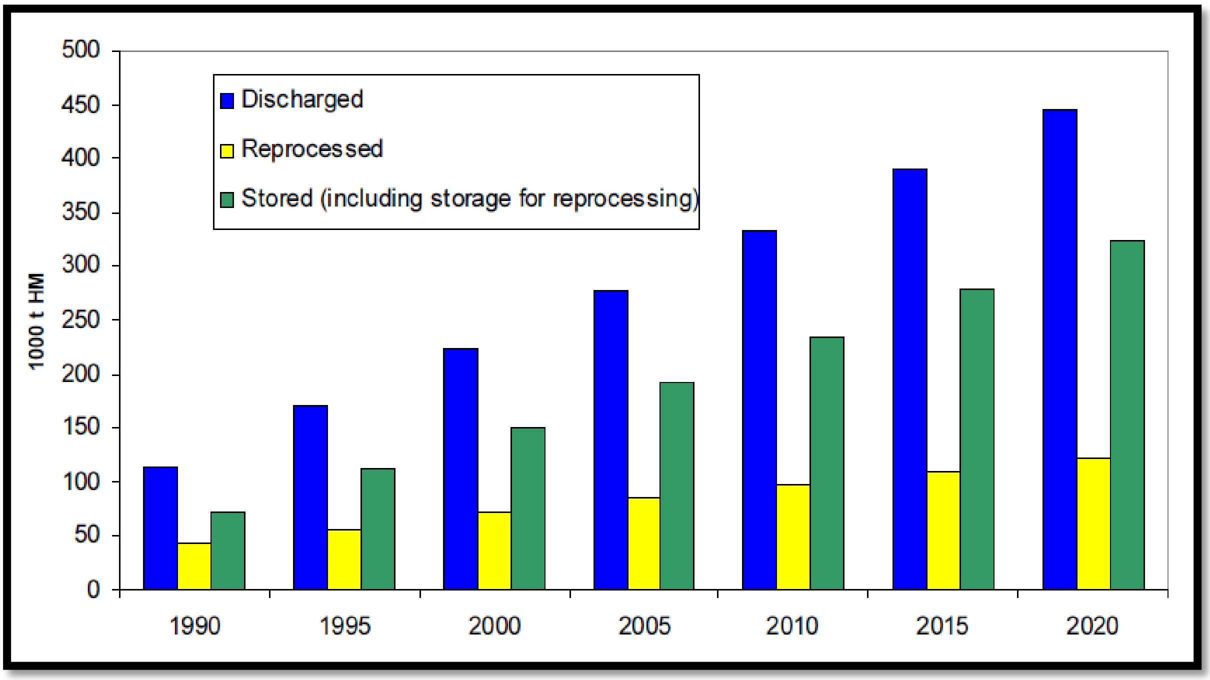
17 Away–from–reactor (AFR) by definition, "an AFR storage system implies that the spent fuel will have to be unloaded from a storage facility at the nuclear power plant and transported to its away-from-reactor site" (IAEA, 2007b)



Source: World Nuclear Association (WNA, 2014)

Figure 6 – Schematic View of PWR Fuel Assembly

Figure 7 shows the spent fuel generated, reprocessed and stored worldwide, with projections through to the year 2020. Over the history of 52 years of civilian nuclear energy, nuclear plants generated 276 000 metric tons of heavy metal (tHM) SNF worldwide. Roughly a third of this value was reprocessed, while others were in wet or dry storage facilities (IAEA, c. 2013).



Source: International Atomic Energy Agency (IAEA, c. 2013)

Figure 7 – Historical and Projected Quantity of Spent Fuel Discharged, Reprocessed and Stored

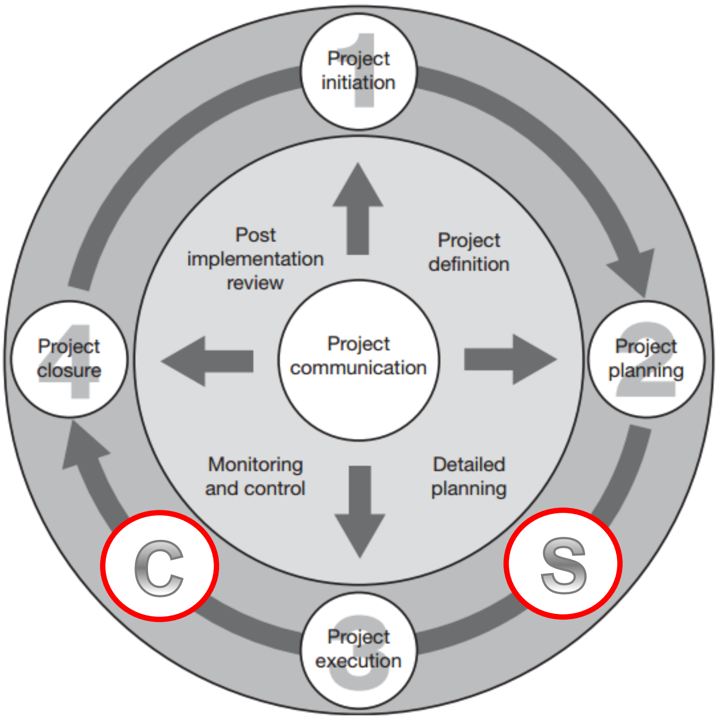
Managing SNF discharged from fission reactors, is the subject of debate for most nuclear programs worldwide. For the nuclear energy industry, many spent fuel management policies endures until a permanent repository is made available, to sufficiently store or dispose of SNF necessary for nuclear power stations to continue operating. Until a permanent solution is available, it will be beneficial to transfer spent fuel from wet to dry cask storage. It offers several key benefits–including the safe optimisation of SNF for decades after nuclear power stations retire.

The implementation of the Koeberg spent fuel storage project the traditional way is complex and challenging. A rethink of PM methods is needed to successfully solve the implications of introducing CCRCS and criticality index concept for selection of the critical chain using Monte Carlo using Eskom Koeberg and Sasol Secunda case studies. This decision lies at the core in the subsequent section, leading to the discussion on PM schedule risk analysis.

2.3. Knowledge of PM Theory

PM is the planning, monitoring and control of projects, with the motivation to achieve the expected time, cost and quality performance. This definition gives emphasises to the fact that PM is basically a difficulty of configuration, co-ordination and control for those involved and producing PM knowledge (Onions, 2007).

PM life cycles are constituted over the initiation, planning, execution and closure phases. They are valuable for project definition, detailed planning, monitoring and controlling control and post implementation review for those involved and producing PM knowledge. Archibald (1976) argues that there are a number of common characteristics shared by several PM life cycle models. These commonalities are due to the major milestones between the phases and the overlapping of the phases.



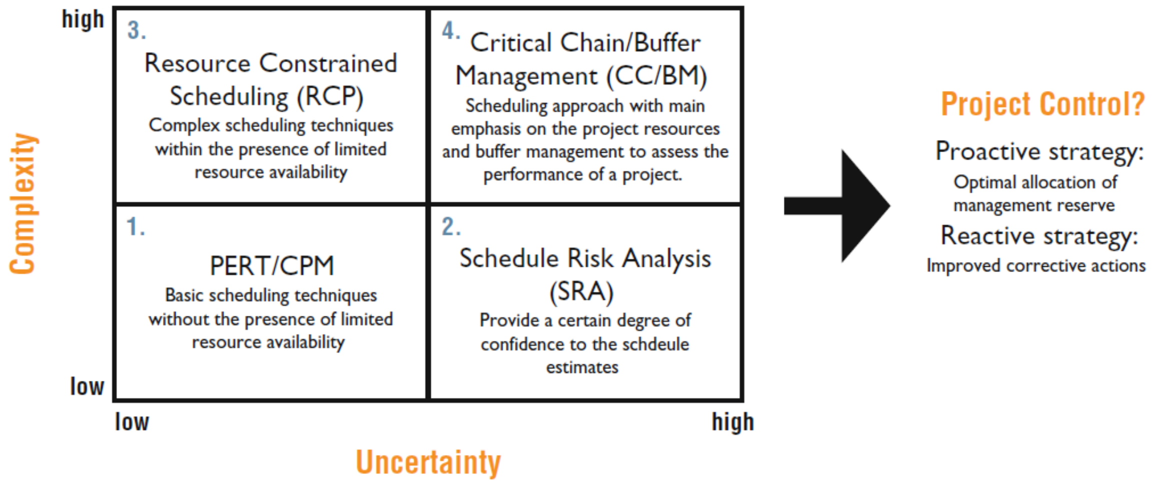
Source: The PM Life Cycle Model (Jason Westland, 2006) **– Adapted to Klein** (2000)

Figure 8 – Phases of the PM Life Cycle

In addition, the 1st edition of the project management body of knowledge (PMBOK), the PM life cycle was not alluded to. Only in future editions Project Management Institute (PMI) included the PM life cycle into the PMBOK. The PM life cycle concept of this research study is adapted to Klein (2000). Klein's concept includes two additional phases (i.e. in which the project has to be **scheduled** is denoted by "**S**" and the project **controlled** is denoted by "**C**") (refer to **Figure 8**).

2.3.1. Mapping the PM Case Study

In this section, guidance is presented on the options of four (4) classifications for the case study techniques, along uncertainty and complexity. The research approach is classified by the researcher and then used throughout the research study.



Source: PM with Dynamic Scheduling Adapted (Vanhoucke, 2013)

Figure 9 – Project Mapping

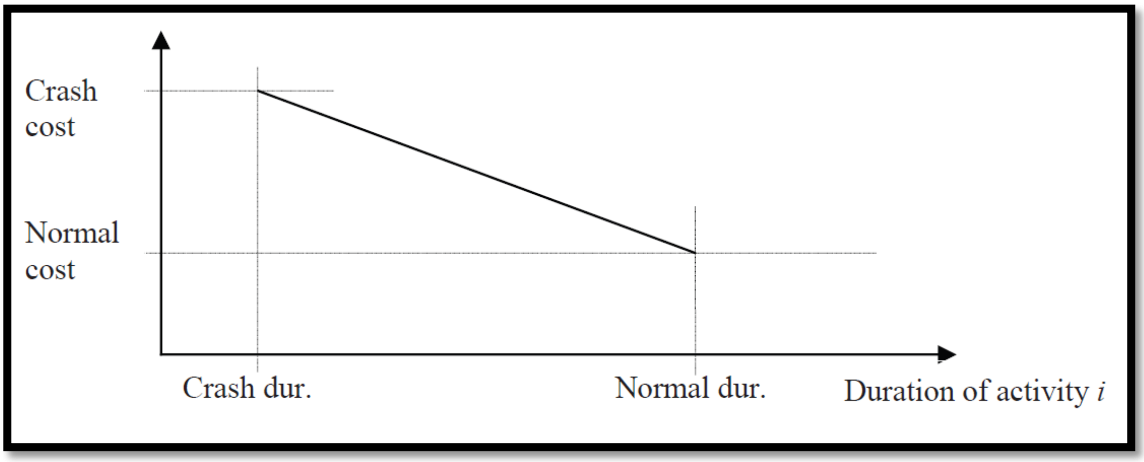
The goal of project managers is to measure and cope with uncertainties and complexities of their projects. **Figure 9** maps out the three (3) dimensions of scheduling dynamically, in particular: 1) **complexity** of project scheduling; 2) **uncertainty** of risk analysis; and 3) **project control**. When the level of uncertainty is high, the schedule of a project becomes more susceptible to change.

The current research study is therefore arranged around the classification along PERT/CPM (quadrant 1), SRA (quadrant 2), Resource Constrained Scheduling (RCS) quadrant 3 and critical chain/buffer management (quadrant 4), are outlined in the following subsections in order to achieve the objectives of the research.

2.3.2. Traditional PM Techniques

Traditional PM has developed several techniques based on scientific methods to be able to plan the process of PM to achieve the expected of time, costs and quality performance of resources. Hajdu (2013) indicated that there are hypotheses underlying every technique. Two (2) models are briefly examined for structuring work, one is the CPM model by Kelley and Walker (1959); and the second is PERT project scheduling by Malcolm et al. in 1957 (Malcolm, 1959).

In 1957 CPM was used to describe the logic among activities in a finite directed graph having one start and one finish activity-on-node. Events were denoted by nodes and activity durations by using arrows. The original hypothesis indicated that the duration of an activity will be shorten when compared to the normal time (duration) up to a point, while project cost will increase. Any change within the project task times between the normal and crash costs are linear as shown in **Figure 10** (Hajdu, 2013).



Source: Procedia - Social and Behavioral Sciences (Hajdu, 2013)

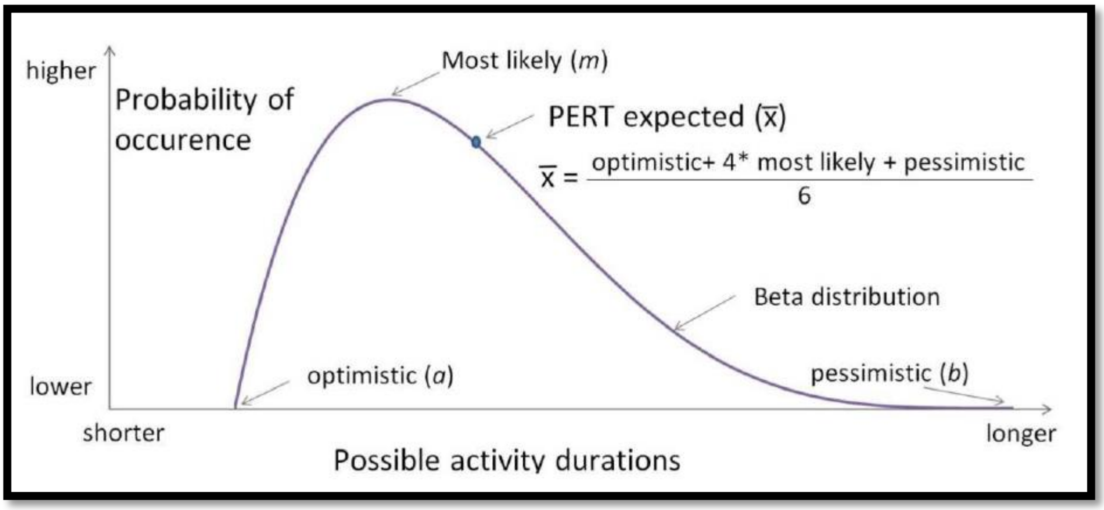
Figure 10 – Time and Cost Trade-off Hypothesis

Significant achievements were made through CPM (i.e. easier algorithms and generalising CPM). Hajdu (2013) indicated that these achievements had lost its significance due to the activity-on-arrow structuring, problematic simulations of real life projects, reliability of data in crash times and costs, and the only use of time and cost trade-offs.

The key difference between CPM and PERT is that task times are defined by stochastic variables. They are also assumed to be independent from each other (Hajdua & Bokora, 2014). The distribution of task time follows a PERT-beta (β) as shown in the formula, $f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(x-a)^{\alpha-1}(b-x)^{\beta-1}}{(b-a)^{\alpha+\beta-1}}, \; a < x < b, \; \alpha, \beta > 0$

In the formula, β and α are the parameters of the beta distribution and are greater than 1 ($\beta > 1$ and $\alpha > 1$); whereas a and b are points on the domain x. The interval outside, $f(x) = 0$. This ensures $f(x)$ tends towards zero (shorter), and $f(x)$ has one maximum (longer) at points on the domain $f(a) = f(b) = 0$. The mean ($\overline{x}$) and variance (σ_x^2) of the task times within PERT are defined in according to $\overline{x} = \frac{a+4m+b}{6}$ (Equation. 2) and $\sigma_x^2 = \left(\frac{b-a}{6}\right)^2$ (Equation. 3) respectively, where (a), (m) and (b) are subjective values, representing (a) optimistic, (m) the most likely and (b)

pessimistic task time of projects. The process of defining these subjective values are known to be PERT three-point estimation (refer to **Figure 11**).



Source: Procedia - Social and Behavioral Sciences (Hajdua & Bokora, 2014)

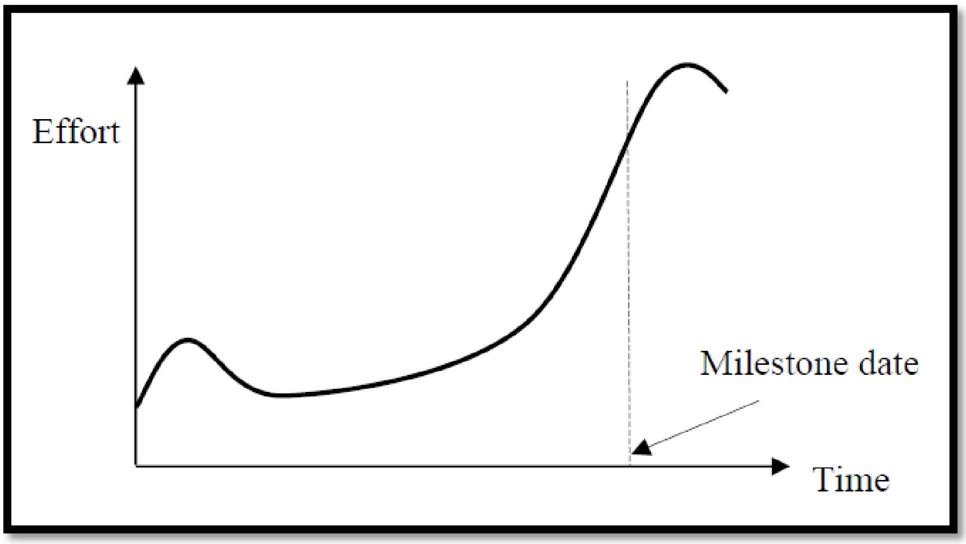
Figure 11 – Typical Density Function of the PERT-beta Distribution

In summary, CPM has lost its significance due to four underlying problems. The three-point estimation method (PERT) plays a much more important role, when determining the distribution of task times on projects. Research has to be continued to test the case of other project task times. To successfully solve the problem within the underlying the research study, $\mathbf{H_1}$ is investigated to test the case that CCRCS task time offers a longer expected project time than the methodology based on PERT.

2.3.3. Critical Chain PM

CPM and PERT project scheduling methods have remained relatively unchanged since its introduction in the 1950s, while CCPM was considered as an innovative breakthrough (Ghaffari & Emsley, 2015).

Goldratt (1997) acknowledged that project costs were a function of project schedule performance. He emphasised that contingency (task) times were being wasted due to its stochastic allocation within project schedules; leading to an issue known as the student syndrome (**Figure 12**). Another problem causing adverse human behaviour is Parkinson's Law.



Source: Project Management Journal (Leach, 1999)

Figure 12 – Student's Syndrome

Attempts were made to simplify the planning, monitoring and control mechanisms of projects and to shorten its times. This was achieved through the methodology on buffer sizing. To allow for uncertainties, the project had to estimate their task times at 50% probability from start to finish. This probability took into consideration project and feeder buffers at the end of each chain of activity. Two buffer sizing methods were suggested by Newbold (1998), the cut and paste, and root square error (RSE) methods.

2.3.3.1. Critical Chain Scheduling and Buffer Setting

The safe estimates for task time were initially decided by the project team. This provided a cushioning effect, approximately the same as the expected task time. For critical chain projects, it will start with the removal of these cushions from its task times, leaving only the average time to be used. The critical chain project scheduling process was developed by Tukel et al. (2006) and is generated over the following 6-steps, in particular:

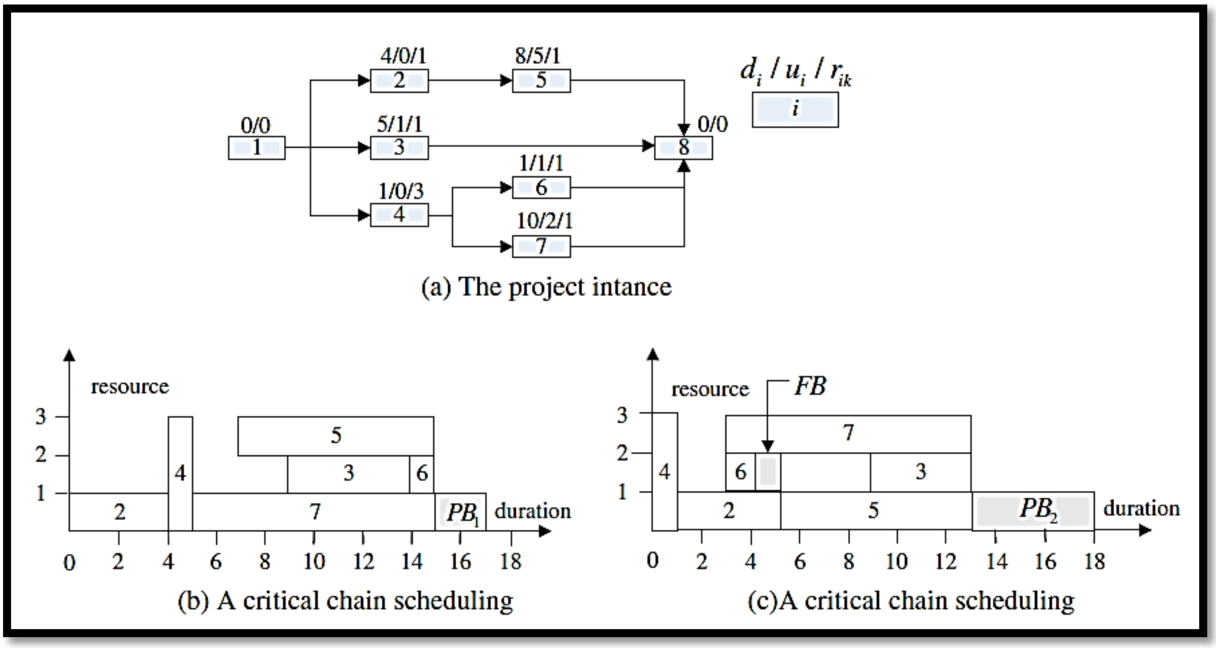
1. Determine the estimated task time at 50% for each task;
2. Move all tasks as late as possible, subject to precedency;
3. Re-structure the tasks to generate a feasible schedule (as the initial schedule), to eliminate resource contentions;
4. Identify the critical chain of the initial schedule that was identified in the preceding step;
5. Add project buffer to the end of each critical chain activity; and
6. Add feeding buffers wherever a non-critical task feeds each critical chain activity and offset the tasks on the feeding chain by the buffer size.

No specific procedure is presented to resolve resource contentions, referred to in step three. In a project instance, several critical chain schedules may be produced, as there may be several initial schedules (Herroelen, 2001).

To gain a better perceptive of CCPM, the project instance in **Figure 13** (a) is further conferred and it illustrates how it saves on task time. One renewable resource k is utilised, while its resource availability is 3. It also shows 8 project activities, where i $(i = 1, 2, 3, \ldots, 8)$ represents a task time, while d_i is a 50% task time estimate of i, u_i is the safety time[18] of i and r_{ik} is the requisites of resource k by the task i. CCS in **Figure 13** (b) and (c) were produced based on separate initial

[18] Duration uncertainty

schedules. The critical chain is $\{2,4,7\}$ as shown in the initial schedule, with the make-span of 15 is shown in **Figure 13** (b). In Figure 1(c), the critical chain is $\{4,2,5\}$, with a make-span of 13. In **Figure 13** (b), the project buffer computed with RSE method is $PB_1\sqrt{u_2^2+u_4^2+u_7^2}=2$. In **Figure 13** (c), the project buffer computed is $PB_2\sqrt{u_2^2+u_4^2+u_5^2}=5$. In **Figure 13** (b) there is no non-critical chain, whereas in **Figure 13** (c) a unique non-critical chain is $\{6\}$. In the traditional method, the feeding buffer of $\{6\}$ computed is $FB=\sqrt{u_6^2=1}$. Introducing PB_1, PB_2 and (feeder buffer) FB into the schedules denoted in **Figure 13** (b) & (c), the make-span is altered to 17 and 18 respectively (Penga & Huangb, 2013).



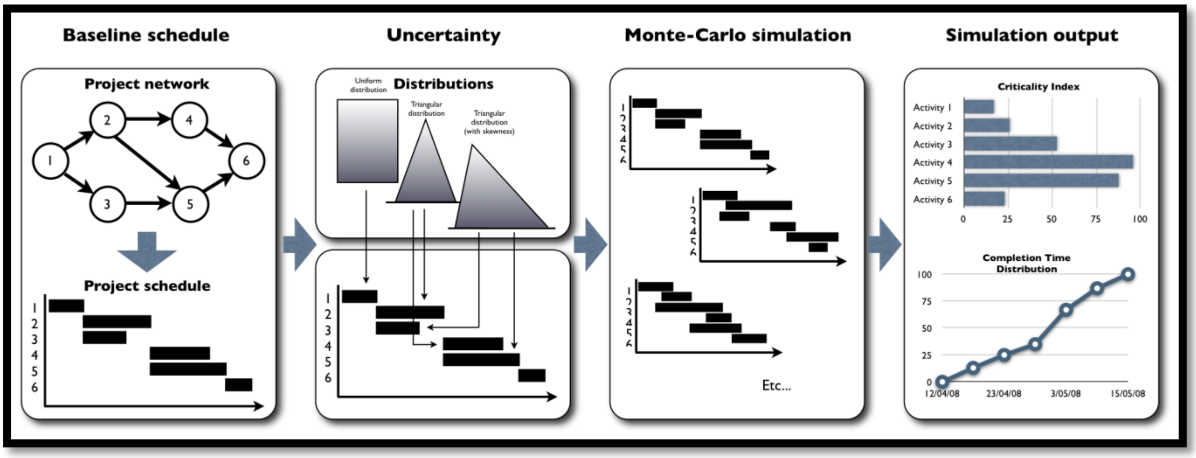
Source: International Journal of Production Research (Penga & Huangb, 2013)

Figure 13 – Project Instance and Critical Chain Scheduling

From the project instance in **Figure 13**, it may be concluded that there may be more than one viable CCS. The viability of solutions does not mean a corresponding CCS with a shorter make-span. In addition, the FB is more complex and may lead to new resource contentions (refer to problem provided by Rizzo (1999)). It is noteworthy that the precision of introducing feeding buffers is provided by Goldratt (1997). To date, there is no general optimization method for CCRCS due to its complexity. For the researcher to conform to **H_2**, the subsequent section on PM schedule risk analysis supports the framework for the criticality index concept for selection of the critical chain using Monte Carlo simulation.

2.4. PM Schedule Risk Analysis

In this section, a graphical overview of the four (4) steps on SRA is outlined into facet along the next subsections.



Source: PM with Dynamic Scheduling (Vanhoucke, 2013)

Figure 14 – Steps for SRA

The first step requires a baseline schedule and serves as a reference for the three (3) remainder steps. These three (3) steps are the risk of uncertainty, Monte-Carlo and output simulations of a particular project (refer to **Figure 14**).

2.4.1. Baseline Schedule and Uncertainty

Step 1: The baseline schedule serves as a reference point for projects. It is generally accepted and the baseline schedule plays a central role in a SRA. Vanhoucke (2013) states that a lack of baseline scheduling may lead to biased results or incomparable data. In **Step 2,** the level of detail may vary in accordance with the level of expertise of the statistics and mathematics in SRA, as refer to in the following bullets:

- Basic knowledge on statistical terminology and the reliance on easy-to-use software tools will allow the project manager to easily set up a SRA. The use of PERT may also be used as an alternative to complex statistical tools;
- Statistical analysis formulae are to be recognised and understood; and
- The categorisation of project activities and their risk class makes the SRA technique manageable for those you does not know any statistical analysis.

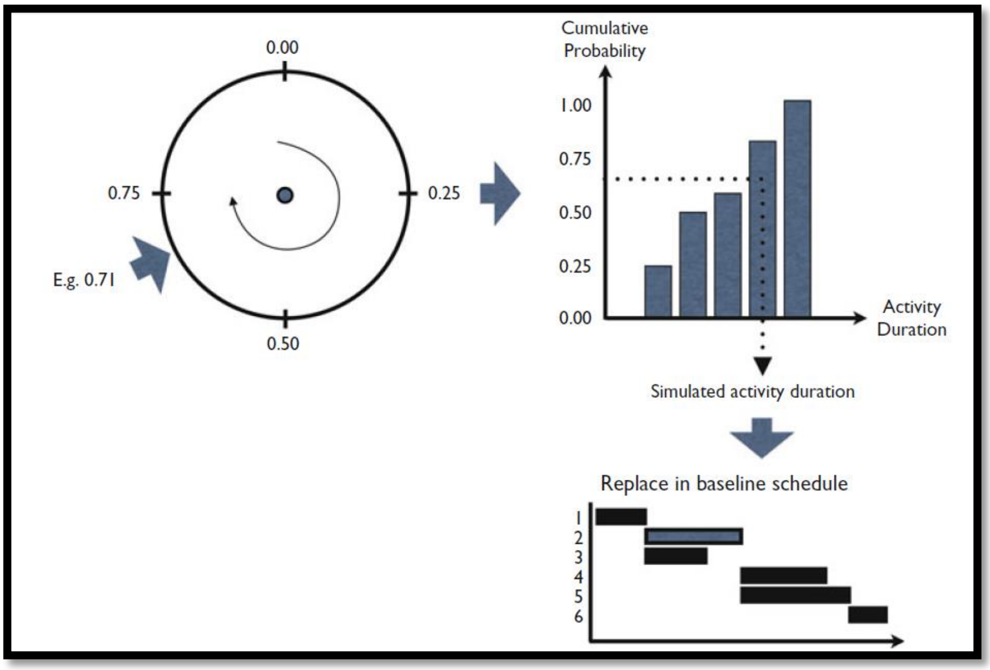
2.4.2. Monte-Carlo and Output Simulations

In Step 3, a basic principle of a Monte-Carlo simulation run used in a SRA is shown in **Figure 15**. The software simulation run is generated for a task time underlying a certain pre-defined profile, as described along the following lines:

1. “Generate a continuous uniform random number from the interval [0,1]”;

2. “Add the number as the u parameter in the cumulative distribution function and search for the corresponding real” task time; and

3. Baseline time is replaced by the newly generated number and then re-calculate the critical path.



Source: PM with Dynamic Scheduling (Vanhoucke, 2013)

Figure 15 – Basic Principle of Monte-Carlo Simulation

According to Vanhoucke (2013), this task time generated by the simulation run might differ from their original baseline values, changing the set of activities that is critical. In the last SRA run the effects of these changes is measured. In **Step 4,** the output of a SRA provides a set of measurements. It defines the degree of criticality and sensitivity of a task on the critical path, as described along the following bullets:

- Criticality index (CI) measures the probability that a task is on the critical path.
- Significance (SI) index measures the relative importance of a task.
- Schedule Sensitivity index (SSI) measures the relative importance of a task taking the criticality index into account.
- Crucially index (CRI) measures the correlation between the task time and expected project time, which is a requisite for the case study under investigation.

Each measurement index provides project managers with an indication of how sensitive the task (time) is towards the final project time.

2.5. Summary

Chapter 2 provides an overview of the PM case study and reviews South Africa's nuclear fission reactors codes: ZA-1; and ZA-2. It also reviews the schematics of PWR fuels assembly and the quantity of spent fuel discharged, reprocess and stored, to gain a better understanding of the research. The chapter conferred the relevance of knowledge of PM theory, phases of the PM life cycle, dynamic scheduling, time and cost trade-off hypothesis, typical density function of the PERT-beta distribution, student syndrome, project instance and CCRCS, and the SRA simulation steps – including the degree of criticality and sensitivity of a task (time) on the critical path. The Chapter revealed that significant knowledge was made through the CPM but it had lost its significance, specifically due to the activity-on-arrow structuring, problematic simulations of real life projects, reliability of data in crash times and costs, and the only use of time and cost trade-offs knowledge. Knowledge of the critical path, the degree of criticality and sensitivity of a task (time) is a specific problem requiring further research. This research study makes that contribution to the knowledge gap of the nuclear industry in South Africa.

CHAPTER 3: EXPERIMENTAL DESIGN

3.1. Introduction

Chapter 3 provides an overview of the research experimental design specifically focusing on the gaps identified in the research literature in Chapter 2. A broad overview of the experimental design is depicted in **Figure 16**. The Chapter also provides an overview of the scoping review to appraise the research viability and then covers the process of theory development as it relates to the objective of the research study. The Chapter will conclude with an overview of the validation study to assess the results of the application of TOP using the research PM case study.

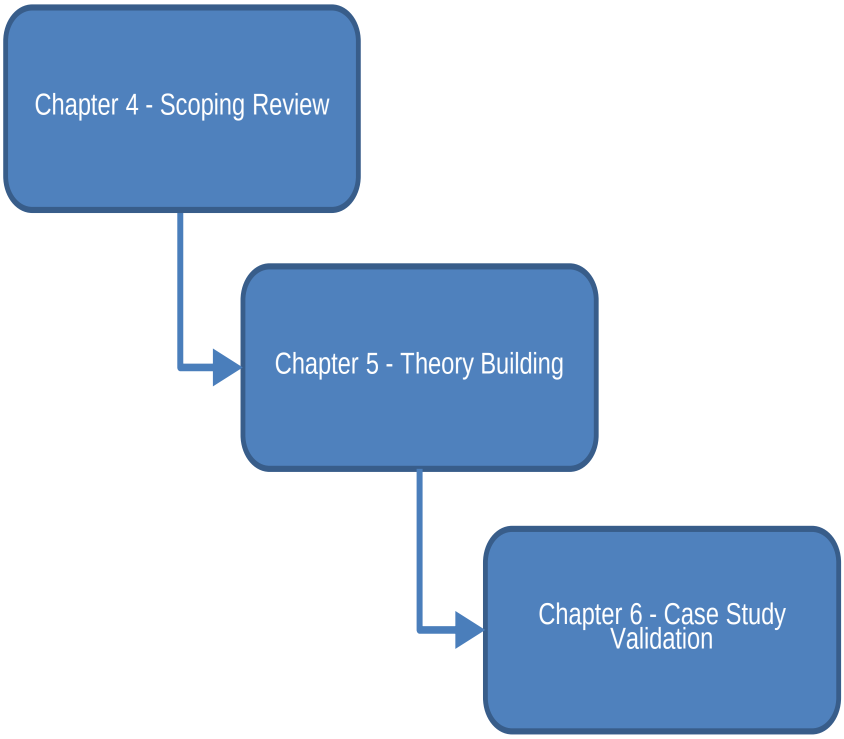


Figure 16 – Experimental Design Framework

"...great difficulties are felt at first and these cannot be overcome except by starting from experiments ... and then be conceiving certain hypotheses ... But even

so, very much hard work remains to be done and one needs not only great perspicacity but often a degree of good fortune" (Christiaan Huygens, 14 April 1629 – 8 July 1695, Physicist and Astronomer). Restated this quote leads to a usable abstract definition that great difficulties are overcome through experiments and conceiving hypotheses. However, hard work remains to be performed [through the theory–building process] and one not only requires intelligence but often a degree of good fortune [through verification and validation]. For the researcher to conform to the usable abstract definition, the subsequent sections support the framework for the experimental design research study.

3.2. Statement of Hypotheses

Two (2) research hypotheses with their corresponding null hypotheses were developed to evaluate their applicability and validity for the TOP methodology along the following subsections.

3.2.1. Research Hypothesis H_1

Hypothesis (**H_1**) is formulated to fundamentally assess the relationship between the CCRCS and PERT on the PM case study nuclear project A and its project time.

The research hypothesis (**H_1**) and its corresponding null hypothesis (**$H_{1.0}$**) are detailed as follows:

H_1: CCRCS *task time* offers a longer *expected project time* than the methodology based on PERT; and

$H_{1.0}$ is stated as: *Task time* for CCRCS does not offer a longer *expected project time* than the methodology based on PERT.

The research hypothesis (**H_1**) is appraised by the researcher during the scoping review in Chapter 4.

3.2.2. Research Hypothesis H_2

The research hypothesis **H_2** appraises the TOP using Monte-Carlo simulation and assays its effectiveness for nuclear projects. The research hypothesis **H_2** and its corresponding null hypothesis **$H_{2.0}$** are detailed as follows:

H_2: Implementing a methodology based on TOP will reduce the risk of the *expected project time*; with corresponding **$H_{2.0}$** that implementing a methodology based on the TOP will not reduce the risk of the *expected project time*. **H_2** appraises the TOP by Monte-Carlo simulation.

To date, there is no general optimisation method due to its complexity. The researcher conforms to **H_2** through empirical testing and confirms the benefits of using the TOP. The selection of the PM case study nuclear project B together with the measurement of the criticality and sensitivity to improve the accuracy of expected project time is not a trivial decision made by the researcher. Assenting to **H_2** confirms that the two–folded measuring process (i.e. criticality and sensitivity) will reduce the risk of the *expected project time* and its consequent success of projects.

Project control (refer to **Figure 9**) underlying earned value management (EVM) is briefly covered during the mapping and assessment of **H_2**. Vanhoucke (2013) states that EVM system relies on metrics to measure the overall health of a project. It was used since the 1960s by the USA Defence Department as a standard to measure project performance. In this context it may be iterated that ***"If you can't measure it, you can't improve it"*** *(Lord Kelvin also known as William Thompson, 26 June 1824 – 17 December 1907, Physicist and Engineer).* Further restating this abstract in terms of the TOP methodology, a hypothetical connotation is proposed by the researcher: **If you can measure it, you can improve it**.

On 15 September 2016 the researcher performed a search in EBSCOhost and established that the associated context of Lord Kelvin **"*If you can't measure it, you can't improve it*"** is reported across only 12 source types between 1986 and 2016, primarily within 4 periodicals within the health services (Berenson, 2016a), environment technology (Beatty, 2000), food industry (Friedman, 1997) and infection control (Nakanishi Y. , 2015a), followed by 4 academic journals within management information systems (Ryan, 1986), psychometrics (Ashburn, Witkin, & Pain, Aug, 2012), health service (Berenson, 2016b) and infection control (Nakanishi Y. , June 2015b). It is also reported in 4 newspaper articles within the Buffalo Newspaper (Buffalo News, The (NY), 04/05/2015 (AN: 2W6430739504)), Washington Newspaper (Washington Times, The (DC), 06/24/2014, p3-3. 1p), Tribune (Kokomo Tribune (IN), 03/06/2007. (AN: 2W62W63127786249)), and Australian Newspaper (The Australian, 02/18/2002 (AN: 200202181034769011))). Unexpectedly, nothing was obtained by the researcher across source type underlying the field of nuclear project management.

Similarly, on 16 September 2016 the researcher performed a search in EBSCOhost and established that the hypothetical connotation proposed by the researcher in terms of the TOP methodology: **If you can measure it, you can improve it** is also reported across only 10 source types between 2000 and 2016, primarily within the already stated 2 periodicals within health services (Berenson, 2016a) and environment technology (Beatty, 2000), and in 1 periodical within total quality management (Chopra & Kanji, 2011). Correspondingly, it is reported in 3 academic journals within hospital management (Yokl, 2007), clinical and experimental rheumatology (Mikuls, 2007) and health services (Berenson, 2016b), equally in 3 newspaper articles within the Washington Times (Washington Times, The (DC), 06/24/2014, p3-3. 1p), UK Times (Times, The (United Kingdom). 01/22/2013, p8-8. 1.) and USA Today (USA Today, 03/26/2010). Finally, 1 is sourced in the Editorial & Opinion within clinical leadership & management (Hill, 2006). On the contrary, nothing was obtained by the researcher across source type underlying the nuclear project management domain.

The search within EBSCOhost established that both iterations (by Lord Kelvin and the researcher) were obtainable, except for in nuclear project management. Thus, the subsequent research focuses on the development of a practical methodology using empirical testing of the hypotheses to improve the accuracy of the expected project time from theory–building.

3.3. Scientific Theory–Building Process

In this section, the theory–building concepts of empirical research is outlined as it links to the questions concerning the methodology to follow, data collection process and theory of the research study along the following paragraphs.

At this point, a question emerges on “What is theory?” For research purposes a general definition is provided by Gioia (1990): theory is based on a hypotheses statement and their interrelationships, which show how or/and why an event occurs. One of the most documented articles on theory is by Lewin (1945) who states that “nothing is quite so practical as a good theory” therefore: “good theory is practical precisely because it advances knowledge in a scientific discipline, guides research toward crucial questions, and enlightens the profession of management” (Van de Ven, 1989).

Several processes of theory–building from case study research have been identified across the research literature. One of the recent documented works is on grounded theory by Strauss (1987). The theory relies on the constant comparison of data and theory starting with the data collection process. Miles & Huberman (1984) outline techniques specifically for the qualitative data analyses process, which includes the use of devices such as graphs and tabular displays, while Yin (1984) describes the design of a case study research as a research strategy. The approach brings together the concerns of research reliability and validity to the design of the PM case studies.

At this convergence, Eisenhardt (1989) states that the roadmap for building case study research theories are through the synthesis of information of previous work such as the grounded theory–building (Strauss, 1987), qualitative data analysis of the research study (Miles, 1984) and designing of the case study by Yin (1984). The 8–step theory–building process from the case study of Eisenhardt (1989) provides a more complete roadmap than what has existed in the past. Computer software simulations are particularly valuable and are positioned in the “sweet spot” in theory–building as researchers are able to develop formal modelling, case study inductive research and theory–testing according to Eisenhardt (2007), et al.

Comparably, Christensen (2006) reveals that the theory–building process may be mapped over two (2) key stages: descriptive and the normative theory stages. In each of these stages the theory–building will proceed through 3–steps and iterates through the 3–steps over and over again. This theory–building has evolved considerably through the work of scholars who refined the process. Among the notable advances to date have been Adner (2002), Adner & Zemsky (2003), et al.

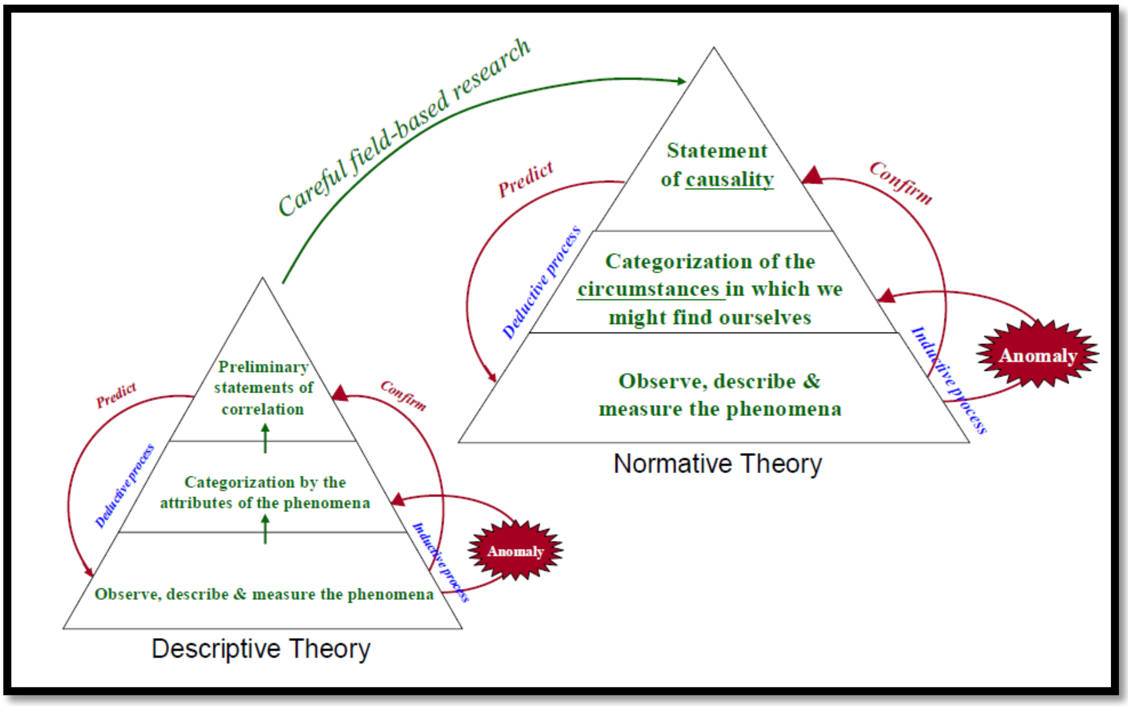
Eisenhardt, et al. together with the Christensen theory–building process is presented to assess the hypotheses with their corresponding null hypotheses and to validate the TOP methodology. The process to develop theory from case studies is therefore presented by summarising the contributions of Eisenhardt and Christensen respectively. These summaries provide the foundation of the experimental design for the scoping review, theory–building and research validity along the following subsections.

3.3.1. Christensen 3–Step Theory–Building

According to Christensen (2006), the *preliminary* stage of theory–building is through descriptive theory. Generally, researchers pass through descriptive theory before developing the normative theory. The three (3) steps researchers use to build descriptive theory are by observation, categorization, and association.

Step 1: In this step *observation*, *definition* and *measurement* of the phenomena in numbers and words is vital to researchers. By agreeing on the description of phenomena, then improving the research theory will not be problematic. The phenomena being explored is not just limited to the people, technology and organisations, but also to the processes being explored. **Step 2:** With the phenomena covered, researchers then classify the underlying categories the phenomena. The *classification* underlying the categories are often referred to as *typologies* or *frameworks*. **Step 3:** In the final step, researchers *define relationships* between the categories of the phenomena and observations of their outcomes. Regression analysis for estimating the relationships among variables is often useful in the descriptive theory–building stage of the ressearch.

Theory–building efforts from descriptive theory are typically categorised by the attributes of the phenomena. They are easy to observe and measure, alike, attributes and its outcomes are also easy to hypothesize. Kuhn (1962) on the other hand noted, the contradiction and confusion of the descriptive theory as a typical norm. This contradiction and confusion by Kuhn was resolved when researchers defined what had caused its outcome.



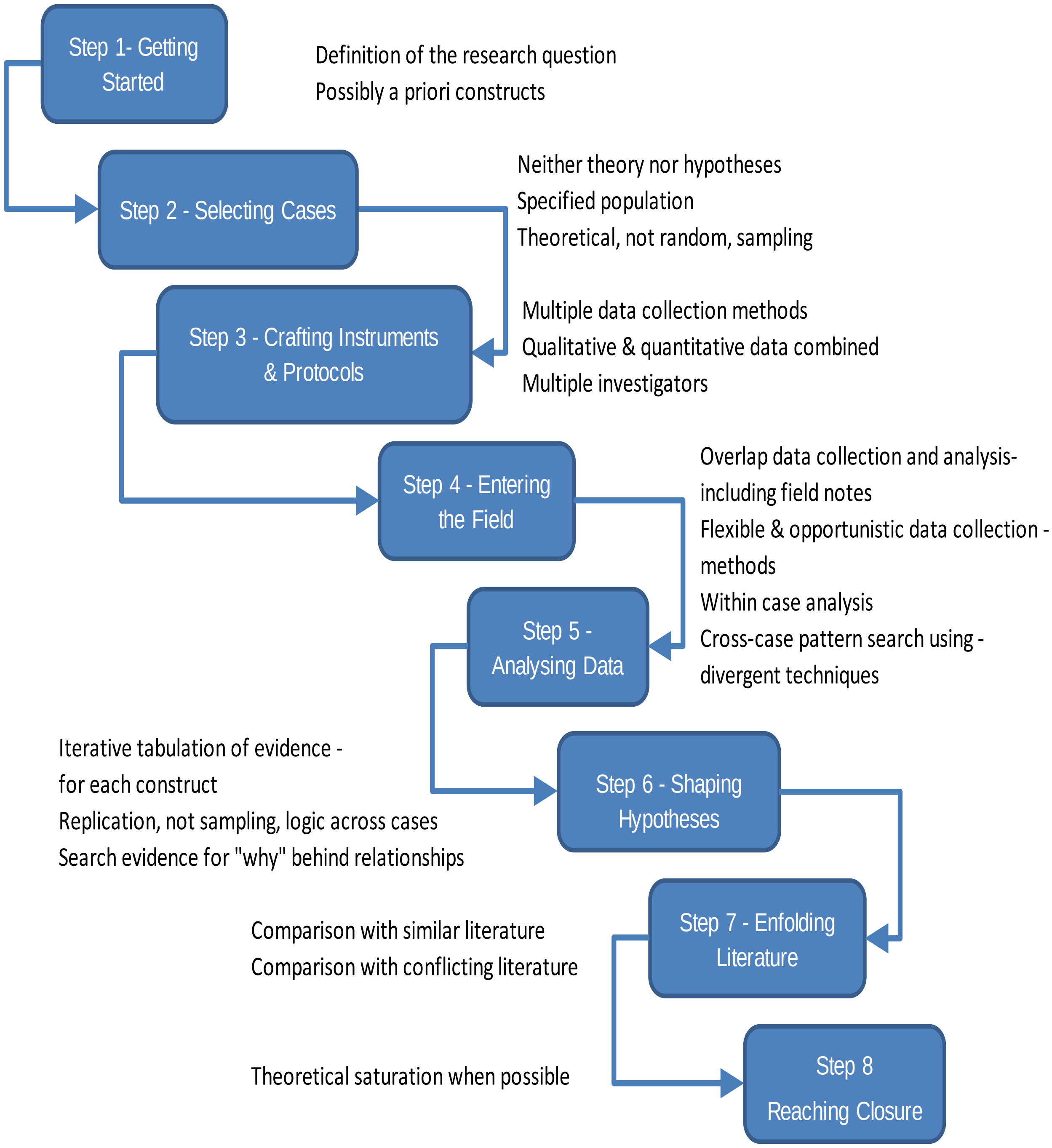
Source: The Cycles of Theory–Building in Management Research (Christensen C.M, 2004)

Figure 17 – Christensen Descriptive & Normative Theory

Researchers have improved the theory by following the exact 3 steps and through careful field-based research, hypothesise that their statement of causality were correct. When an anomaly is encountered, then researchers will delve into the research category stage. **Figure 17** shows the field-based research transition from descriptive to normative theory (Christensen C.M, 2004). Normative theory is used for this research as it guides the researcher with what actions will and will not lead to the desired research study results.

3.3.2. Eisenhardt 8–Step Theory–Building

Restated, Eisenhardt's (1989) roadmap for building case study theory are through the synthesis of information by grounded theory–building (Strauss, 1987), qualitative data analysis of the research study (Miles, 1984) and designing of the case study by Yin (1984). This roadmap for building case study research theories is depicted along the following steps (refer to **Figure 18**).



Source: Adapted Building Theories from Case Study Research (Eisenhardt, 1989)

Figure 18 – Eisenhardt Theory–Building Process

Step 1: Focuses on research study efforts. This step provides a better grounding of the construct[19] measures. **Step 2:** Retains theoretical flexibility, constrains extraneous variation and shapens external validility. The step focuses on efforts on theoretically useful cases. **Step 3:** Strenghtens grounding theory by triangulation of evidence and synthesise the evidence and foster divergent perspetives and strenghten grounding. **Step 4:** Speeds up the analyses and reveals helpful adjustment to data collection. In this step it allows investgators to take advantage of emergent themes and unique case features. **Step 5:** Gains familiarity with the data and preliminary theory generation. This step forces invetigators to look the beyond initial impressions and view evidence through multiple lenses. **Step 6:** Sharpens the contruct defintion, measurability and validity. This step confirms, extends and shapens the research theory. This step builds up to internal validity. **Step 7**: Builds internal validity, raises theoretical level and sharpens generalizability. This this step contruct–defintion is improved and theoritical level raised. **Step 8:** Ends with the theory building process when the marginal improvement becomes minimal (Eisenhardt, 1989). More recently, computer software simulations **steps** were particularly valuable for the researcher as he could perform formal modelling, case study inductive research and theory–testing according to Eisenhardt (2007), et al. (refer to **Figure 28**)

Thus *"[t]he formal scientific definition of theory is quite different from the everyday meaning of the word. It refers to a comprehensive explanation of some aspect of nature that is supported by a vast body of evidence." (National Academy of Sciences)*. For the researcher to conform to this usable quote, the subsequent sections integrate both theory–building steps for the TOP methodology. It is summarised along the following lines by commencing with **Part 1:** Scoping review, followed by **Part 2:** Theory–building ending with **Part 3:** Case study validation.

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[19] An image, idea, or theory – (www.dictionary.com)

3.4. Scoping Review by Case Study

Research Parts 1 of the scoping review study "*aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available, and can be undertaken as stand-alone projects in their own right, especially where an area is complex or has not been reviewed comprehensively before*" (Mays, 2001). These research case studies are subsequently mapped to the Christensen and Eisenhardt theory–building concepts described along the following sections.

3.4.1. Part 1: Scoping Review

Part 1 of the scoping review (or preliminary study) fundamentally assess the relationship between the CCRCS and PERT on the PM case study nuclear project A and its project time. Part 1 is referenced to the Christensen theory–building concept. The scoping review consolidates the observation, categorisation and measurement in numbers and words, followed by the classification underlying categories, and the investigation between the categories and observations of their outcomes. An initial regression analysis for estimating the relationships among variables of $\mathbf{H_1}$ is evaluated for the research. Nuclear Project A was identified (refer to section 1.1) and is selected by the researcher as it has vast referencing empirical testing data. The scoping review by case study Part 1 is outlined in more detail within Chapter 4.

3.4.2. Part 2: Theory–Building

Part 2 appraises the TOP and assays its effectiveness for critical chain scheduling on the PM case study nuclear project B and its project time. Part 2 is referenced to Eisenhardt, et al. theory–building concepts. By combining the contributions of Eisenhardt (**Figure 18**) and Eisenhardt, et al. (**Figure 28**), it is revealed that *measurability* lies at the core of the theory–building concept for the PM case study under investigation.

“The grandest discoveries of science have been but the rewards of accurate measurement and patient long-continued labour in the minute sifting of numerical results” (Lord Kelvin also known as William Thompson, 26 June 1824 – 17 December 1907, Physicist and Engineer). The researcher impulsively raised questions on *measurability*, which were used to formulate the research questions. Once research questions were refined, the PM case study was selected, and the measurement instruments formulated for the data collection process.

Monte-Carlo simulation analyses for estimating the relationships among variables of $\mathbf{H_2}$ were evaluated for the research. Nuclear Project B was identified (refer to section 1.1) and selected by the researcher as it also had vast reference data for empirical testing. The theory–building by case study Part 2 is outlined in more detail within Chapter 5.

3.4.3. Part 3: Validation Study

Part 3 of the research validation study is referenced to the Eisenhardt, et al. theory–building concept (**Figure 28 – Developing Theory Through Simulation Methods**). This latest method of developing theory (through simulation) was adapted by the researcher after considering Eisenhardt former theory–building process (refer to **Figure 18 – Eisenhardt Theory–Building Process**). Through the validity study the research problem is solved. The rigor underlying this validity study is outlined in more detail within Chapter 6.

3.5. Summary

Chapter 3 provides an overview of the experimental design for the PM case studies and reviews the statement of hypotheses with their corresponding null hypotheses. It also reviews the theory–building concepts of empirical research, to gain a better understanding of the research design. The Chapter confers the Christensen and Eisenhardt roadmaps for building case study research theories. It was revealed that *measurability* lies at the core of the Christensen and Eisenhardt theory–building process. Parts 1, 2 and 3 of the research study are also covered. At this onset, the experimental design proceeds systematically into Part 1: Scoping Review of Chapter 4.

CHAPTER 4: SCOPING REVIEW

4.1. Introduction

Chapter 4 presents Part 1 of the scoping review in the form of a preliminary study. It assesses the relationship between the CCRCS and PERT on the PM case study nuclear project A. Part 1 is referenced to the Christensen theory–building concept, previously covered under section 3.3.1. This SR represents the observation, categorisation, and association of the research study.

An initial regression analysis for estimating the relationships among variables of $\mathbf{H_1}$ is evaluated in the form of a preliminary study. Nuclear Project A was identified (refer to section 1.1). The research hypothesis $\mathbf{H_1}$ is dealt with and evaluated by the researcher during this SR section.

Testing the $\mathbf{H_1}$ theory on Nuclear Project A, indeed correlates with the outcomes as predicted. The results demonstrated support for the hypothesis as outlined in the following sections.

4.2. Inductive Reasoning

Inductive[20] reasoning is achieved in the SR, and consolidates the underlying *observations*, *categorisation* and *association* of the PM case study. This SR is presented in **Figure 19.**

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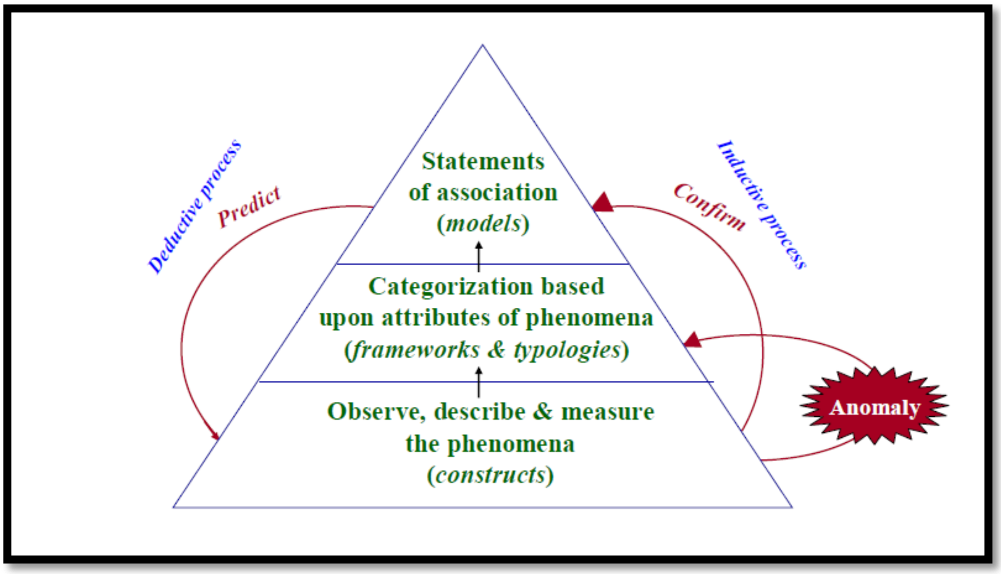
[20] Inductive is a bottom–up approach, where the researcher formulates a tentative plan and end with a general conclusion (Lavelot, 2014)

4.2.1. Observations

In this first step, the researcher *observed* the phenomena and systemically *defines* and *measured* what he had seen. The foundation of the research phenomena is theorised. Without insightful narration, the researcher might have found the data collection and optimizing process unreliable. Christensen (2006) states that abstractions[21] are often developed in this step, which are constructs to understand the phenomena. Constructs help us understand and visualize what the phenomena are and how they operate.



Source: The Cycles of Theory–Building in Management Research (Christensen C.M, 2004)

Figure 19 – Christensen Normative Theory

The researcher performed observations for more than twenty five years across the engineering, quality, construction and nuclear industry in the field of project management. During this time, delivering projects as expected was often found to be one of the biggest challenges being observed. The common cause of project failures observed were mostly due to inaccurate *task time* estimates,

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[21] An impractical idea; something visionary and unrealistic (www.dictionary.com)

resource dependency, inaccurate resource forecasting, limited resources, team member procrastination and task dependency. The apparent observations led to question being asked by the researcher, described along the following paragraphs.

The observations, considered in the light of the phenomena by Herroelen (On the Merits and Pitfalls of Critical Chain Scheduling, 2001) led to the question: a) Why were no specific procedures presented for resolving resource contention? This question preceded to more relevant research questions; b) Why there were no general optimisation methods for CCRCS (Penga & Huangb, 2013)? c) What research should be considered to improve the expected project time? These questions were further refined to; d) What the difference between CCRCS task time and the expected project time methodology based on PERT; e) How may the theory of optimisation contribute to improvement the accuracy of the expected project time of nuclear projects? Later observations were considered in light of Cserháti & Szabó comment (The relationship between success criteria and success factors in organisational event projects, 2014), and led to the question f) Why are most important criteria for project success are environmental impact, technical success and effects on business operations?

4.2.1.1. Hypothesis

The purpose of the SR was to assess the relationship between the CCRCS and PERT (without CCRCS) on the PM case study project and its project time. With observation covered and phenomena defined, the research hypothesis with its corresponding null hypothesis was then developed by the researcher. The research hypothesis $\mathbf{H_1}$ and its corresponding null hypothesis $\mathbf{H_{1.0}}$ are detailed as follows: $\mathbf{H_1}$: CCRCS *task time* offers a longer *expected project time* than the methodology based on PERT. $\mathbf{H_{1.0}}$ is stated as: *Task time* for CCRCS does not offer a longer *expected project time* than the methodology based on PERT.

4.2.2. Categorisation

In the previous step, the researcher observed the phenomena and systemically described what he had seen. In this second step, the phenomenon is classified into categories. Normative theory is used for this research as it provides the researcher with the desired research study results. The proposed typology[22] for the research is categorised chronologically.

The proposed typology consists of the main research categories. It is further divided into subcategories schemes. Two models are used as the main research categories, one is PERT project scheduling by Malcolm et al. in 1957 (Malcolm, 1959) and the other CCPM by Goldratt (1997). Their related subcategories: (a) optimistic, (m) the most likely and (b) pessimistic *task time* and *expected project time* is computed for the PERT and CCRCS respectively for the PM case study project.

4.2.3. Association

In this third step, the correlations between the attributes of the category and outcomes are explored. The initial formulae to estimate the relationships among variables of $\mathbf{H_1}$ are observed for the research. The output of studies in this step is often referred to as models. Restated, two models were used, PERT project scheduling (without CCRCS) and the other with CCRCS to compute the PM case study project and its project time.

The distribution of task time following a PERT-beta (β) is shown in the formula, $f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(x-a)^{\alpha-1}(b-x)^{\beta-1}}{(b-a)^{\alpha+\beta-1}}, \ a < x < b, \ \alpha, \beta > 0$ .In the formula, β and α are the parameters of the beta distribution and are greater than 1 ($\beta > 1$ and $\alpha > 1$);

[22] Typology is a systematic classification or study of types (www.dictionary.com)

whereas a and b are points on the domain x. The interval outside, $f(x) = 0$. This ensures $f(x)$ tends towards zero (shorter), and $f(x)$ has one maximum (longer) at points on the domain $f(a) = f(b) = 0$. The mean ($\overline{x}$) and variance (σ_x^2) of the task times within PERT are defined in according to $\overline{x} = \frac{a+4m+b}{6}$ and $\sigma_x^2 = \left(\frac{b-a}{6}\right)^2$ respectively, where (a), (m) and (b) are subjective values, representing (a) optimistic, (m) the most likely and (b) pessimistic task time of projects. The critical chain project scheduling process is generated over 6-steps (refer to section 2.3.3.1).

With PERT project scheduling and CCRCS covered, the qualitative risk rating outcomes were explored for the PM case study. Consequently, Nuclear Project A time estimates were computed to determine whether the risk of the project time would have a (a) high–confidence (low–risk), (m) medium–confidence (medium–risk) or (b) low–confidence (high–risk) duration rankings for the research hypothesis $\mathbf{H_1}$ under investigation.

4.3. Deductive Reasoning

After no anomaly, deductive[23] reasoning was achieved through the SR by testing the hypothesis $\mathbf{H_1}$, which was inductively developed in the preceding section. The researcher explored correlations between the attributes of the category and their outcomes using the data the hypothesised relationships were induced with using the case study Nuclear Project A.

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[23] Deductive is known as the top–down approach, where the researcher works his way down a broad spectrum to a specific conclusion (Lavelot, 2014)

4.3.1. PM Case Study Nuclear Project A

The review period for the historical Nuclear Project A exceeded the expected 2 week project time. This review was considered to be unacceptable to the nuclear project management department as none of the subsequent projects were completed following several requests for additional task time. An initiative has to be launched to resolve the failure and address the extension of the expected project time. The researcher started with the simulation of critical tasks activities, the sequencing of tasks and their durations for the preliminary study. Modern methods of computing aided the researcher with the mapping of CCRCS and PERT PM case study project.

4.3.1.1. Appraisal of SR

Modern methods of computing were utilised to appraise the relationship between the CCS and without CCS (PERT) on the PM case study project and its project time. To evaluate **H_1**, the task time and expected project time were simulated by the researcher using MS Project 2010 and Pro Track V3 (refer to **Figure 20** to **Figure 27**).

4.3.1.1.1. Without CCS Software Simulation

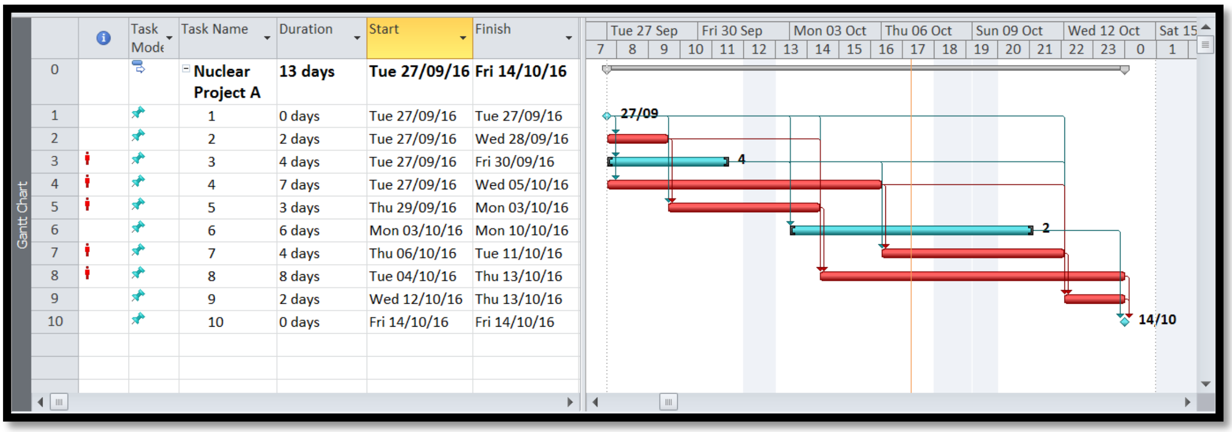

Figure 20 – Without CCS by Software Package MS Project 2010

In the Gantt chart that Microsoft Project uses to display information, the expected project time is *13 days* without CCS (refer to **Figure 20)**. The critical tasks 2; 4; 5; 7; 8 and 9 are to start and finish on time for the project to end on schedule. The project resources are constrained at activities 3; 4; 5; 7 and 8, which might cause project delays. RCS will have to be taken into consideration when simulating CCRCS, not to tolerate any overloading of the 3 renewable resources[24].

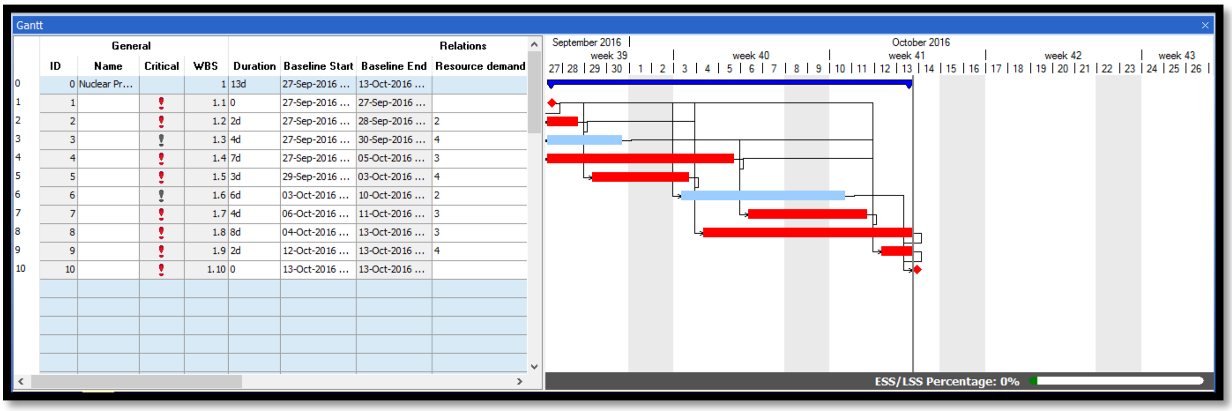

Figure 21 – Without CCS by Software Package Pro Track V3

In **Figure 21,** the Gantt chart that Pro Track uses to display information, the expected project time of *13 days* is confirmed without CCS. Alike Microsoft Project, the critical tasks 1.2; 1.4; 1.5; 1.7; 1.8 and 1.9 are to start and finish on time for the project to end on schedule, while the project resources are constrained (not displayed in the Gantt chart).

[24] Renewable resources are available on a period–by–period basis and not on a total project basis

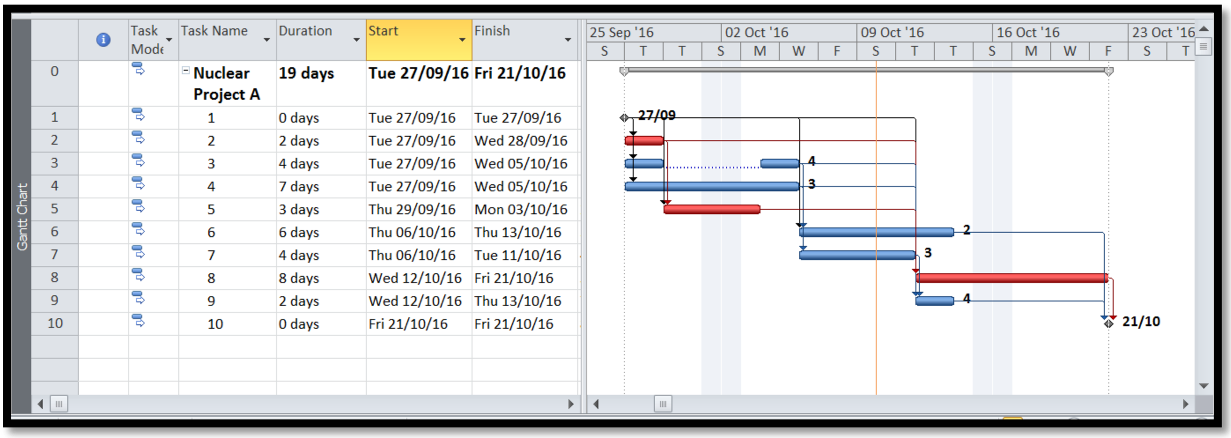

Figure 22 – Without CCS with RCS by Software Package MS Project 2010

In the Gantt chart that Microsoft Project uses to display information, the expected project time is *19 days* without CCS with RCS (refer to **Figure 22)**. The critical tasks 2; 5; and 8 are to start and finish on time for the project to end on schedule. The project resources are no longer constrained at activities 3; 4; 5; 7 and 8. Therefore, the 3 renewable resources are no longer overloaded for achieving the project goals.

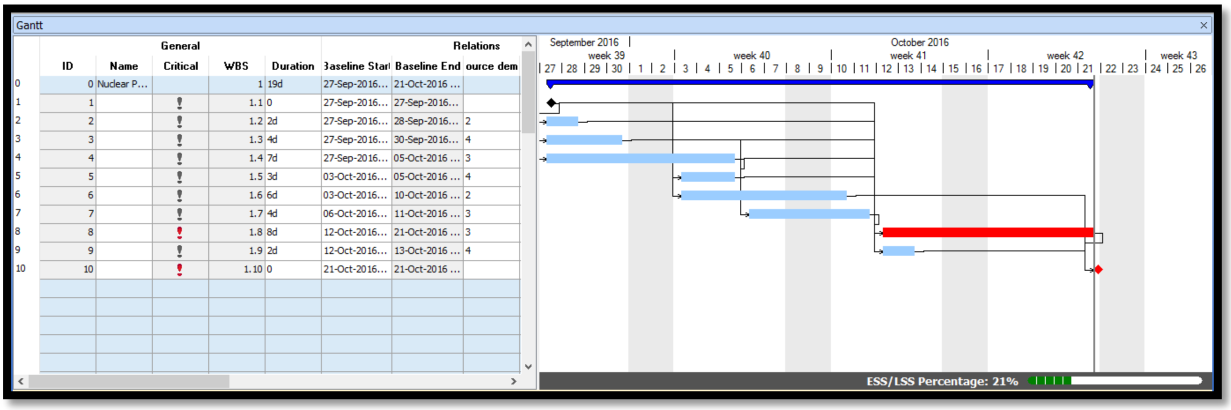

Figure 23 – Without CCS with RCS by Software Package Pro Track V3

In **Figure 23,** the Gantt chart that Pro Track uses to display information, the expected project time of *19 days* is confirmed without CCS with RCS. The critical task 1.8 is to start and finish on time for the project to end on schedule, while the project resources are no longer constrained (not displayed in the Gantt chart).

4.3.1.1.2. With CCS Software Simulation

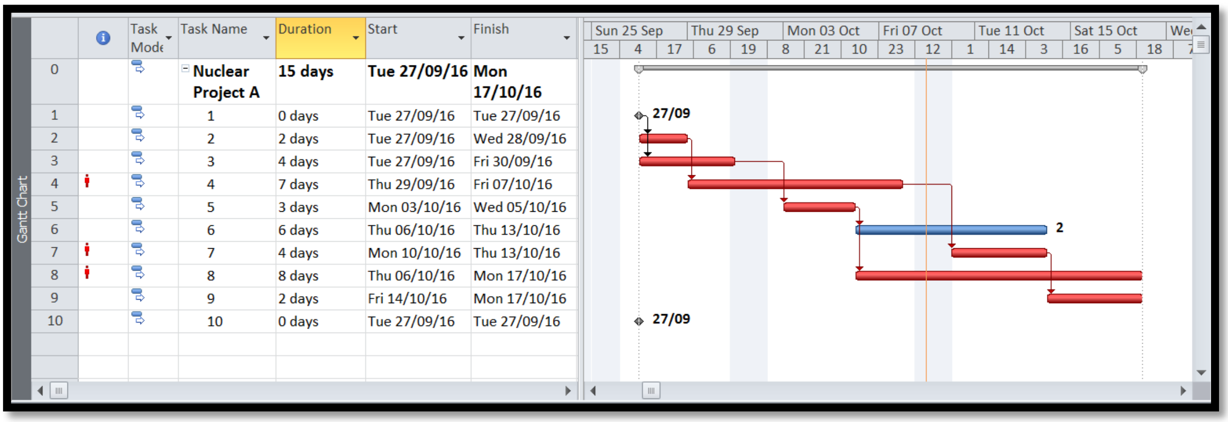

Figure 24 – With CCS by Software Package MS Project 2010

In the Gantt chart that Microsoft Project uses to display information, the expected project time is *15 days* with CCS (refer to **Figure 24**). The critical tasks 2; 3; 4; 5; 7; 8 and 9 are now to start and finish on time for the project to end at *15 days*. The project resources are now constrained at activities 4; 7 and 8, which might lead to project delays. RCS will have to be taken into consideration when simulating CCRCS, not to tolerate any overloading of the 3 renewable resources. After resource optimization to match the available 3 renewable resources, the needs of the nuclear project management department will be achieved for the established project goals.

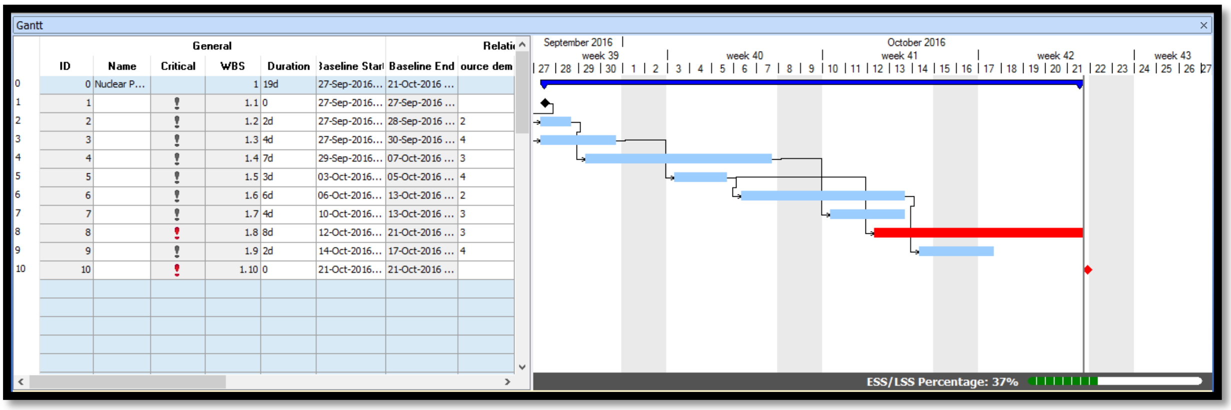

Figure 25 – With CCS by Software Package Pro Track V3

In **Figure 25,** the Gantt chart that Pro Track uses to display information, the expected project time of *19 days* is confirmed with CCS. The expected project time of *19 days* is displayed after several feasible schedule simulations. The critical task 1.8 is to start and finish on time for the project to end on schedule, while the project resources are constrained (not displayed in the Gantt chart).

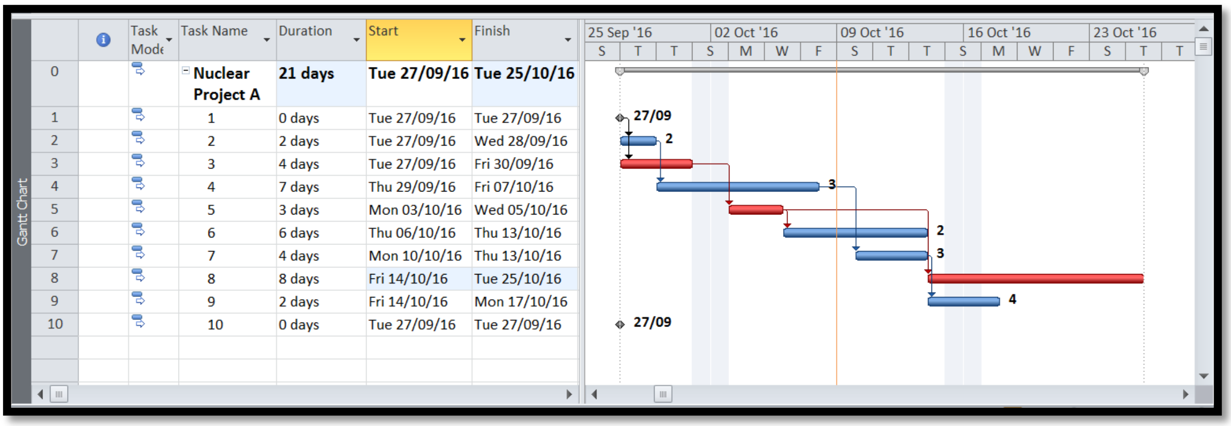

Figure 26 – With CCRCS by Software Package MS Project 2010

In the Gantt chart that Microsoft Project uses to display information, the expected project time is *21 days* with CCRCS (refer to **Figure 26**). The critical tasks 3; 5; and 8 are now to start and finish on time for the project to end at *21 days*. All resources are now levelled and the needs of the nuclear project management department will be achieved for the established project goals.

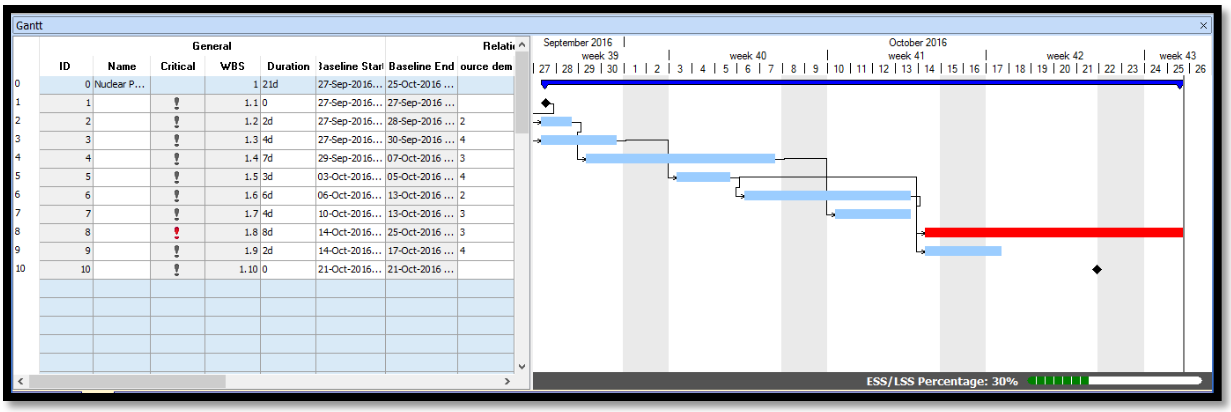

Figure 27 – With CCRCS by Software Package Pro Track V3

In **Figure 27,** the Gantt chart that Pro Track uses to display information, the expected project time of *21 days* is confirmed with CCRCS. The critical task 1.8 is to start and finish on time for the project to end on schedule, while the project resources are no longer constrained (not displayed in the Gantt chart).

4.3.2. Analysis of SR Test Results

The analysis of the SR test results With CCS and **Without** CCS software simulations are shown in **Table 2**. To evaluate research $\mathbf{H_1}$, the expected project time were simulated using estimates across several confidence levels. The means, variations, and standard deviations were also computed.

Table 2 – Software Simulation Results of Nuclear Project A

Software Simulations	High-confidence expected project time	Medium–confidence expected project time	Low–confidence expected project time	Mean	Variation	Standard deviation	Alpha distribution	Beta distribution
Without CCS by Software Package MS Project 2010	11	13	15	13.00	0.44	0.67	2.00	2.00
Without CCS by Software Package Pro Track V4	10	13	14	12.67	0.44	0.67	3.00	1.00
Without CCS with RCS by Software Package MS Project 2010	16	19	20	18.67	0.44	0.67	3.00	1.00
Without CCS with RCS by Software Package Pro Track V3	17	19	21	19.00	0.44	0.67	2.00	2.00
With CCS by Software Package MS Project 2010	13	15	18	15.17	0.69	0.83	1.60	2.40
With CCS by Software Package Pro Track V3	16	19	20	18.67	0.44	0.67	3.00	1.00
With CCRCS by Software Package MS Project 2010	19	21	23	21.00	0.44	0.67	2.00	2.00
With CCRCS by Software Package Pro Track V3	19	21	23	21.00	0.44	0.67	2.00	2.00

4.3.3. Pearson's Chi-square Test

Pearson Product-Moment Correlation is used as it is the most common measurement as it displays the degree of the linear relationship between two variables. It is designated by the Greek letter rho (ρ) when measuring a population. Pearson's Correlation analyses are computed from the two sets of SR test data results, to evaluate whether a strong link exists With CCS and **Without** CCS (refer to **Table 2**). If the results of the correlation had a value of +1, then the data set is a perfect positive correlation. If zero, then there is no correlation (values not linked), while -1 is a perfect negative correlation (Lane, 1997a).

In the **Table 3**, the values show how good the correlations are with CCRCS and without CCRCS. The two sets of data are strongly linked ($0.96 \leq \rho \leq 0.99$). A uniform relationship exists between the two variables on the Nuclear Project A. It is shown that the CCRCS task time offers a longer expected project time than the methodology based on PERT (without CCRCS). The high correlation coefficient favours a significant correlation, however further analysis is required.

Table 3 – Pearson's Chi-square Test for Independence of Nuclear Project A

Data Set	Without CCS by Software Package MS Project 2010	With CCS by Software Package MS Project 2010	Without CCS by Software Package Pro Track V4	With CCS by Software Package Pro Track V3	Software Package MS Project 2010	With CCRCS by Software Package MS Project 2010	Software Package Pro Track V3	With CCRCS by Software Package Pro Track V3
Pearson's Correlation coefficient (rho)	0.993		0.961		0.961		0.993	
Chi-square Test with 2 df [25] (*p*-value)	0.584		0.095		0.590		0.678	

The chi-square test is further applied to the two variables using with CCS and without CCS for the single population. The chi-square test is used to determine whether a significant association exists between two variables by using the p-values in **Table 3**. The variables are independent across all data sets. Microsoft Excel 2010 software is used to find the p-values. As the p-values are greater than the 0.05 significance level, we do not reject the null hypothesis $\mathbf{H_{1.0}}$ that the CCRCS task time offers a longer expected project time than the methodology based on PERT (without CCRCS). The research hypothesis ($\mathbf{H_1}$) is strongly supported and neither a type I error[26] nor a type II error are applicable for the historical Nuclear Project A.

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[25] Degrees of freedom – "Number of independent units of information (measurements) in a sample relevant for estimating a parameter or computation of a statistic" – (www.businessdictionary.com/definition/degrees-of-freedom.html)

[26] Type I errors occurs when the $\mathbf{H_{1.0}}$ is incorrectly rejected, whereas type II errors occur $\mathbf{H_{1.0}}$ is incorrectly accepted.

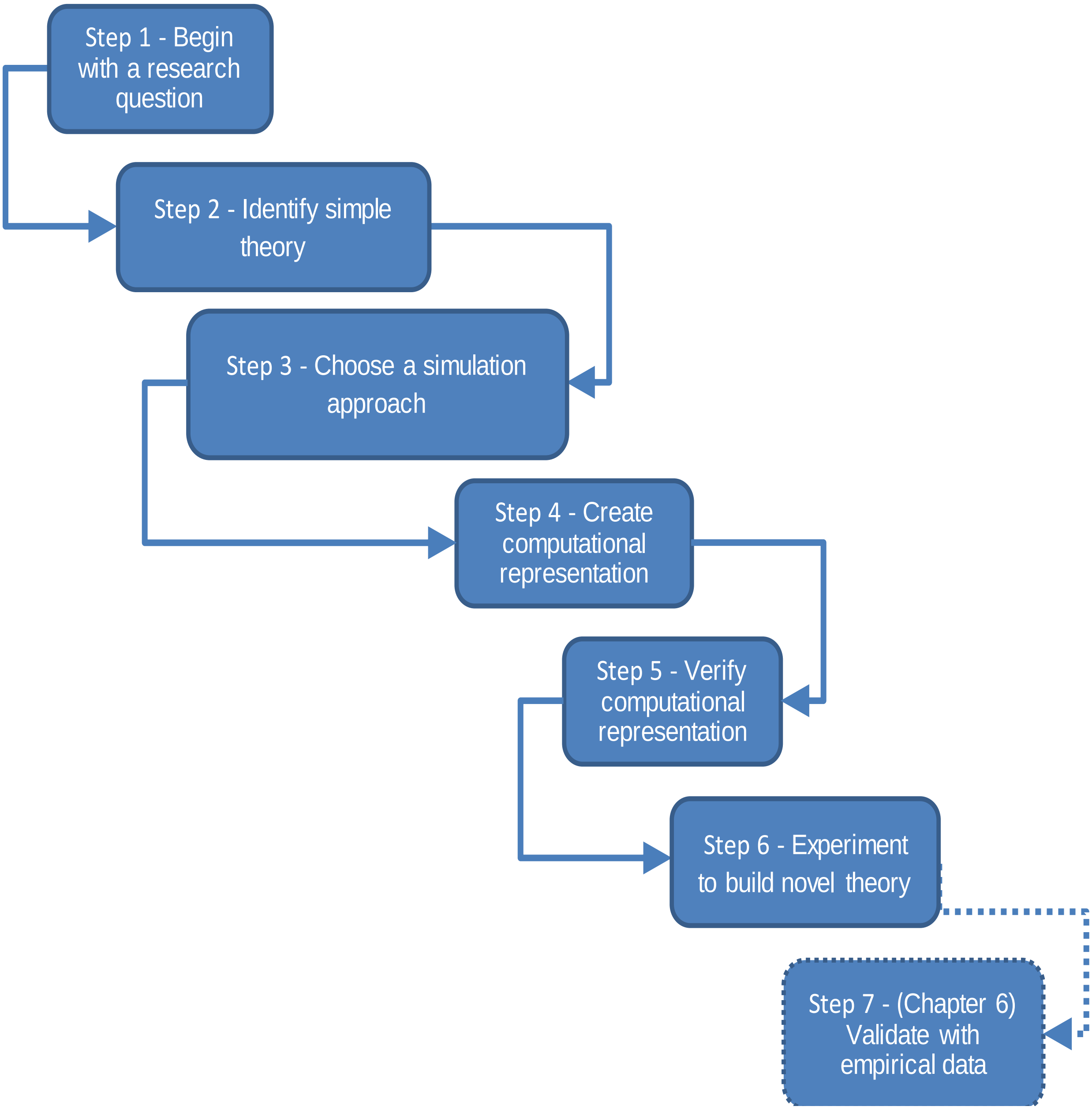
4.4. Summary derived from SR

The results deduct support for $\mathbf{H_1}$. Testing the $\mathbf{H_1}$ theory on an existing historical Nuclear Project A and observing it across two contexts, correlate with the outcomes as predicted. The rationale behind the scoping review was to consolidate observations, categorisation, and association on the experimental design using the Christensen theory–building process. As a result, $\mathbf{H_1}$ is supported as stated: CCRCS *task time* offers a longer *expected project time* than the methodology based on PERT, while $\mathbf{H_{1.0}}$ is rejected as the *Task time* for CCRCS does not offer a longer *expected project time* than the methodology based on PERT. With the preliminary study covered, the next step in theory–building process systematically establishes a theory of optimisation for projects.

CHAPTER 5: THEORY–BUILDING

5.1. Introduction

Chapter 5 provides an overview of the contribution to nuclear project management by documenting the development of the TOP. A broad overview of the framework is depicted in **Figure 28 – Developing Theory Through Simulation Methods**. The Chapter chronically documents the researcher’s original contribution and establishes the context for the case study validation of the research study in Chapter 6.



Source: Developing Theory Through Simulation Methods (Eisenhardt K.M, 2007)

Figure 28 – Developing Theory Through Simulation Methods

Restated, one of the most documented articles on theory is by Lewin (1945) who states that "nothing is quite so practical as a good theory" therefore: "good theory is practical precisely because it advances knowledge in a scientific discipline, guides research toward crucial questions, and enlightens the profession of management" (Van de Ven, 1989).

5.2. Developing Theory

Theory building using software simulation begins with simple theory, which focuses on a fundamental phenomenon (Eisenhardt K.M, 2007). This simple theory will form the platform from which powerful theory can be developed by discrete event simulation[27] using Pro Track V3 software along the following paragraphs. It reveals the benefits of using the CI concept using Mont-Carlo simulation than doing it subjectively.

5.2.1. Research Question

In this first step, the researcher defined a testable *research question* after observing the substantial theoretical issue (referred to in **CHAPTER 1: INTRODUCTION**) and the subsequent inaccurate *task time* estimates, resource dependency, inaccurate resource forecasting, limited resources, team member procrastination and task dependency (Weick, 1989). This led to a key question on theory–building research, in particular: Implementing a methodology based on the TOP will reduce the risk of *expected project time?* Through computer software simulation. This key question developed into a testable hypothesis. The research hypothesis $\mathbf{H_2}$ and its corresponding null hypothesis $\mathbf{H_{2.0}}$ were developed as follows: $\mathbf{H_2}$: Implementing a methodology based on TOP will reduce the risk of the *expected project time*; with corresponding $\mathbf{H_{2.0}}$ that implementing a methodology based on the TOP will not reduce the risk of the *expected project time*. $\mathbf{H_2}$ appraises the TOP by Monte-Carlo simulation and assays its effectiveness as a supporting tool for structuring nuclear projects.

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[27] Discrete event simulation – involves modelling the organizational system as a set of entities evolving over time according to the availability of resources and the triggering of events (Dooley, 2002)

5.2.2. Simple Theory

In this second step, the researcher selected a *simple theory,* which addressed hypothesis **H_2** of the research study. This theory led to the selection of recognized and understood measurements and formulae. The information formed the basis for computational representation.

The following notations laid the foundation for the sensitivity measure formulae for the research under investigation (Vanhoucke, 2013):

nrs	$\text{Monte} - \text{Carlo simulation runs } (k)$
d_i	$\text{Time of task } i$
tf_i	$\text{Total float of task } i$
RD	$\text{Expected project time}$

5.2.2.1. Criticality Index CI

CI sensitivity measures the probability ($\Pr$) of a task on the critical path by Monte-Carlo simulations. The CI of task i is given as follows:

$$CI = \Pr(tf_i = 0)$$

with $\Pr(\mathrm{x})$ used to denote the probability of x.

5.2.2.2. Significance Index SI

SI sensitivity measures the relative importance between tasks as follows:

$$SI = E\left(\frac{d_i}{d_i + tf_i} . \frac{RD}{E + (RD)}\right)$$

with $\mathrm{E}\,(\mathrm{x})$ used to denote the expected value of x.

Qualitative risk analysis method combines the task time and expected project time standard deviations (σ_{di}) and (σ_{RD}) with the criticality index. It is referred to as the SSI, which measures the relative importance of a task taking the CI into account as follows:

$$SSI = \left[\sqrt{\frac{Var(d_i)}{Var(RD)}}\right].CI$$

Nine heterogeneous Monte-Carlo simulation scenarios were formulated for project progress and are discussed along the following paragraphs.

5.2.3. Software Simulation Approach

With the basis of computational representation covered, several well-known models used for theory development in the literature were deliberated. The researcher eventually chose a simulation approach, which uses simulation typologies. The discrete event approach is used together with Pro Track V3 software from the 3 different emerging (i.e. discrete event, system dynamics[28] and Agent-based[29]) simulation models in this step 3.

Discrete event approach fitted best with the research question in step 1 and is appropriate given the research study at hand. It is stated that discrete event

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[28] System dynamics simulation – involves identifying the key "state" variables that define the behaviour of the system, and then relating those variables to one another through coupled, differential equations (Dooley, 2002)

[29] Agent-based simulation – involves agents that attempt to maximize their fitness (utility) functions by interacting with other agents and resources; agent behaviour is determined by embedded schema which are both interpretive and action-oriented in nature (Dooley, 2002)

simulations are used best when the organisation system variables are adequately described such as in the case of Nuclear Project B (Dooley, 2002).

5.2.4. Computational Representation

In this step 4 and 5, computational representation was core to theory–building process. The theoretical constructs become operational, algorithms were built, and assumptions were specified interdependently.

The researcher embodied the theory of Nuclear Project B in the software to test the theoretical construct of $\mathbf{H_2}$ for the research study. Pro Track V3 aided the researcher with the formulation of the computer algorithm. The simple theory in step 2 ensured computational representation, which resulted in a theoretically valuable experiment by Monte-Carlo Simulation. Tasks in the project network; precedence relationships; time and cost estimates; and task constraints information were used as basic project data to automatically generate a baseline schedule using Pro Track V3 software.

The researcher further verified the computational representation with robust sensitivity measurements, which showed computational representation stability for internal validity during the theory–building session.

5.2.5. Building Novel Theory

Implementing Nuclear Project B the traditional way is complex and challenging. A rethink of PM methods is needed to successfully reduce the risk of the *expected project time* by using modern methods of computing. In this step 6, the researcher reveals the benefits of measuring the probability ($\Pr$) of task i on the critical path using Monte-Carlo simulation together with rather than doing it arbitrarily (Ghaffari & Emsley, 2015). Each experiment consisted of 100 Monte-Carlo simulation runs over

9 experiments using the data of Nuclear Project B to test hypothesis **H_2**. The researcher selected $k = 100$ for the number of simulation runs on all experiments to replicate the simple theory to confirm the accuracy and robustness check of computational representation across four (4) steps along the following paragraphs.

Step 1: Nuclear Project B baseline schedule (A licensing plan for coupling a nuclear energy source to a chemical process plant. SASOL Secunda as a case study, 2014) was applied as a reference to simulate real project progress to determine **H_2** of the research study. The baseline schedule represented a central role in this process and the lack thereof would have led to incomparable computational representation of its data. **Step 2:** The researcher's analytic skills and basic knowledge of statistics equipped him to accurately estimate the effects of the unexpected events of the simulation outcomes. Measurements were used to express whether there were no risks or whether task delays were more likely than early task times and visa-versa. **Step 3:** The Monte-Carlo approach was used by the researcher to generate the task time that might differ from their original baseline values. **Step 4:** Pro Track V3 recorded all critical paths. Project progress was simulated to measure the degree of task criticality and sensitivity, which were appraised by the researcher.

5.2.5.1. Appraisal of Theory

Modern methods of computing were utilised to appraise the TOP by Monte-Carlo simulation to test hypothesis **H_2**. The *expected project time* were simulated for the Nuclear Project B case study. The simulations performed were kept by this sequence, in particular:

1. Generate nine heterogeneous simulations by ProTrack 3.0 version running on Windows;

2. The input parameters were: number of activities in a project 42[30] and number of resource types 3;
3. Enter the generated information to ProTrack 3.0 software;
4. Record the finish date of the expected project schedule;
5. Generate 42 task times using ProTrack 3.0 software;
6. Calculate new expected project time;
7. Limit the sensitivity threshold sizing rule to 50% for the crucially index;
8. Record the completion date of the case study project and compare it to the expected project deadline;
9. Repeat the steps for different percentages and different probabilities;
10. Summarize and analyse results; and
11. Validate experimental results using correlation coefficient value range between 0.00 and +1.00.

Table 4 – Nuclear Project B Correlation Coefficient Values

Value	Correlation
0.00	No correlation
+0.10	Weak positive correlation
+0.30	Moderate positive correlation
+0.60	Strong positive correlation
+1.00	Perfect positive correlation

5.2.5.1.1. Experimental Simulation 1, 2, 5, 8 & 9

The researcher computed the Nuclear Project B case study critically index (%), significant index (%) and schedule sensitivity index (%) in order to measure the

[30] Parameter based on bottom-up approach (Lavelot, 2014) and area of significance for KNPS

degree of criticality and sensitivity of tasks for five scenarios 1, 2, 5, 8 & 9 along the following paragraphs.

5.2.5.1.1.1. Experimental Simulation 1 & 2

The researcher computed the case study critically index (%), significant index (%) and schedule sensitivity index (%) for scenarios 1 and 2. These scenarios were used to determine the average project progress, where the project was simulated to ***finish earlier than planned.***

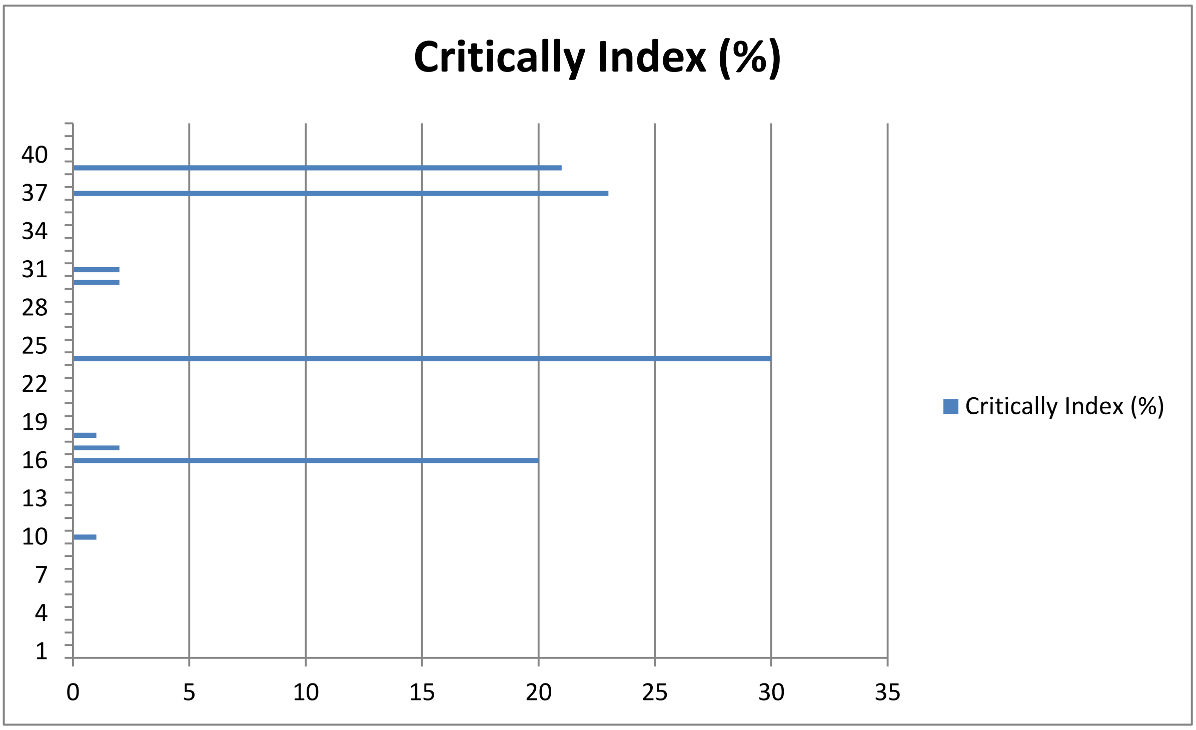


Figure 29 – CI Bar Chart[31] for 42 Tasks after 100 simulation runs of Scenario 1

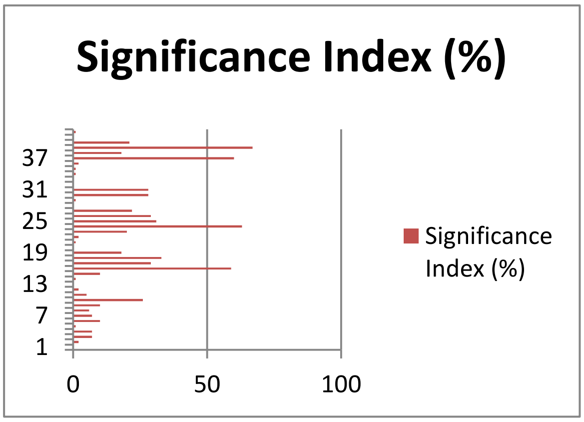


Figure 30 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 1

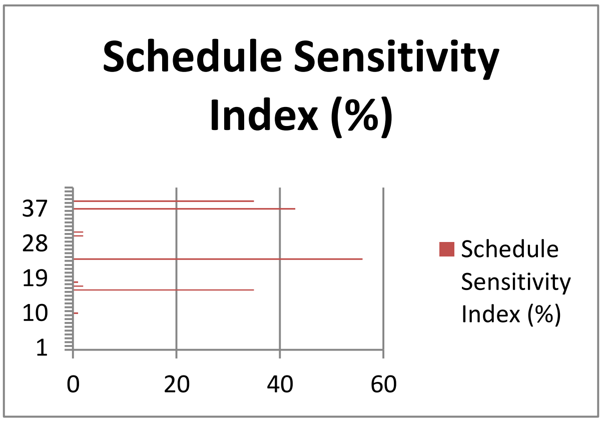


Figure 31 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 1

In **Figure 29,** all *criticality index (%)* tasks presented are below 30%. The probability of any task(s) being on the critical path is very low. No action is required

[31] A bar chart is a graph with rectangular bars. Each bar's length or height is proportional to the bars' represented values (http://www.statisticshowto.com/what-is-a-bar-chart/)

as it does not exceed the sensitivity threshold of 50%. The *significance index (%)* tasks 39 (67%), and 37 (60%) exceeds the 50% sensitivity threshold (**Figure 30** – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 1). The tasks measure high and are considered relatively important tasks for project success. Task 24 (56%) is merely presented on the *schedule sensitivity index (%)* (**Figure 31** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 1) taking the CI into account. The schedule sensitivity index combines both the task time and project time standard deviations with the CI.

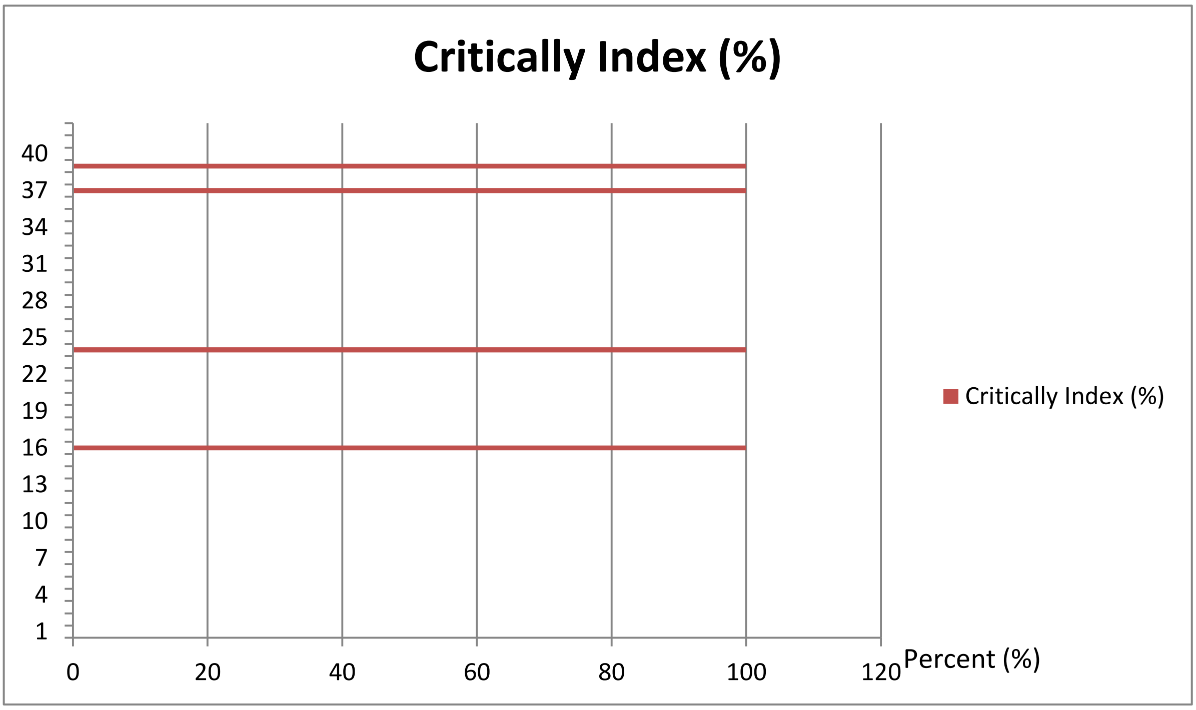


Figure 32 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 2

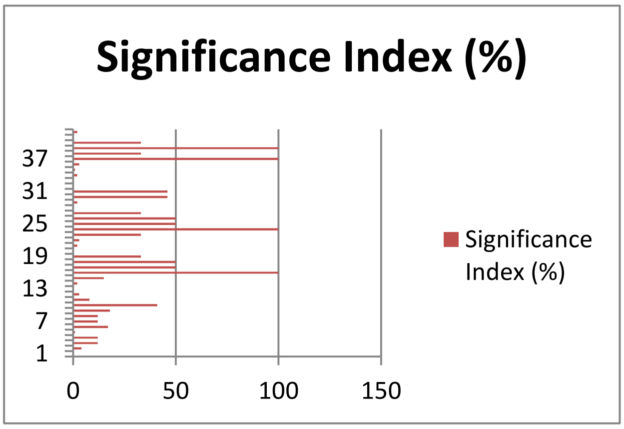


Figure 33 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 2

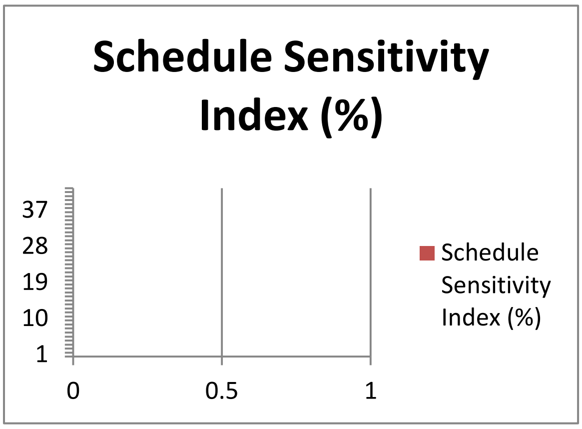


Figure 34 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 2

For the *criticality index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) probability of being on the critical path is very high at 100% for the project to finish earlier than scheduled (**Figure 32** – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 2). In **Figure 33**, the *significance index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) exceeds the degree of sensitivity threshold (50%). These three tasks measure high and are extremely important tasks for project success. All *schedule sensitivity index (%)* task values are zero (**Figure 34** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 2).

In summary, scenarios 1 and 2 reported on the average project progress and the Nuclear Project B ***finishing earlier than planned*****.** All *criticality index (%)* tasks presented requires no action to be taken in scenario 1, while scenario 2, tasks 39 (100%), 37 (100%) and 16 (100%) probability of being on the critical path is 100%. Action needs to be taken for three project tasks in order to finish the project earlier than planned. The *significance index (%),* tasks 39 (67%), and 37 (60%) exceeds 50% threshold in scenario 1, similarly for tasks 39 (100%), 37 (100%) and 16 (100%) in scenario 2. Three tasks under both scenarios measure high and are extremely important for project success. In scenario 1, task 24 (56%) is merely presented in the *schedule sensitivity index (%)* and is shown as relatively important taking the criticality index into account, while no values are shown for all task under scenario 2.

5.2.5.1.1.2. Experimental Simulation 5

The critically index (%), significant index (%) and schedule sensitivity index (%) were computed for scenario 5. The scenario was used to determine the project progress, where Nuclear Project B was simulated to be ***completed on time***.

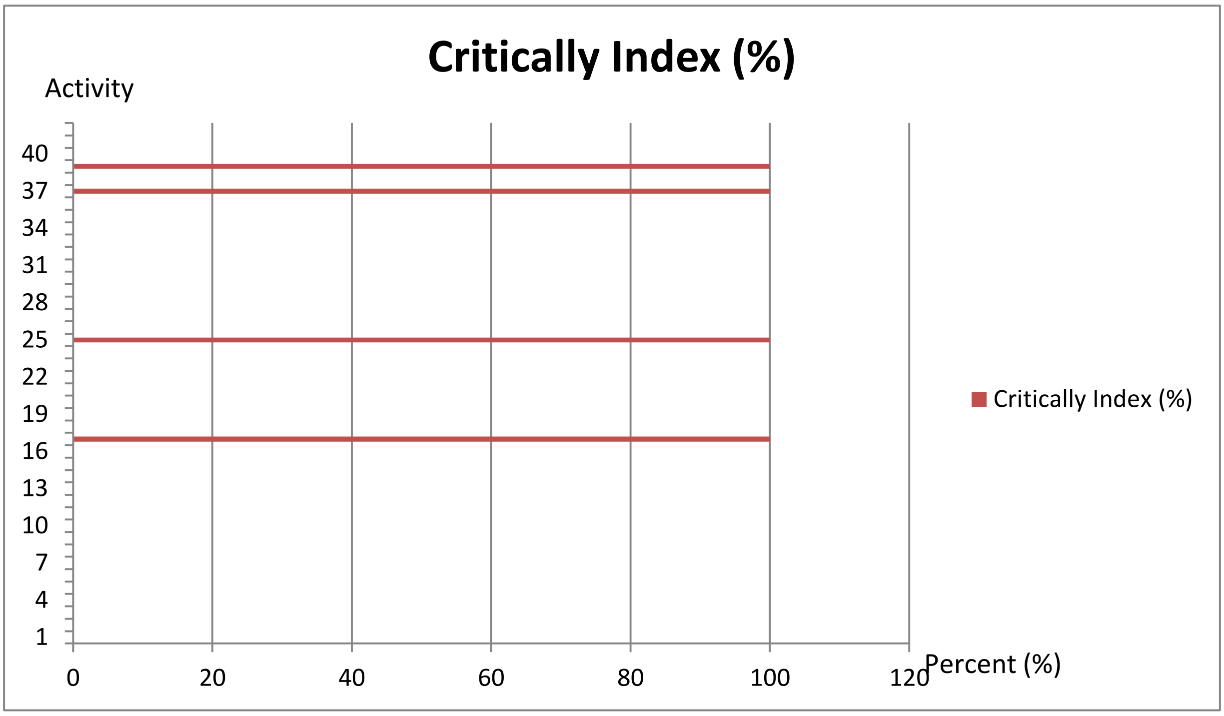


Figure 35 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 5

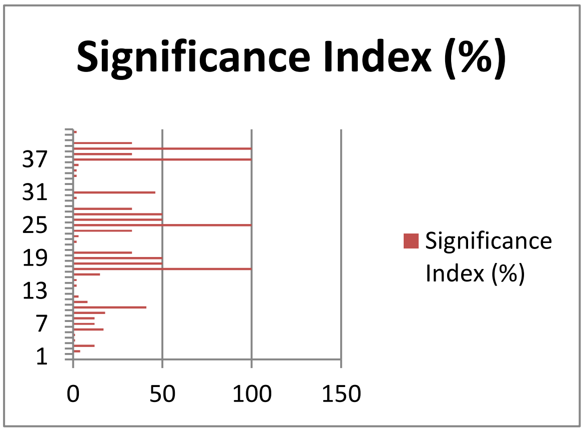


Figure 36 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 5

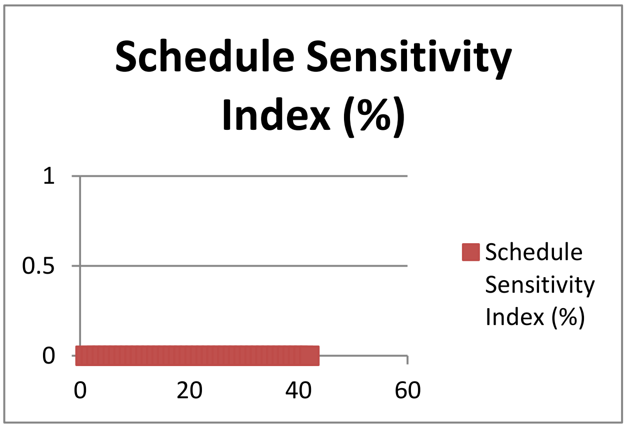


Figure 37 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 5

For the *criticality index (%)*, tasks 39 (100%), 37 (100%), 25 (100%) and 17 (100%) probability of being on the critical path is very high at 100% for the project to be completed on time (**Figure 35** – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 5). For the *significance index (%)*, tasks 39 (100%), 37 (100%), 25 (100%) and 17 (100%) exceeds the degree of sensitivity threshold (50%). These four tasks measure high and are extremely important tasks for project success (**Figure 36** – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 5). All *schedule sensitivity index (%)* task values for discernibility are zero in **Figure 37**.

5.2.5.1.1.3. Experimental Simulation 8 & 9

Nuclear Project B critically index (%), significant index (%) and schedule sensitivity index (%) were computed for scenarios 8 and 9. These scenarios were used to determine the average project progress, where the project was simulated to ***finish later than scheduled.***

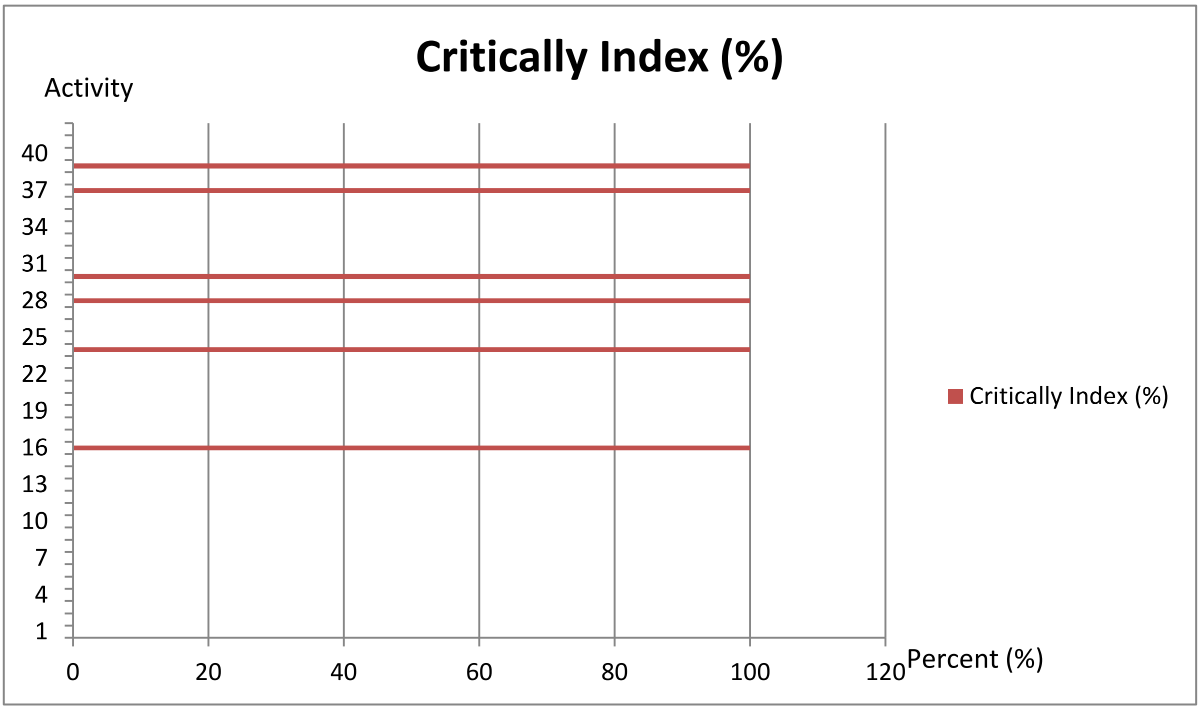


Figure 38 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 8

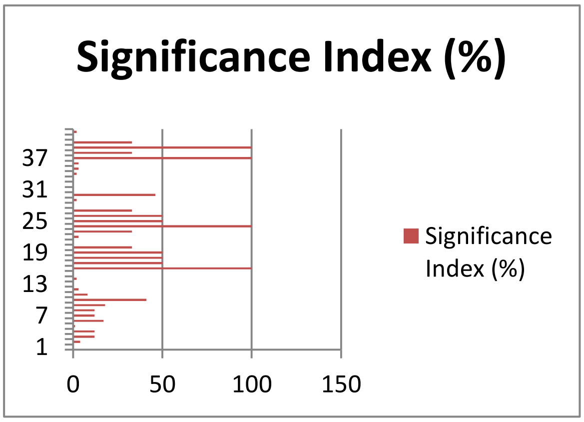


Figure 39 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 8

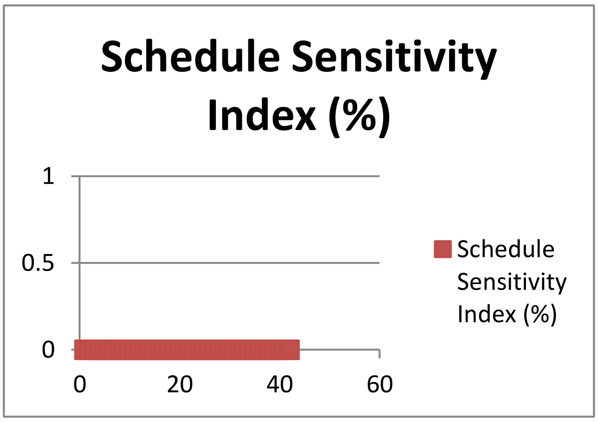


Figure 40 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 8

In **Figure 38**, the *criticality index (%)*, tasks 39 (100%), 37 (100%), 30 (100%), 28 (100%), 24 (100%) and 16 (100%) probability of being on the critical path is very high at 100% for the project to finish later than scheduled. For the *significance index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) exceeds the degree of sensitivity threshold (50%) (**Figure 39** – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 8). These three tasks measure high and are extremely important tasks for project success. All schedule *sensitivity index (%)* task values on the bar chart for discernibility are zero in **Figure 40**.

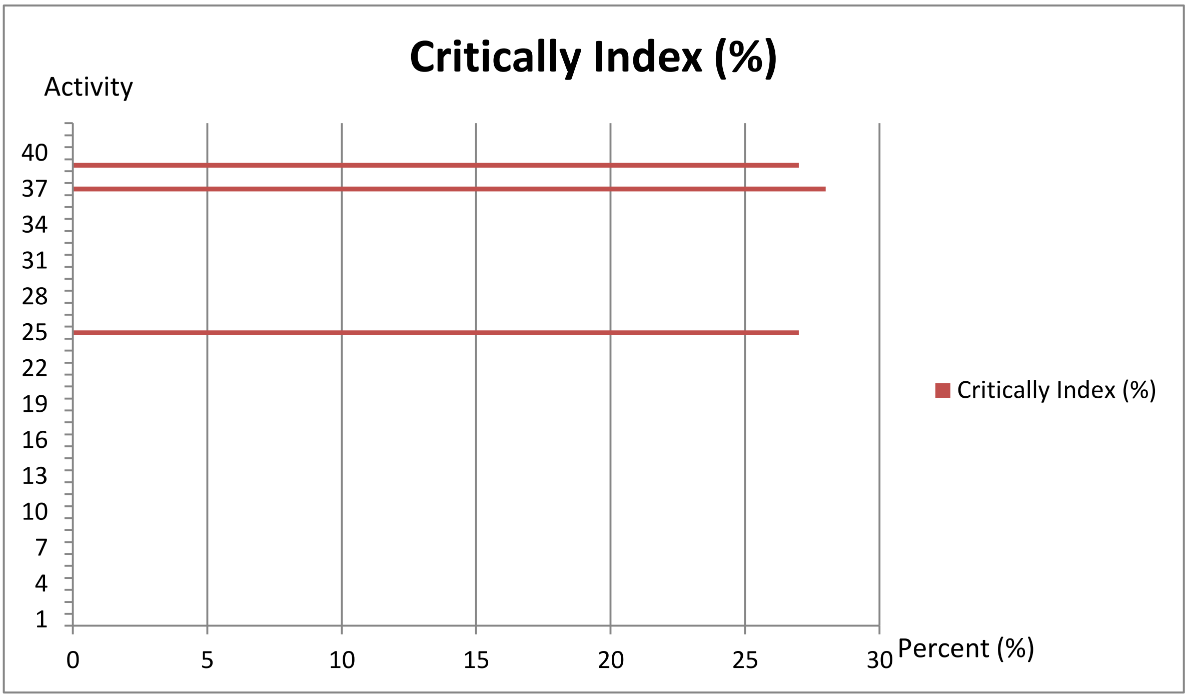
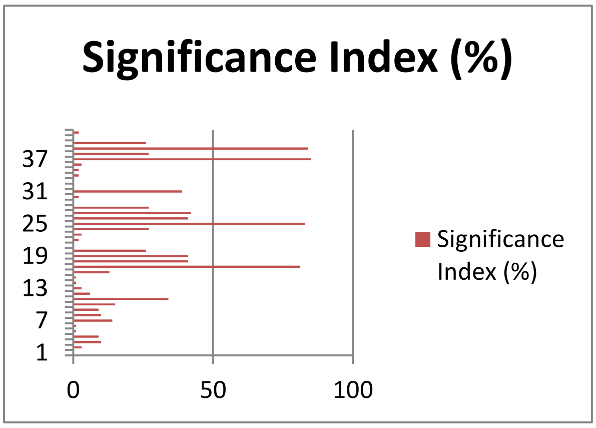


Figure 41 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 9



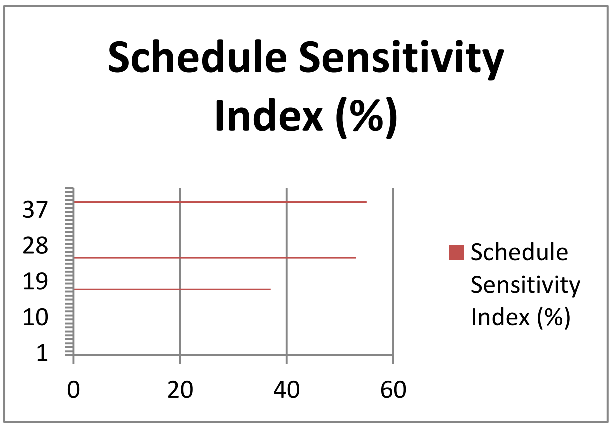


Figure 42 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 9

Figure 43 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 9

The *criticality index (%)* tasks presented in **Figure 41** are all below 30%. The probability of any task(s) being on the critical path is very low. As a result, no action is required as it does not exceed the sensitivity threshold of 50%. In **Figure 42**, the *significance index (%)*, tasks 39 (84%), 37 (85%), 25 (83%) and 17 (81%) exceeds the degree of sensitivity threshold (50%). These three tasks measure high and are extremely important tasks for project success. Task 39 (55%) and 25 (53%) are merely presented on the *schedule sensitivity index (%)* and are relatively important task taking the CI into account (**Figure 43** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 9).

In summary, scenarios 8 and 9 reported on the average project progress and Nuclear Project B ***finishing later than scheduled.*** The *criticality index (%)*, tasks 39 (100%), 37 (100%), 30 (100%), 28 (100%), 24 (100%) and 16 (100%) probability of being on the critical path is very high at 100% for scenario 8, while tasks presented for scenario 9 are all below 30%. The probability of any task(s) being on the critical path is very low and no action is required. The *significance index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) exceeds the degree of sensitivity threshold (60%) for scenario 8, while tasks 39 (84%), 37 (85%), 25 (83%) and 17 (81%) exceeds the degree of sensitivity threshold (50%) for scenario 9. All schedule *sensitivity index (%)* tasks are imperceptible in scenario 8, while Task 39 (55%), 25 (53%) and 17 (37%) are merely presented in scenario 9.

5.2.5.1.2. Experimental Simulation 4 & 6

Nuclear Project B critically index (%), significant index (%) and schedule sensitivity index (%) were computed for scenarios 4 and 6. These scenarios were used to determine the average project progress, where the project was simulated to ***finish exactly on time*** (referred to as the misleading simulation scenarios).

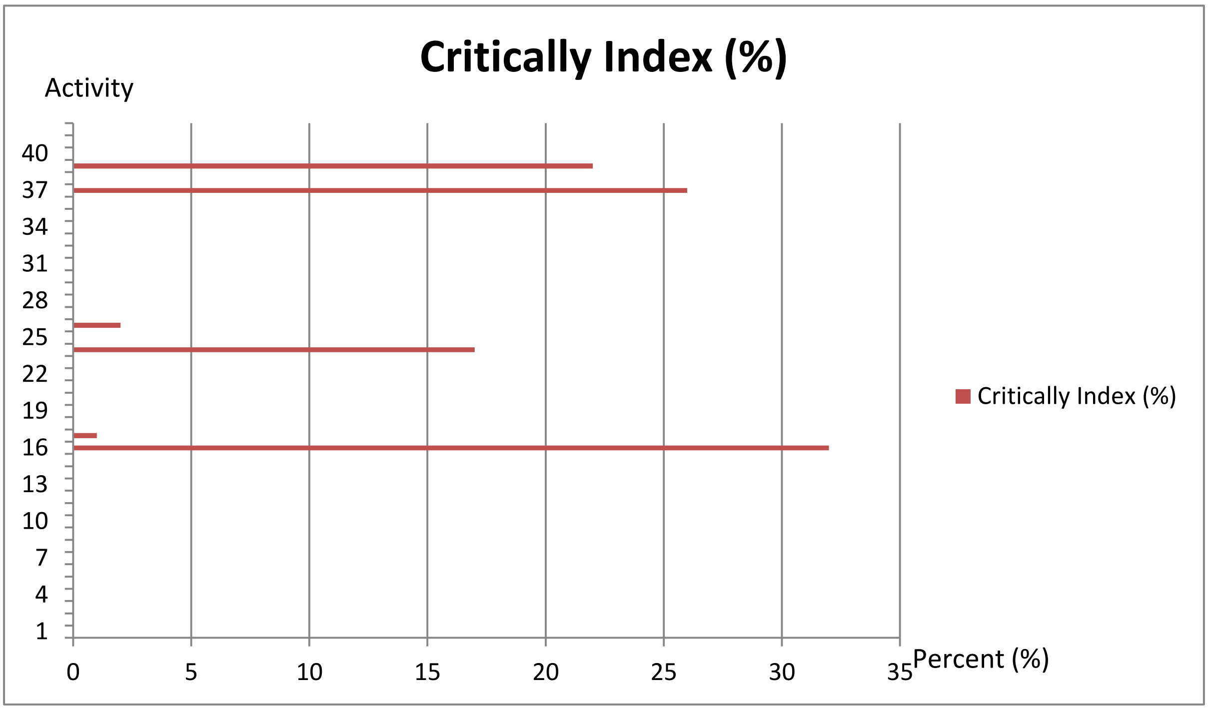


Figure 44 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 4

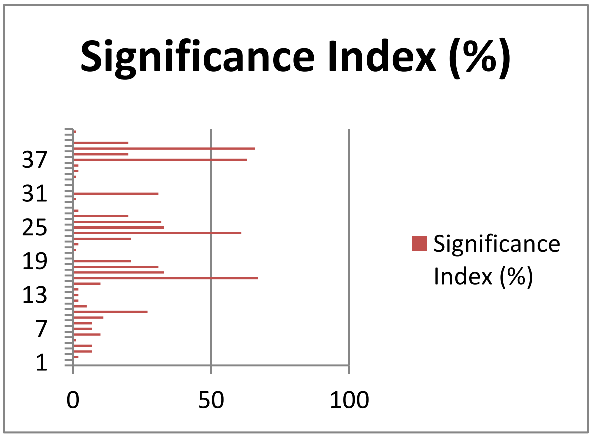


Figure 45 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 4

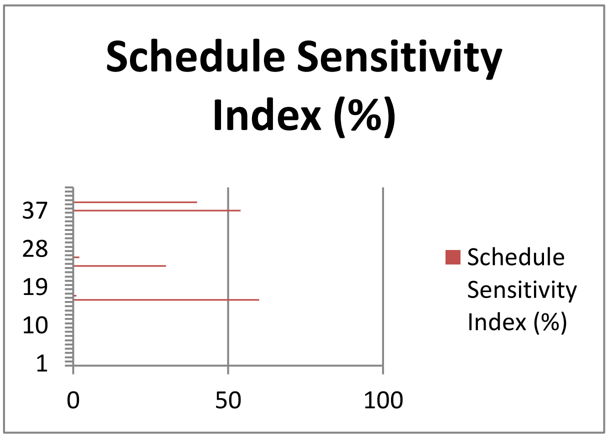


Figure 46 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 4

The *criticality index (%)* tasks presented in **Figure 44** are all below 32%. The probability of any task(s) being on the critical path is very low. As a result, no action is required as it does not exceed the sensitivity threshold of 50%. For the *significance index (%),* tasks 39 (66%), and 37 (63%), 24 (61%) and 16 (67%) exceeds the 50% sensitivity threshold (**Figure 45)**. They measure high and are considered relatively important tasks for project success. Tasks 37 (54%) and 16 (60%) are merely presented on the *schedule sensitivity index (%)* as a relatively important task taking the CI into account under the existing scenario (**Figure 46** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 4).

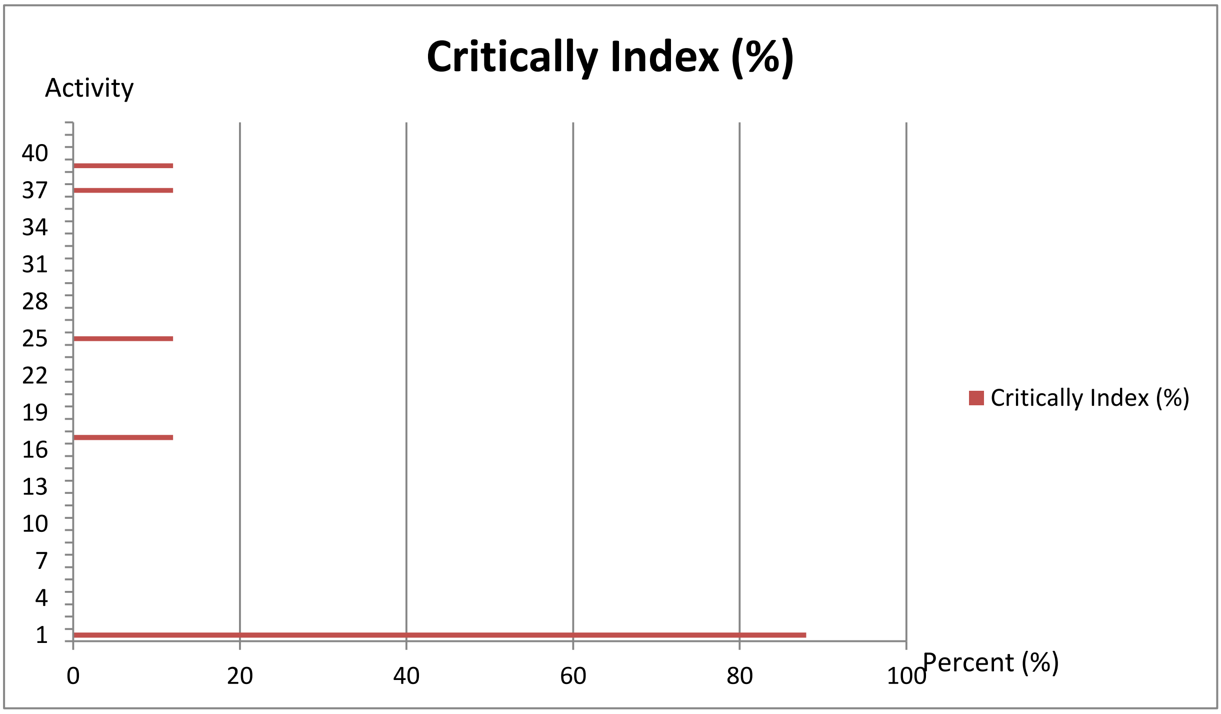


Figure 47 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 6

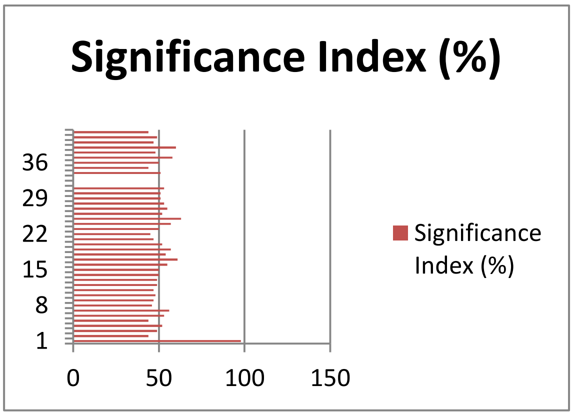


Figure 48 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 6

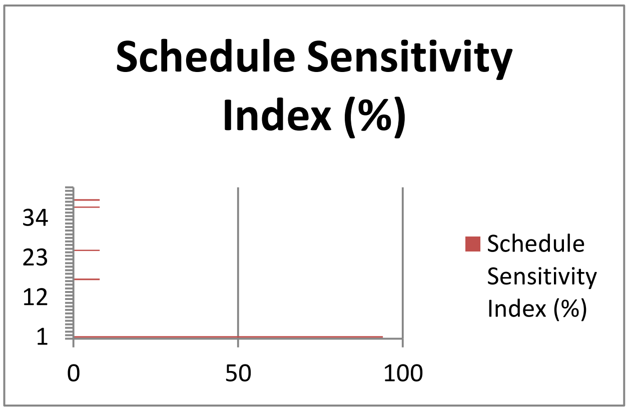


Figure 49 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 6

The criticality index (%) task 1 (88%) presented exceeds the 50% threshold (**Figure 47**). The probability of this task being on the critical path is very high. For the significance index (%), tasks 39 (60%), 37 (58%), 36 (50%), 34 (51), 31 (53), 30 (51%), 29 (51%), 28 (53%), 27, (55%), 26 (52%), 25 (63%), 24 (57%), 23 (50%), 20 (52%), 19 (57%), 18 (54%), 17 (61%), 16 (55%), 15 (50%), 14 (50%), 7 (56%), 6(53%), 4 (52%) and 1 (98%) exceeds the 50% sensitivity threshold (**Figure 48** – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 6). They measure high and are considered relatively important tasks for project success. Task 1 (94%) is merely presented on the schedule sensitivity index (%) (**Figure 49**) as a relatively important task taking the CI into account under the existing scenario. The schedule sensitivity index combines both the task time and project time standard deviations with the CI.

In summary, scenario 4 and 6 reports an average project progress with Nuclear Project B ***finishing exactly on time.*** The *criticality index (%)* tasks presented in scenario 4 are all below 32%. Hence, the probability of any task(s) being on the critical path is very low, while task 1 (88%) presented in **scenario 6** exceeds the 50% threshold. The probability of this task being on the critical path is very high. The *significance index (%),* tasks 39 (66%), and 37 (63%), 24 (61%) and 16 (67%) exceeds the 50% sensitivity threshold in scenario 4 and are considered relatively important tasks for project success, while tasks 25 (63%), 17 (61%) and 1 (98%) exceeds the 50% sensitivity threshold in scenario 6 and are also considered relatively important tasks for project success. Tasks 37 (54%) and 16 (60%) are merely presented on the *schedule sensitivity index (%)* as a relatively important task taking the CI into account under scenario 4, while Task 1 (94%) is merely presented as a relatively important task in scenario 6 taking the CI into account.

5.2.5.1.3. Experimental Simulation 3 & 7

Nuclear Project B critically index (%), significant index (%) and schedule sensitivity index (%) were computed for scenarios 3 and 7. Scenario 3 was used to determine the average project progress, where the project was simulated to ***finish earlier than planned.*** On the other hand, scenario 7 was used to determine the average project progress, where the project was simulated to ***finish later than planned*** (both are referred to as false simulation scenarios).

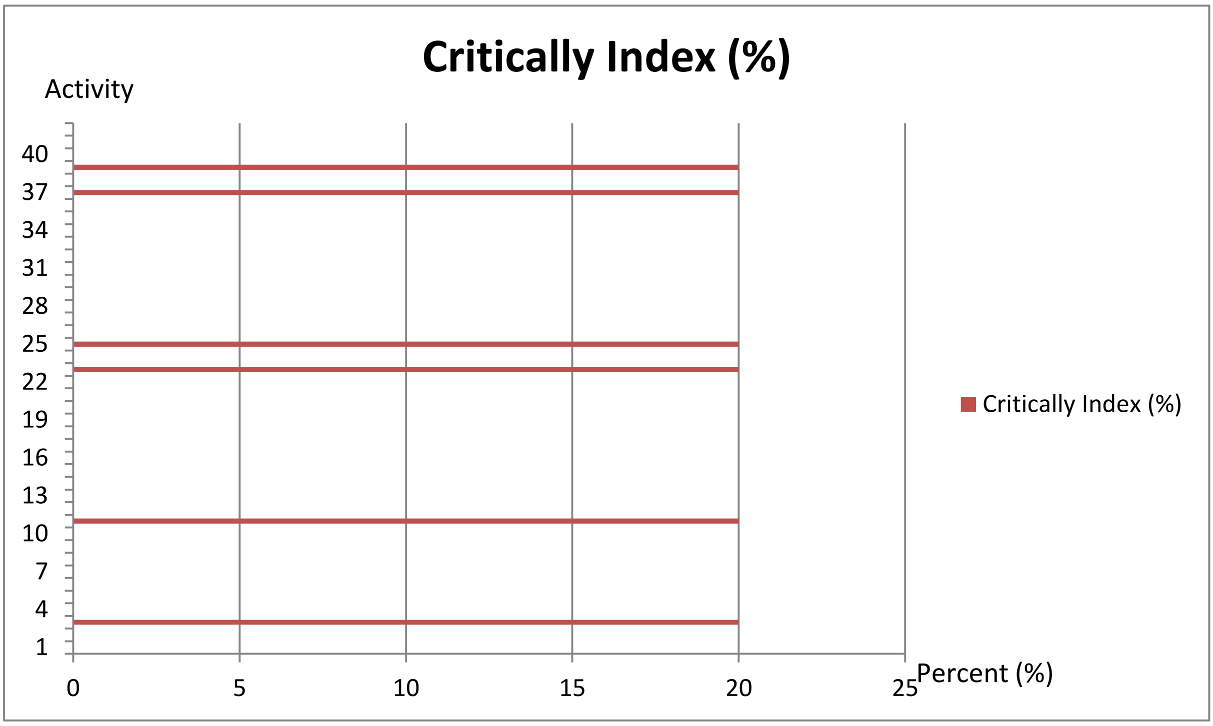


Figure 50 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 3

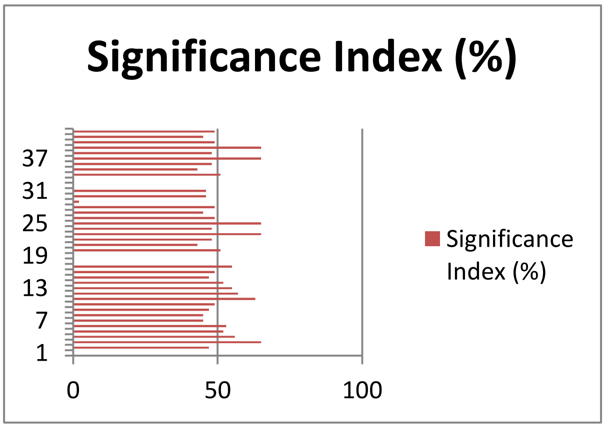


Figure 51 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 3

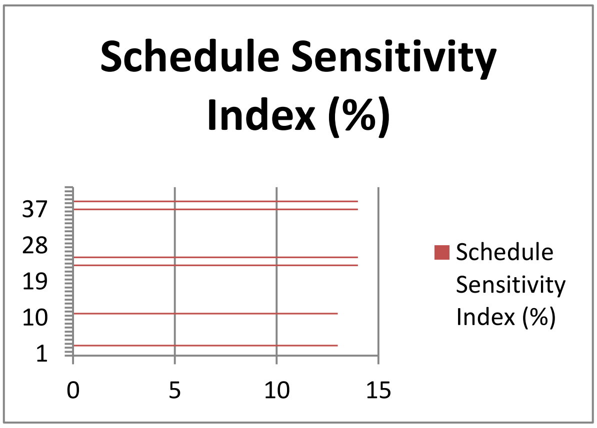


Figure 52 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 3

In **Figure 50**, the criticality index (%) tasks presented are all below 20%. The probability of any task(s) being on the critical path is very low. For the significance index (%), tasks 39 (65%), 37 (65%), 34 (51%), 25 (65%), 23 (65%), 20 (51%), 17 (55%), 14 (52%), 13 (55%), 11 (63%), 12 (57%), 11 (63%), 6 (53%), 4 (56%), 5 (52%), 4 (56%) and 3 (65%) exceeds the 50% sensitivity threshold (**Figure 51**). They measure high and are considered relatively important tasks for project success. Most tasks are low in the schedule sensitivity index (%) (**Figure 52** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 3).

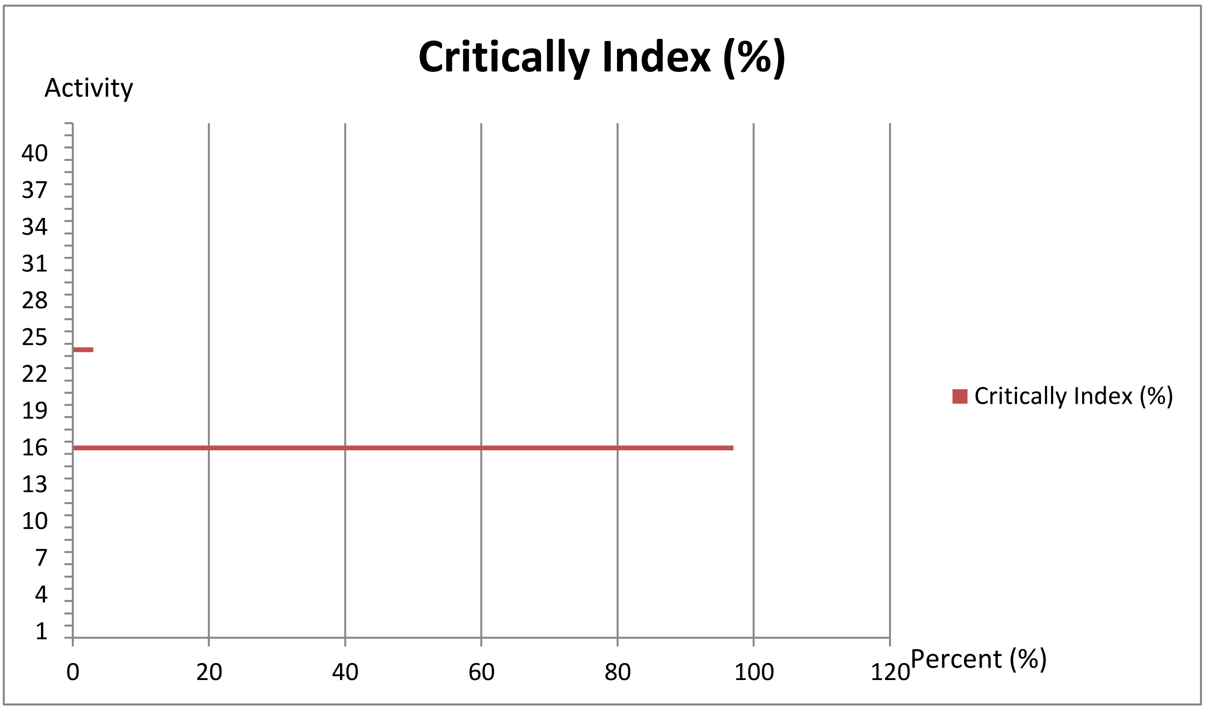


Figure 53 – CI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 7

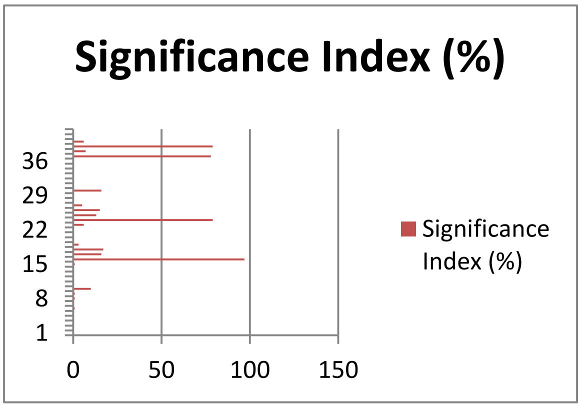


Figure 54 – SI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 7

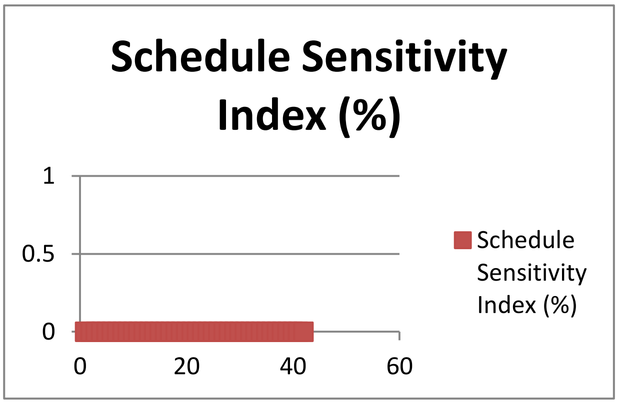


Figure 55 – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 7

The *criticality index (%)* task 16 (97%) presented in **Figure 53** exceeds the 50% threshold. The probability of this task being on the critical path is very high. For the *significance index (%),* tasks 39 (79%), 37 (78%), 24 (79%) and 16 (97%) exceeds the 50% sensitivity threshold (**Figure 54)**. They measure high and are considered relatively important tasks for project success. All schedule *sensitivity* *index (%)* task values on the bar chart for discernibility are zero (**Figure 55** – SSI Bar Chart for 42 Tasks after 100 simulation runs of Scenario 7).

In summary, scenario 3 reports an average progress with Nuclear Project B ***finishing earlier than scheduled.*** On the other hand, scenario 7 reports an average project progress with Nuclear Project B ***finishing later than scheduled.*** The *criticality index (%)* tasks presented in scenario 3 are all below 20%. The probability of any task(s) being on the critical path is very low, while task 16 (97%) presented in scenario 7 exceeds the 50% threshold. The probability of this task being on the critical path is very high. For the *significance index (%),* tasks 39 (65%), 37 (65%), 25 (65%), 23 (65%), 11 (63%) and 3 (65%) exceeds the 50% sensitivity threshold in scenario 3. They measure high and are considered relatively important tasks for project success, while tasks 39 (79%), 37 (78%), 24 (79%) and 16 (97%) exceeds the 50% sensitivity threshold in scenario 7. All tasks are merely low in the *schedule sensitivity index (%)* and the tasks are imperceptible in both scenarios 3 and 7.

5.2.5.2. Results from Experimental Simulations

The researcher complemented the nine heterogeneous Monte-Carlo simulations for each task time for the purpose of analysing the behaviour of Nuclear Projects B.

5.2.5.2.1. Elaboration of Experiment 1 & 2

Scenario 1 reported that no action is required. **Scenario 2** reported a 100% probability that the NNR formal safety review phase, application for a decontamination and decommissioning license, and receipt of final safety case by NNR are important tasks on the critical path for reducing the risk of the *expected project time*:

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;

- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time; and

- **Task 16** – Receipt of final safety case by NNR for the applicant site license must be completed on time for the project to finish earlier than scheduled.

5.2.5.2.2. Elaboration of Experiment 5

Scenario 5 reported a 100% that the NNR formal safety review phase, application for a decontamination and decommissioning license, NNR formal safety review phase (combined license), and NNR formal safety review phase (site license) are important tasks on the critical path for reducing the risk of the *expected project time*:

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;

- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time;

- **Task 25** – NNR formal safety review phase post combined license must be completed for the project finishes exactly on time; and

- **Task 17** – NNR formal safety review phase post application for a site license must be completed for the project finishes exactly on time.

5.2.5.2.3. Elaboration of Experiment 8 & 9

Scenario 9 reported that no action is required. **Scenario 8** reported a 100% probability that the NNR formal safety review phase, application for a decontamination and decommissioning license, and receipt of final safety case by NNR are important tasks on the critical path for reducing the risk of the *expected project time*:

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;

- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time;

- **Task 30** – Authorisation to design must be completed on time before authorisation manufacture;

- **Task 28** – NNR Board review and decision (issue NIL) must be completed on time;

- **Task 24 & 16** – Receipt of final safety case by NNR for the applicant site license must be completed on time for the project to later than scheduled.

5.2.5.2.4. Elaboration of Experiment 4 & 6

Scenario 4 reported that no action is required. **Scenario 6** reported 88% probability that the compilation and submission of the Environmental Impact Assessment (EIA) application is an important task on the critical path for reducing the risk of the *expected project time*:

- **Task 01** – Compilation and submission of the EIA application must be finish exactly on time not to delay the authority acceptance of the EIA application.

5.2.5.2.5. Elaboration of Experiment 3 & 7

Scenario 3 reported that no action is required. **Scenario 7** reported 97% probability that the receipt of final safety case by NNR is an important task on the critical path for reducing the risk of the *expected project time*:

- **Task 16** – Receipt of final safety case by NNR must be finished exactly on time not to delay the NNR formal safety review phase.

5.3. Summary derived from Experiments

Theory building using software simulation began with simple theory after identifying a testable research question based on the observation of the theoretical issues. The key question was merely: Implementing a methodology based on TOP will reduce the risk of the *expected project time?* through computer software simulation. Simple theory formed the platform from which powerful theory was developed through discrete event simulation[32]. The simple theory ensured computational representation, which resulted in a theoretically valuable experiment by Monte-Carlo Simulation.

[32] Discrete event simulation – involves modelling the organizational system as a set of entities evolving over time according to the availability of resources and the triggering of events (Dooley, 2002)

Table 5 – Heterogeneous Critical Tasks Activities of Nuclear Project B

Critical Tasks	Scenario(s)
Task 01 – Compile and submit of the EIA application	6 - Finishing Exactly on Time
Task 16 – Receipt of final safety case by NNR	2 - Finishing Earlier than Planned; 8 - Finishing Later than Planned; and 7 - Finishing Later than Planned
Task 17 – NNR formal safety review phase	5 - Finishing Exactly on Time
Task 24 – Receipt of final safety case by NNR	8 - Finishing Later than Planned
Task 25 – NNR formal safety review phase	5 - Finishing Exactly on Time
Task 28 – NNR Board review and decision (issue NIL)	8 - Finishing Later than Planned
Task 30 – Authorisation to design	8 - Finishing Later than Planned
Task 37 – Application for the decontamination and decommissioning license	2 - Finishing Earlier than Planned; 5 - Finishing Exactly on Time; and 8 - Finishing Later than Planned
Task 39 – NNR formal safety review phase	2 - Finishing Earlier than Planned; 5 - Finishing Exactly on Time; and 8 - Finishing Later than Planned

It was illustrated with Nuclear Project B that an analysis of the several different possible scenarios by Monte-Carlo simulation provided insight to manager for decision making. Criticality index is not an inclusive meaningful indicator for assessing the task time influencing the expected project time. In the next chapter, the crucially index provides complementary information to establish a theory of optimisation for projects through simulation. Crucially index measures the correlation between the task time and the expected project time for the case study under investigation.

CHAPTER 6: THEORY–BUILDING THROUGH EMPIRICAL STUDY

6.1. Introduction

The research study is validated with empirical data and referenced to the Eisenhardt, et al. theory–building concept (**Figure 28 – Developing Theory Through Simulation Methods**). This latest method of developing theory (through simulation) was adapted by the researcher after considering Eisenhardt former theory–building process (refer to **Figure 18 – Eisenhardt Theory–Building Process**). Through the validity study the research problem is solved. The rigor underlying the validity study is outlined along the following paragraphs to support the building of theory. Simulation research strength lays in construct validity and subsequent accuracy of the specification and measurement of the constructs (Cook, 1979).

6.2. Theory–Building Correlation Results

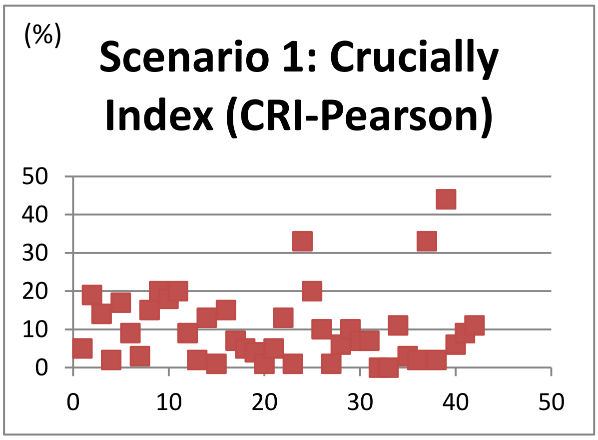
In this research, three measurements validated the time sensitivity of tasks on the expected project time by correlation. These measurements were calculated by using Pearson's Product-Moment, Spearman's Rank and Kendall's Tau Rank Correlation. These correlations were used in the research study to display the degree of linear relationship between the *task time* and *expected project time*. Spearman's differs from Pearson's Correlation only in that the computations are performed after the values are converted to ranks (Lane, 1997b). Thereafter, the degree of similarity is further displayed between two sets (i.e. task time and expected project time) of ranks for the same set of objects by Kendall's Rank Correlation (Kendall, 1955). A visual representation of the correlation results are presented and discussed along the following paragraphs.

6.2.1. Finishing Nuclear Project B Earlier than Planned

In scenarios 1, non-critical and critical tasks were ahead. While scenario 2, non-critical tasks were on plan and critical tasks were ahead. The average project progress were discussed to distinguish between the time sensitivity or insensitivity relationship between the *task time* and *expected project time* by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.1.1. Pearson's Product-Moment Correlation I & II Crucially Index

In scenario 1, Pearson's product-moment (CRI-Pearson) reports a weak positive correlation when the simulated tasks are *finishing earlier than planned*. When non-critical and critical tasks are ahead, the correlation is between 0 ≤ CRI-Pearson ≤ 0.44. It is shown that all 42 tasks have a low to moderate potential impact on Nuclear Project B (**Figure 56** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 1).



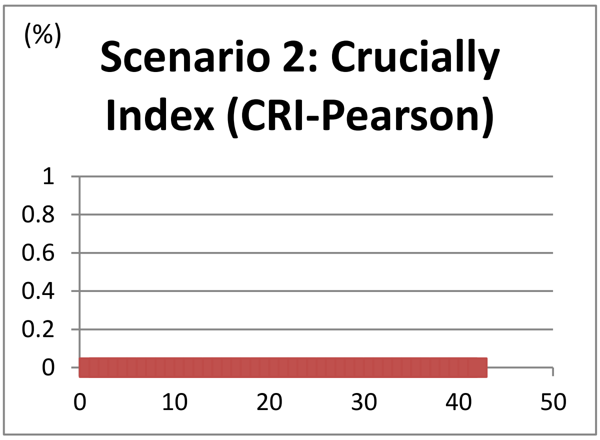


Figure 56 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 1

Figure 57 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 2

Other than the probability of tasks 39 (100%), 37 (100%) and 16 (100%) being relatively important in scenario 2, CRI-Pearson reports no correlation when the simulated tasks are *finishing earlier than planned* (**Figure 57)**. All 42 tasks are insensitive and will not require any special attention from the PM as Nuclear Project B is progressing.

In summary, CRI-Pearson confirms that no action is required for scenario 1. All tasks are insensitive and have a low to moderate potential impact in scenario 1. Similarly, no action is required for scenario 2. All tasks are also insensitive and will not require any special attention from the PM. In both scenarios 1 and 2, it is shown through the CRI-Pearson that the sensitivity values of the absolute tasks are below the sensitivity threshold (50%) for the crucially index.

6.2.1.2. Spearman's Rank Correlation I & II Crucially Index

The crucially index based on Spearman's rank correlation (CRI-Spearman) reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier* *than planned*. When non-critical and critical tasks are ahead, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50. It is shown that only tasks 32 and 33 are sensitive as it equals the threshold of 50% on the crucially index. (**Figure 58** – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of **Scenario 1**).

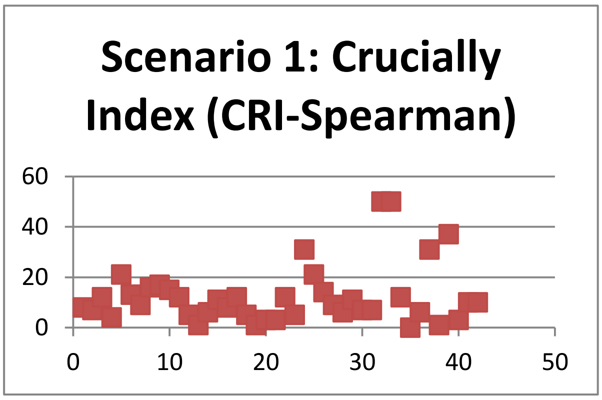


Figure 58 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 1

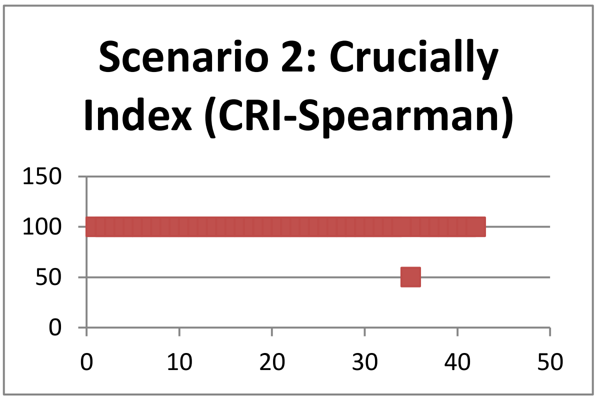


Figure 59 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 2

Other than the probability of tasks 39 (100%), 37 (100%) and 16 (100%) being on the critical path in scenario 2, CRI-Spearman reports a near perfect positive correlation in **Figure 59.** It is shown that 98% of tasks are highly sensitive and should not deviate from their baseline values.

In summary, crucially index based on Spearman's rank correlation (CRI-Spearman) reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier than planned*. In scenario 2, CRI-Spearman reports a near perfect positive correlation**.** It is shown that 98% of tasks are highly sensitive as it exceeds the sensitivity threshold of 50% on the crucially index.

6.2.1.3. Kendall's Tau Rank Correlation I & II Crucially Index

Kendell's tau rank correlation (CRI-Kendell) reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier than planned* except for task 32 (100%) and 33 (100%). Majority of tasks are insensitive and have a low potential impact on Nuclear Project B (**Figure 60** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 1).

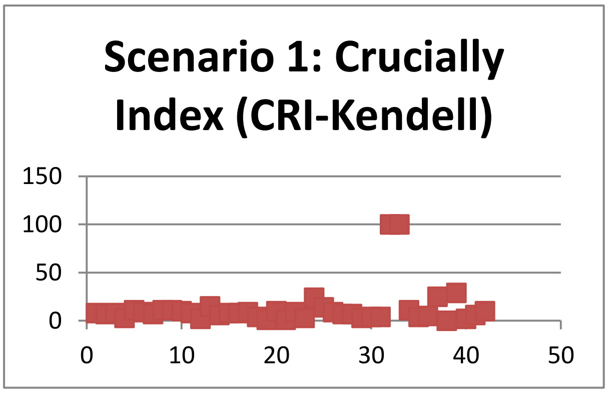


Figure 60 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 1

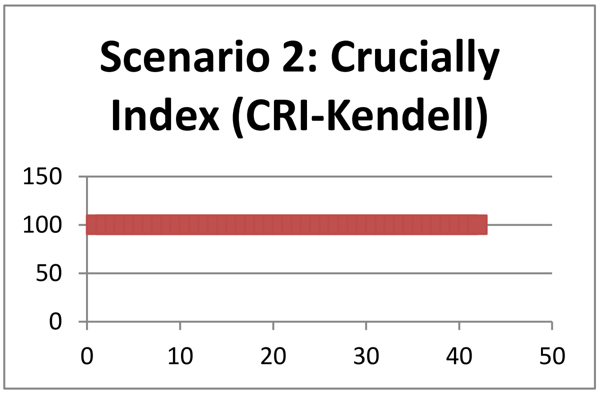


Figure 61 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 2

Other than the probability of tasks 39 (100%), 37 (100%) and 16 (100%) being on the critical path in scenario 2, CRI-Kendell reports a perfect positive correlation (**Figure 61** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 2). It is shown that 100% of tasks are highly sensitive and must be under constant surveillance.

In summary, CRI-Kendell reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier than planned* except for task 32 (100%) and 33 (100%) in scenario 1. CRI-Kendell reports a perfect positive correlation and must be under constant surveillance in scenario 2.

6.2.2. Summary derived from Finishing Nuclear Project B Earlier than Planned

In scenarios 1, non-critical and critical tasks were ahead, while in scenario 2 non-critical tasks were on plan and critical tasks were ahead. In **Table 6**, the relationship between the *task time* and *expected project time* is documented to construct validity and to measure the constructs by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations.

Table 6 – Summary of Finishing Nuclear Project B Earlier than Planned

Scenario 1 **Non-critical & critical tasks are ahead**	**Scenario 2** **Non-critical tasks are on plan & critical tasks are ahead**
• Pearson reports a weak positive correlation	• Pearson reports no correlation
• Spearman reports a weak to moderate positive correlation	• Spearman reports a near perfect positive correlation
• Kendell reports a weak to moderate positive correlation	• Kendell reports a perfect positive correlation

6.2.3. Finishing Nuclear Project B Exactly on Time

Scenario 5 reports a 100% on time performance. The average project progress is discussed to distinguish the sensitivity or insensitivity of the relationship between the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.3.1. Pearson's Product-Moment Correlation, Spearman's & Kendell's Tau Rank V Crucially Index

In scenario 5, CRI-Pearson reports no correlation for 100% on time performance. All tasks are insensitive and do not require any special attention (refer to **Figure 62** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 5). However, further analysis is required for on time performance to be able to improvement the accuracy of the task sensitivity and to reduce potential impact on expected project time.

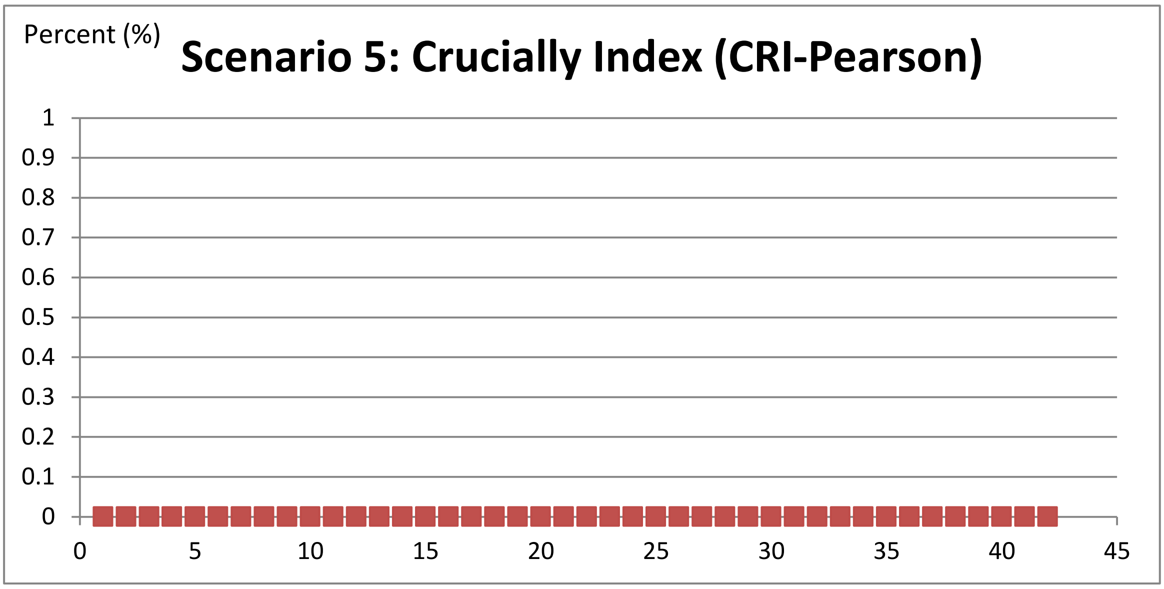


Figure 62 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 5

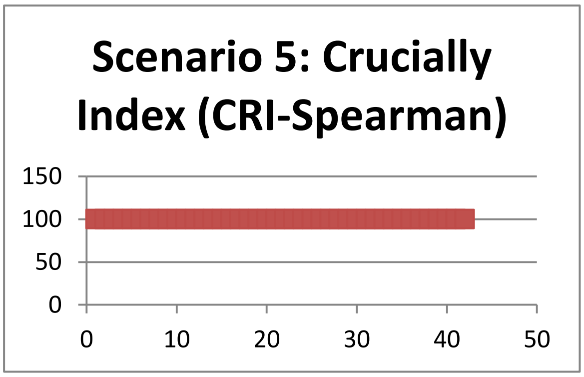


Figure 63 – Spearman's rank correlation for 42 Tasks after 100 simulation runs of Scenario 5

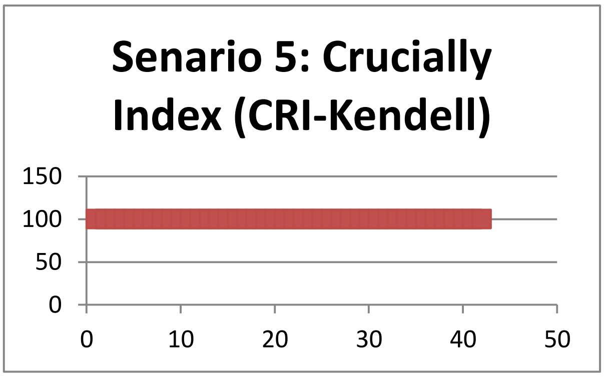


Figure 64 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 5

Other than the probability of tasks 39 (100%), 37 (100%) and 25 (100%) being on the critical path in scenario 5 (refer to section in Experimental Simulation 5), CRI-Spearman and CRI-Kendell reports a perfect positive correlation (refer to **Figure 63** & **Figure 64)**. It is shown that 100% of tasks are highly sensitive and have a high potential impact on Nuclear Project B. Despite the tedious results observed in scenario 5, it was shown that the more effort dedicated to experimental simulations, the more the likelihood of reducing the risk of the *expected project time* in the case of 100% on time performance.

Table 7 – Finishing Nuclear Project B Exactly on Time

Scenario 5 100% on time performance
• Pearson reports no correlation
• Spearman reports perfect positive correlation
• Kendell reports a perfect positive correlation

6.2.4. Finishing Nuclear Project B Later than Planned

In scenarios 8, non-critical tasks were on plan and critical tasks were delayed. While scenario 9, non-critical and critical tasks were delayed. The project progress are discussed to distinguish between time sensitivity or insensitivity of the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.4.1. Pearson's Product-Moment Correlation VIII & IX Crucially Index

In scenario 8, CRI-Pearson reports no correlation when the simulated tasks are *finishing later than planned*. When non-critical tasks are on plan and critical tasks were delayed, the correlation is equal to zero. All tasks are insensitive and do not require any special attention (refer to **Figure 65** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 8).

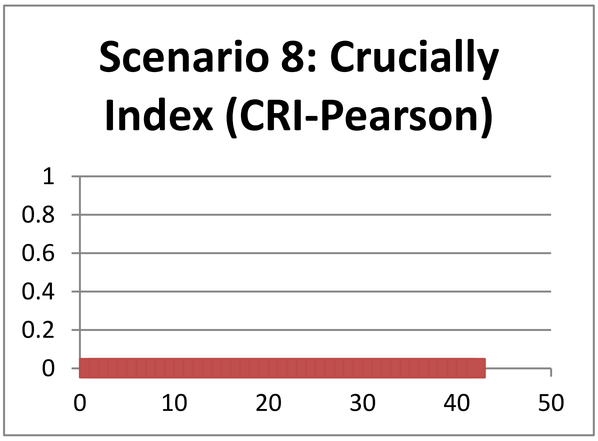


Figure 65 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 8

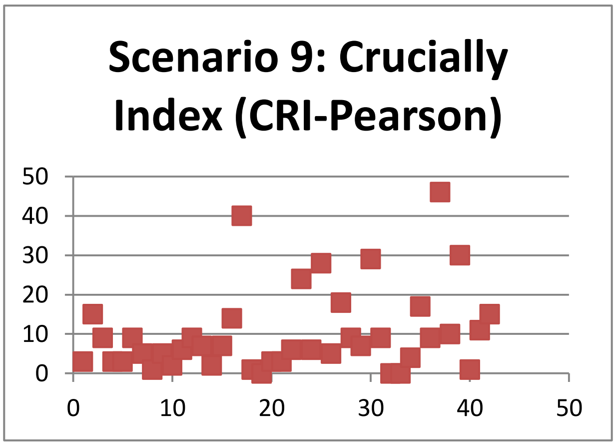


Figure 66 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 9

CRI-Pearson reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks are delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50. All tasks are insensitive and will not require any special attention from the PM when Nuclear Project B is progressing (**Figure 66** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 9).

6.2.4.2. Spearman's Rank Correlation VIII & IX Crucially Index

The crucially index based on CRI-Spearman reports a near perfect positive correlation except for tasks 26 (50%) and 36 (50%) (**Figure 67** – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 8). Majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

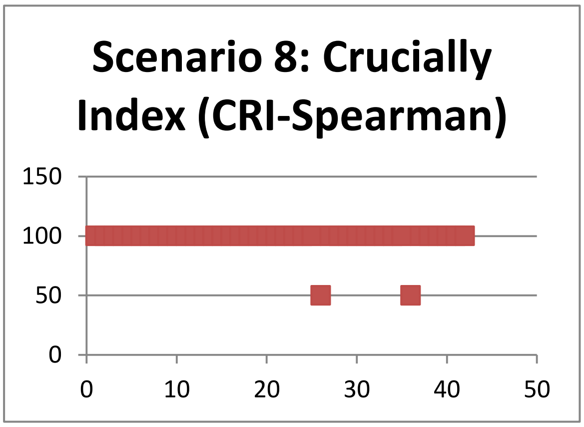


Figure 67 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 8

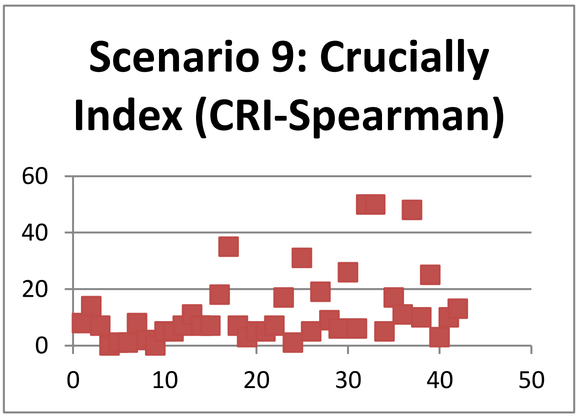


Figure 68 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 9

CRI-Spearman reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks were delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50**.** It is shown that

98% of tasks are insensitive in scenario 9 (**Figure 68** – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 9).

6.2.4.3. Kendell's Tau Rank Correlation VIII & IX Crucially Index

Other than the probability of tasks 39 (100%), 37 (100%), 30 (100%), 28 (100%), 24 (100%) and 16 (100%) being on the critical path. The crucially index based on CRI-Kendell reports a perfect positive correlation when the simulated tasks are *finishing later than planned*. All tasks are sensitive and have a high potential impact on Nuclear Project B. (**Figure 69** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 8).

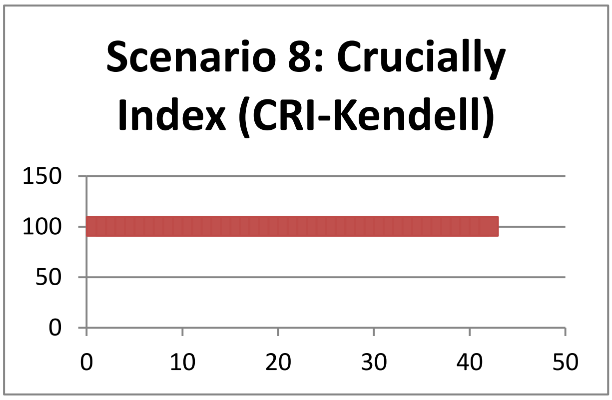


Figure 69 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 8

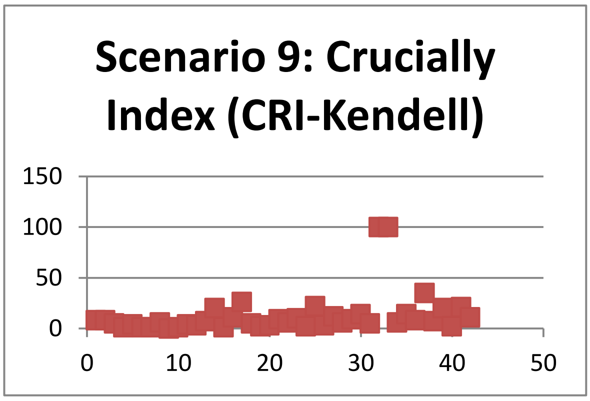


Figure 70 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 9

CRI-Kendell reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks were delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.35 except for task 33 (100%) and 32 (100%) (**Figure 70** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 9)**.** It is shown that 98% of tasks are insensitive.

Table 8 – Summary of Finishing Nuclear Project B Later than Planned

Scenario 8 Non-critical & critical tasks are on plan	Scenario 9 Non-critical and critical tasks are delayed
• Pearson reports no correlation	• Pearson reports a weak to moderate positive correlation
• Spearman reports a near perfect positive correlation	• Spearman reports a weak to moderate positive correlation
• Kendell reports a perfect positive correlation	• Kendell reports a weak to moderate positive correlation

6.2.5. Finishing Nuclear Project B Exactly on Time

In scenarios 4, non-critical tasks are ahead and critical tasks are on plan. While scenario 6, non-critical tasks are delayed and critical tasks are on plan. The project progress are discussed to distinguish between time sensitivity or insensitivity of the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.5.1. Pearson's Product-Moment Correlation IV & VI Crucially Index

In scenario 4, CRI-Pearson reports a weak to moderate positive correlation when simulated tasks are exactly on time. All tasks are insensitive and do not require any special attention (**Figure 71** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 4).

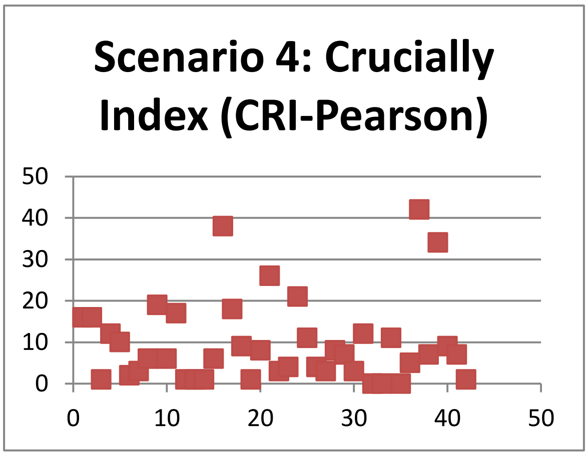


Figure 71 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 4

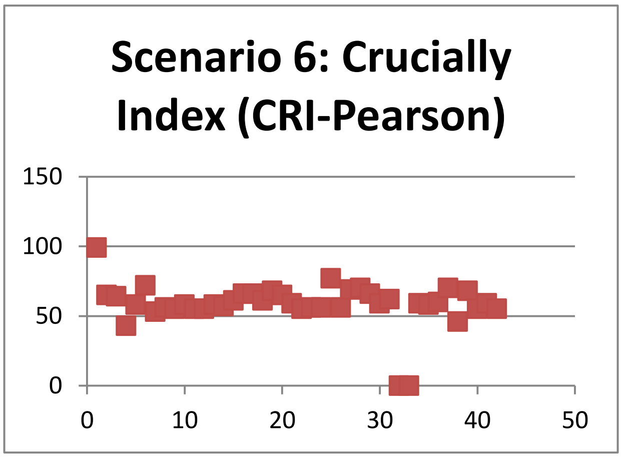


Figure 72 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 6

CRI-Pearson reports a moderate to perfect correlation when simulated tasks are exactly on time. Majority of tasks are sensitive and will require any special attention as Nuclear Project B is progressing (**Figure 72** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 6).

6.2.5.2. Spearman's Rank Correlation IV & VI Crucially Index

The crucially index based on CRI-Spearman reports a weak to moderate positive correlation when simulated tasks are exactly on time (**Figure 73** – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 4). Majority of tasks are insensitive and have a low potential impact on Nuclear Project B.

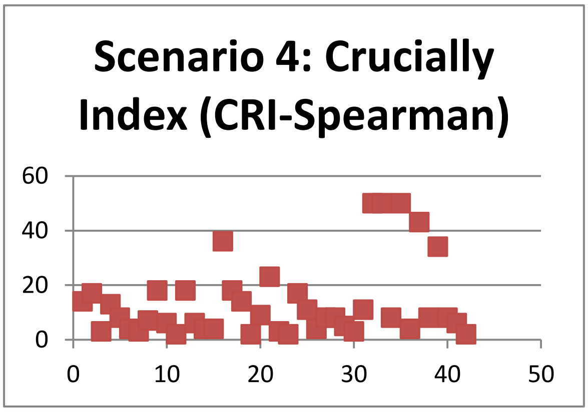


Figure 73 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 4

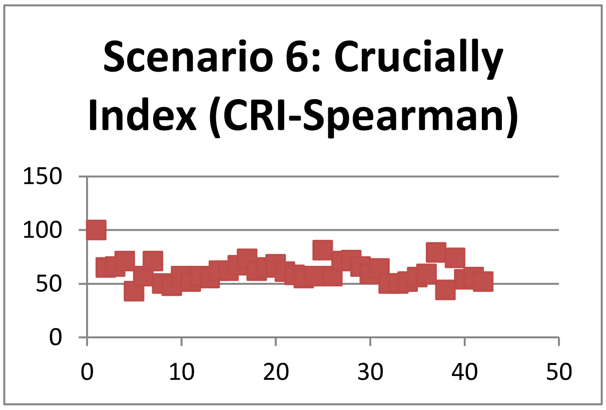


Figure 74 – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 6

The crucially index based on CRI-Spearman report a moderate to perfect positive correlation (**Figure 74** – Spearman's rank correlation values for 42 Tasks after 100 simulation runs of Scenario 6). Majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

6.2.5.3. Kendell's Tau Rank Correlation IV & VI Crucially Index

CRI-Kendell reports a weak to moderate positive correlation when simulated tasks are exactly on time. Majority of tasks are insensitive and have a low potential impact on except for tasks 32 (100%), 33 (100%) and 35 (100%) (**Figure 75** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 4).

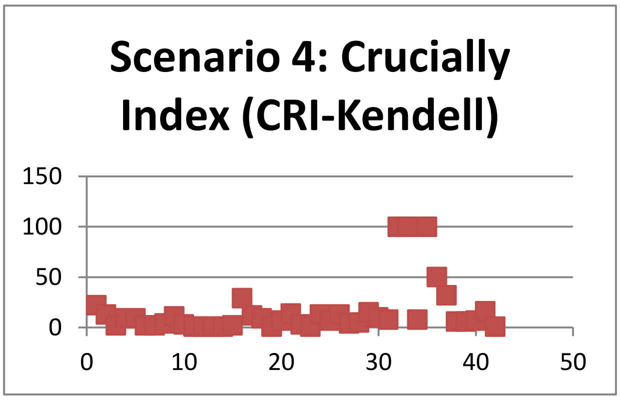


Figure 75 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 4

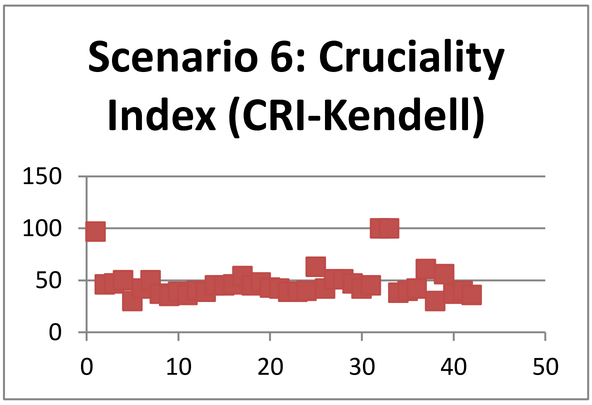


Figure 76 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 6

Other than the probability of task 1 (88%) being on the critical path is high (refer to section in Experimental Simulation 4 & 6), CRI-Kendell reports a moderate to perfect positive correlation and will require special attention (**Figure 76** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 6).

Table 9 – Summary of Finishing Nuclear Project B Exactly on Time

Scenario 4 **Non-critical tasks are ahead & critical tasks are on plan**	**Scenario 6** **Non-critical tasks are delayed & critical tasks are on plan**
• Pearson reports a weak to moderate positive correlation	• Pearson reports a moderate to perfect positive correlation
• Spearman reports a weak to moderate positive correlation	• Spearman reports a moderate to perfect positive correlation
• Kendell reports a weak to moderate positive correlation	• Kendell reports a moderate to perfect positive correlation

6.2.6. Finishing Nuclear Project B Earlier than Planned

Non-critical are delayed and critical activities are ahead for scenario 3. The average project progress is discussed to distinguish the sensitivity or insensitivity of the relationship between the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.6.1. Pearson's Product-Moment Correlation, Spearman's & Kendell's Tau Rank III Crucially Index

In scenario 3, CRI-Pearson reports a moderate to perfect positive correlation when simulated tasks are earlier than planned. Majority of tasks are sensitive and have a high potential impact on Nuclear Project B (refer to **Figure 77** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 3). However, further analysis is required.

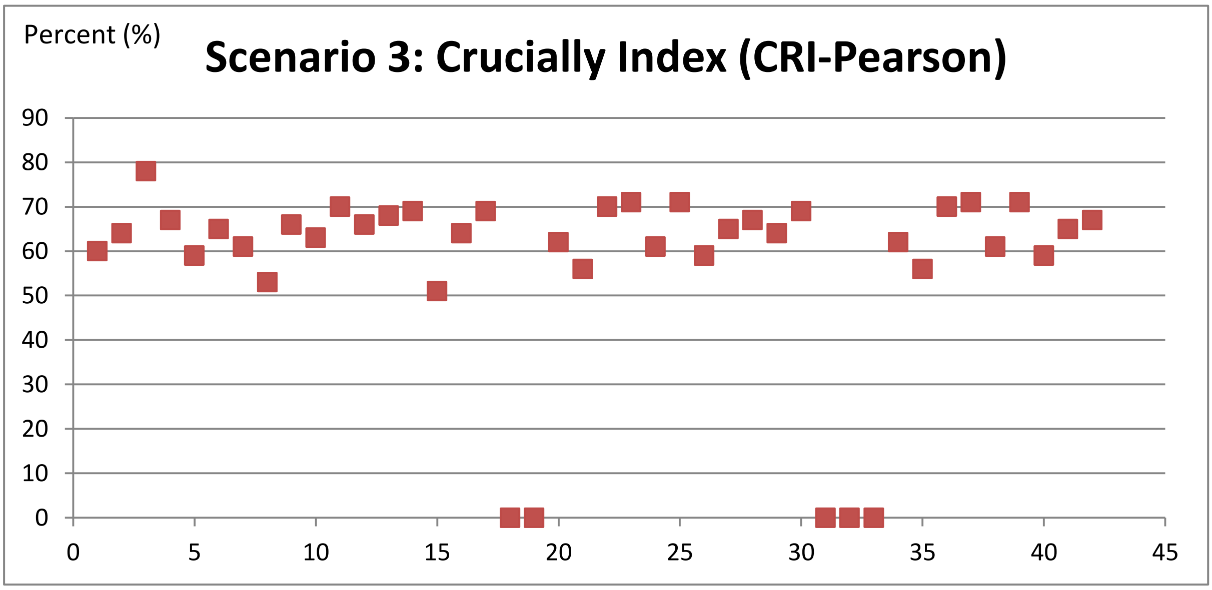


Figure 77 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 3

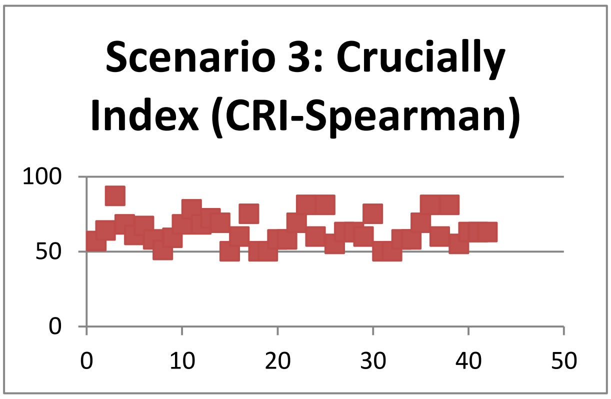


Figure 78 – Spearman's rank correlation for 42 Tasks after 100 simulation runs of Scenario 3

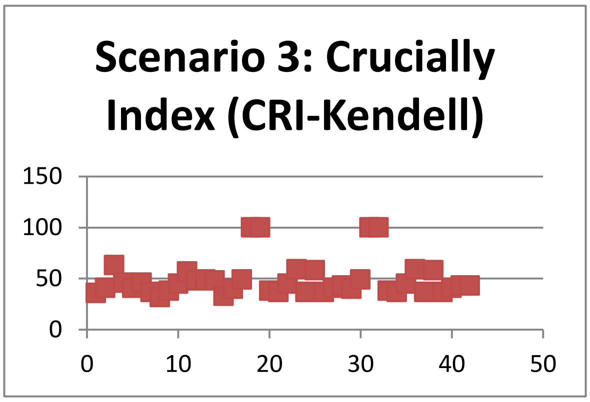


Figure 79 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 3

Other than the low probability of tasks being on the critical path in scenario 3 (refer to section in Experimental Simulation 3 & 7), CRI-Spearman and CRI-Kendell reports a moderate to perfect positive correlation (refer to **Figure 78** & **Figure 79**). It is shown that majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

Table 10 – Finishing Nuclear Project B Earlier than Planned

Scenario 3 Non-critical are delayed & critical activities are ahead
• Pearson reports a moderate to perfect positive correlation
• Spearman reports a moderate to perfect positive correlation
• Kendell reports a moderate to perfect positive correlation

6.2.7. Finishing Nuclear Project B Later than Planned

For scenario 7, non-critical activities are ahead and critical activities are delayed. The average project progress is discussed to distinguish the sensitivity or insensitivity of the relationship between the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank correlations along the following sections.

6.2.7.1. Pearson's Product-Moment Correlation, Spearman's & Kendell's Tau Rank VII Crucially Index

In scenario 7, CRI-Pearson reports a weak to moderate positive correlation when the simulated tasks are later than planned (**Figure 80** – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 7). However, further analysis is required.

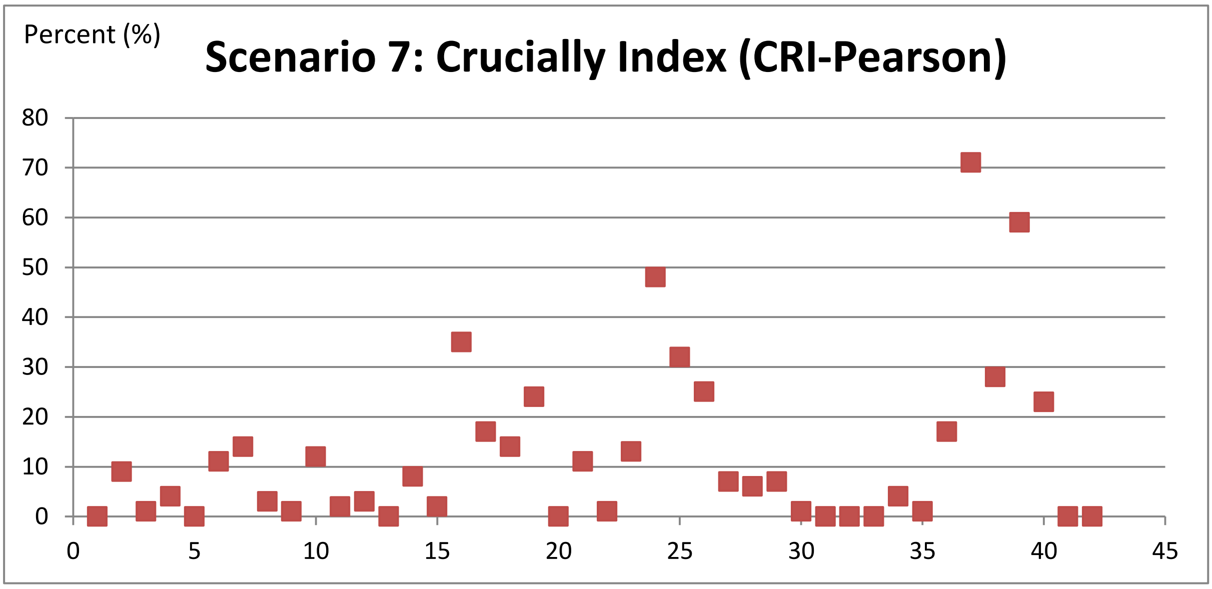


Figure 80 – Pearson's product-moment values for 42 Tasks after 100 simulation runs of Scenario 7

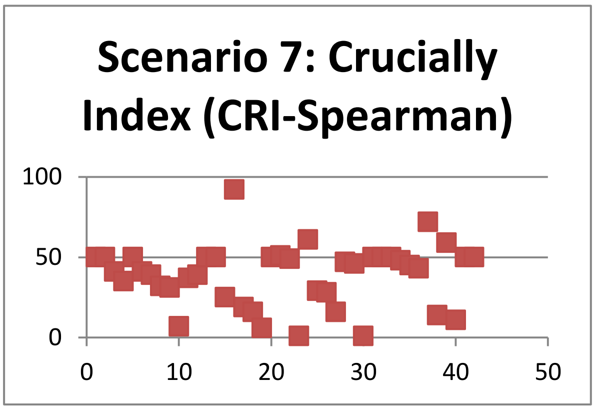


Figure 81 – Spearman's rank correlation for 42 Tasks after 100 simulation runs of Scenario 7

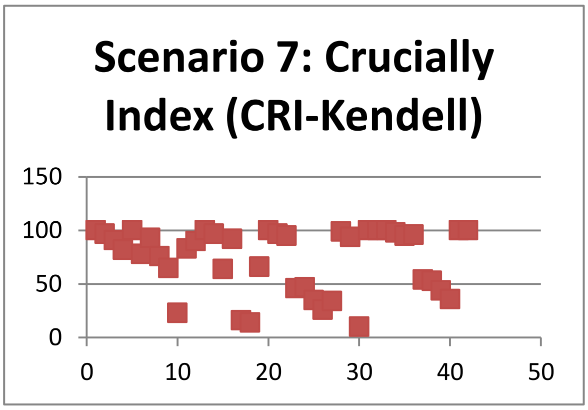


Figure 82 – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 7

Other than the probability of task 16 (97%) being on the critical path in scenario 7 (refer to section in Experimental Simulation 3 & 7), CRI-Spearman and CRI-Kendell reports a moderate to perfect positive correlation (**Figure 81** – Spearman's rank correlation for 42 Tasks after 100 simulation runs of Scenario 7) and (**Figure 82** – Kendell's tau rank correlation values for 42 Tasks after 100 simulation runs of Scenario 7). It is shown that most of tasks are sensitive and have a high potential impact on Nuclear Project B.

Table 11 – Summary of Finishing Nuclear Project B Later than Planned

Scenario 7 Non-critical activities are ahead & critical activities are delayed
• Pearson reports a weak to moderate positive correlation
• Spearman reports a weak to moderate positive correlation
• Kendell reports a moderate to perfect positive correlation

6.3. Summary derived from Theory Building

In summary, the CRI measured the time sensitivity by correlating the task time and expected project time. The measurement was calculated by using the Pearson's product-moment, Spearman's rank correlation and Kendall's tau rank correlation tests and was used to validate the probability of the experimental simulations. The validation process was examined to determine whether the $\mathbf{H_2}$ theory–building results could be correctly represented in the real life practice. The results of the experiments were compared with the task time and expected project time by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher making the total of 900 simulations. It is confirmed that nine heterogeneous key tasks activities denote the likelihood of being critical on the case study (refer to section 5.3). The researcher confirms the TOP methodology by *using the Criticality Index concept for selection of the critical chain using Monte Carlo and validates the time sensitivity of the task time on the expected project time by correlation using 50% time sensitivity* *threshold sizing rule*. The results deduct support for $\mathbf{H_2}$. Testing $\mathbf{H_2}$ theory on an existing Nuclear Project B and observing it across nine heterogeneous contexts, correlate with the outcomes as predicted. Project managers may now be aided to resolve resource contentions by following Tukel et al. (2006) 6-step critical chain project scheduling process referred to in step three (refer to section 2.3.3.1) together with the researcher's methodology based on TOP to reduce the risk of the *expected project time*.

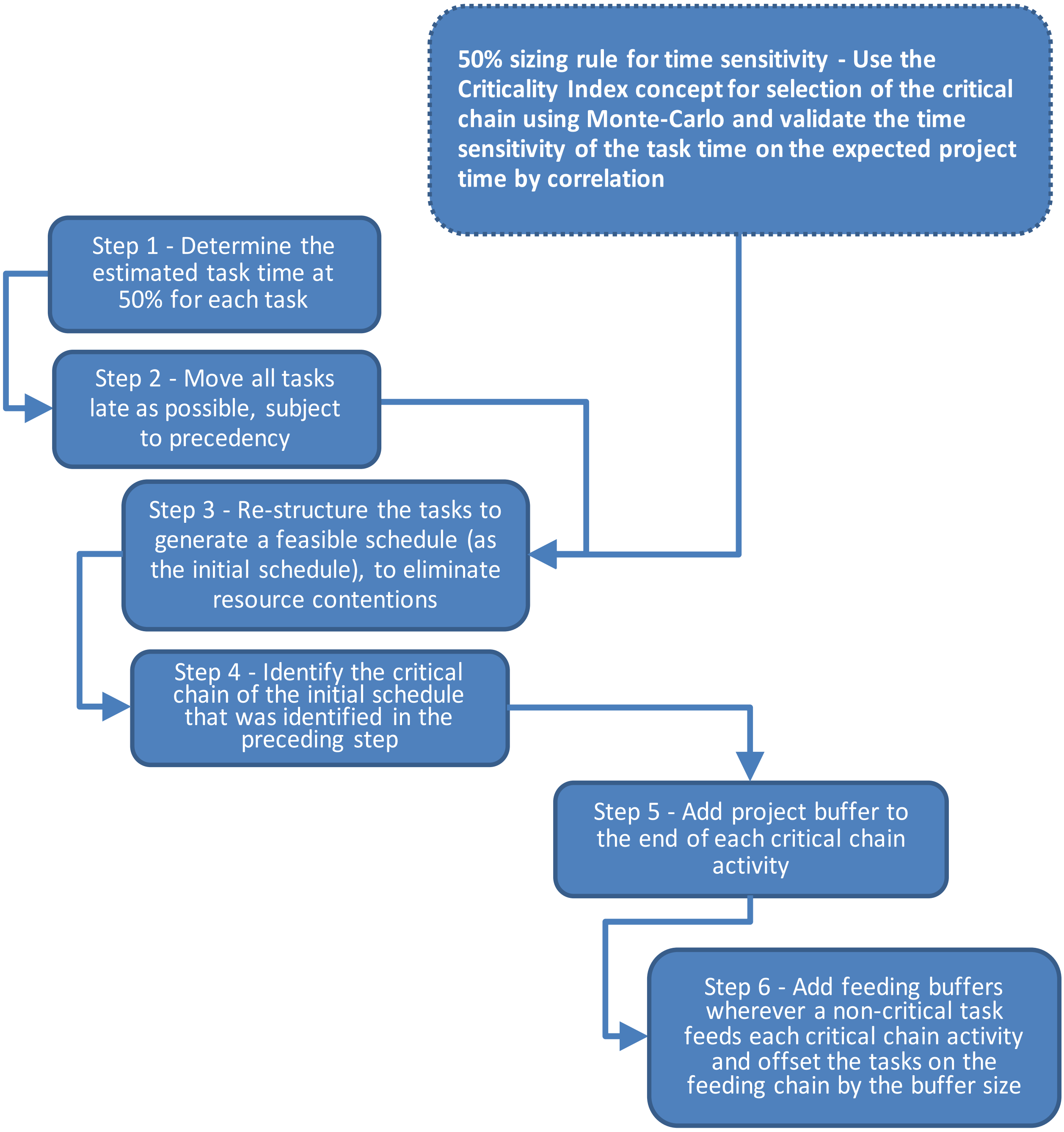


Figure 83 – Proposed Theory of Optimisation for Projects Methodology

No specific procedure is presented to resolve resource contentions, referred to in step three (Herroelen, 2001). The proposed model will contribute to the current integration process in resolving resource contentions as suggested by Tukel et al. (2006) 6-step critical chain project scheduling process by using the Criticality Index concept for selection of the critical chain using Monte Carlo and validate the time sensitivity of the task time on the expected project time by correlation using 50% time sensitivity threshold sizing rule.

CHAPTER 7: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1. Introduction

The thesis aim was to identify the benefits of introducing the Criticality Index concept for selection of the critical chain using Monte-Carlo simulation automated approach (Ghaffari & Emsley, 2015). The main objectives of the research were to present a TOP through simulation and validate the theory through an empirical study. In this final chapter, the thesis will present and discuss the outcome of the objectives, the literature review and empirical findings of the research study case study. The reader is reminded of the research design and research limitations. The main conclusions, recommendations for further research and a discussion of the research contribution to the field of knowledge are covered by the researcher.

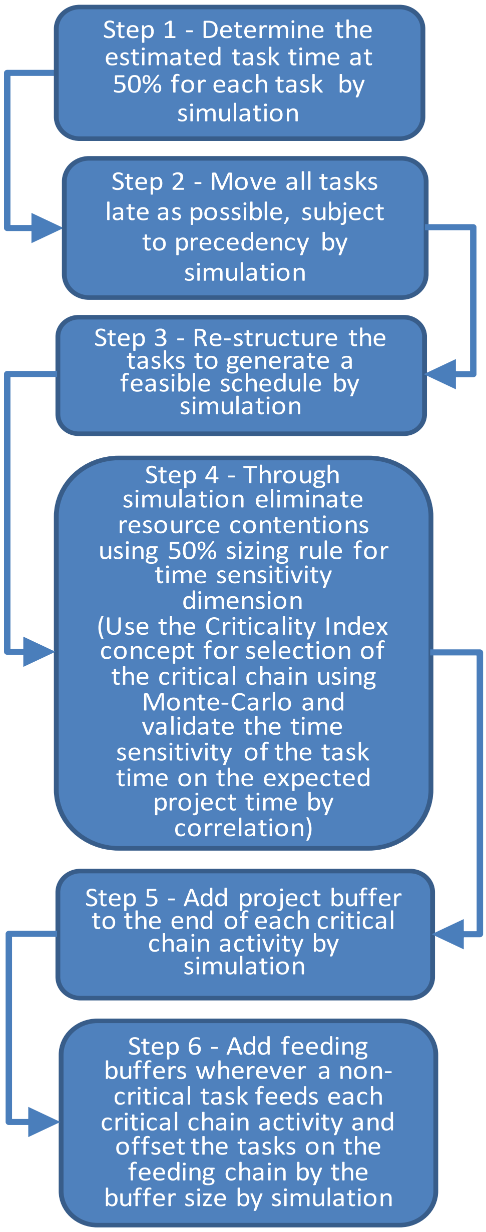
The strengths of the research study are in the selection of the hypothesis $\mathbf{H_1}$ *scoping review* and *simply theory* for addressing hypothesis $\mathbf{H_2}$ of the research study. The *scoping review* and simply theory information formed the basis for computational representation and the theory–building process. The proposed TOP model will contribute to the current integration process in resolving resource contentions as suggested by Tukel et al. (2006) 6-step critical chain project scheduling process. Assenting to $\mathbf{H_2}$ confirms that the two–folded measuring process (i.e. criticality and sensitivity) reduces the risk of the *expected project time* and its consequent success of Nuclear Project B.

Limitations are related to the proposed TOP methodology. The model was developed according to the available information of Nuclear Project A and B derived from extract of baseline schedules, observations and the researcher experience in the nuclear arena in South Africa. Further assumptions were based on the literature reviewed by the researcher.

7.2. Theory of Optimisation for Projects

7.2.1. Summary derived from TOP

Today, it is revealed that there is a lack of PM support to complete projects successfully in organizations. The shortcoming of project failures is problematic to the delivery of projects. The TOP methodology presented (**Figure 84 – Theory of Optimisation for Projects**), integrates different heterogeneous scenarios data sources to reduce the risk of the *expected project time*.



6–step critical chain project scheduling by Author

Figure 84 – Theory of Optimisation for Projects

Selected data sources include the following: Construction of a transient interim storage facility for the storage of casks, to whom the researcher is assigned to as the nuclear project manager (extract of baseline project schedule) and A licensing plan for coupling a nuclear energy source to a chemical process plant. SASOL Secunda as a case study (extract of baseline project schedule) (Lavelot, 2014). For each Nuclear Project the suggested software tools are presented for groundwork and implementation. During the research, to design the TOP the researcher followed part of the area of knowledge of PM theory underlying PERT/CPM and CCPM including the CCRCS life cycle as the methodological approach (refer to see CHAPTER 2: LITERATURE REVIEW).

The researcher performed a search in EBSCOhost and established that the hypothetical connotation proposed by the researcher in terms of the TOP methodology: **If you can measure it, you can improve it** was reported across only 10 source types between 2000 and 2016, primarily within the already stated 2 periodicals within health services and environment technology, and in 1 periodical within total quality management. Correspondingly, it is reported in 3 academic journals within hospital management, clinical and experimental rheumatology and health services, equally in 3 newspaper articles within the Washington Times, UK Times and USA Today. Finally, 1 is sourced in the Editorial & Opinion within clinical leadership & management. Nothing was obtained by the researcher across source type underlying the field in nuclear project management.

7.2.2. Potential Benefits from the TOP

One of the most documented articles on theory is by Lewin (1945) who states that “nothing is quite so practical as a good theory” therefore: “good theory is practical precisely because it advances knowledge in a scientific discipline, guides research toward crucial questions, and enlightens the profession of management” (Van de Ven, 1989).

From the proposed TOP methodology, project managers can view and perform different tasks. The methodology covers only a part of the selected system for resolving resource contentions as suggested by Tukel et al. (2006) critical chain project scheduling process. The TOP can integrate different subject areas as presented (**Figure 84 – Theory of Optimisation for Projects**) and is useful for project management and the decision–making process.

In brief, the main benefits that the proposed TOP methodology can provide to the nuclear arena are the following:

I. Delays are less likely when using the Criticality Index concept for selection of the critical chain using Monte-Carlo to manage highly uncertain tasks. The methodology will provide a unique, integrated and placid source of information.

II. Complete view of heterogeneous critical task activities based on the array of information for validating the time sensitivity of tasks on the expected project time by correlation. The correlations display the degree of linear relationship between the task time and expected project time.

III. Accurate information for project managers to make decisions. Using the TOP the nuclear area will be able to distinguish between the time sensitivity or insensitivity relationship between the task time and expected project time by Pearson product-moment, Spearman's rank and Kendall's tau rank that are not easily available with a simple system.

IV. Ability to validate the time sensitivity of the task time on the expected project time by correlation using 50% sizing rule for time sensitivity dimension. The validity of simulation results increases with a higher number of simulation runs.

7.2.3. Potential Limitations

Though there are several positive facts to adopting the TOP methodology, there are also several shortcomings. These are related to the costs of the ProTrack software system including the costs of human capital. All the information might not always be understood by project manager for decision-making. Creating access and educating several projects managers is another cost drawback for adopting the TOP methodology. Another shortcoming is that the costs to produce project schedules in a timely manner may be too expensive.

The PM life cycle concept of this research study was adapted to Klein (2000). Klein’s concept includes two additional phases (i.e. in which the project has to be **scheduled** is denoted by “**S**” and the project **controlled** is denoted by “**C**”) (refer to **Figure 8**).

The research study was mapped out of three (3) dimensions of scheduling dynamically, in particular: 1) **complexity** of project scheduling; 2) **uncertainty** of risk analysis; and 3) **project control**. When the level of uncertainty is high, the schedule of a project becomes more susceptible to change. The goal of project managers is to measure and cope with uncertainties and complexities of their projects.

The current research study was further arranged around the classification of PERT/CPM, SRA, RCS and critical chain/buffer management.

7.2.4. Implementing the TOP

The implementation of CCPM the traditional way is complex and challenging for larger projects. Minimal efforts were made on the research of optimisation methods for projects (Penga & Huangb, 2013). Implementing a methodology based on TOP will reduce the risk of the *expected project time* and is a supporting tool for structuring nuclear projects.

The initiating point for implementing the TOP is with the selection and definition of the data sources. Having the source of data, we will start with the development of a baseline schedule. The baseline schedule represents a central role in this process and the lack thereof would lead to incomparable computational representation of its data. Determine the estimated task time at 50% for each task by simulation. Move all tasks late as possible, subject to precedency by simulation. Re-structure the tasks to generate a feasible schedule by simulation. Through simulation eliminate resource contentions using 50% sizing rule for time sensitivity dimension (Use the Criticality Index concept for selection of the critical chain using Monte-Carlo and validate the time sensitivity of the task time on the expected project time by correlation). Add buffer to the end of each critical chain activity by simulation. The final step, add feeding buffers wherever a non-critical task feeds each critical chain activity and offset the tasks on the feeding chain by the buffer size by simulation.

In terms of tools, the nuclear project management can use different software tools such as Monte-Carlo simulation contained in the ProTrack V3 version running on Windows. Currently, the nuclear project management at Koeberg does not have the proposed software tools.

7.2.5. Extending the proposed TOP?

In the researcher's view, the subsequent steps need to be considered in order to extend the proposal:

I. Definition of the data model to be implemented;

II. Design of the data model integration process to include the 50% sizing rule for time sensitivity dimension;

III. Creation of access to the data model; and

IV. Users to be educated to perform their analysis on the data model.

7.2.6. How to integrate the data model?

In order to integrate 50% sizing rule, we have to follow the critical chain life cycle of Tukel et al. (2006). The initiating point for implementing the TOP is with the selection and definition of the data sources. Having the source of data, we will start with the development of a baseline schedule. Steps 1 to 2, determine the estimated task time at 50% for each task. Move all tasks late as possible, subject to precedency. Step 3, re-structure the tasks to generate a feasible schedule, ***develop an interface that will allow users to load data using the Monte-Carlo approach for the 50% sizing rule time sensitivity dimension to eliminate resource contentions*** (**Figure 83 – Proposed Theory of Optimisation for Projects Methodology**). Step 4 to 5, identify the critical chain of the schedule and add buffer to the end of each critical chain activity. Final step 6 will be to add feeding buffers wherever a non-critical task feeds each critical chain activity and offset the tasks on the feeding chain by the buffer size.

A description of the proposed model is presented in **Figure 83 – Proposed Theory of Optimisation for Projects Methodology**. The idea of using the TOP data model for decision making in an organization may be widely accepted. Theory building using software simulation began with simple theory using Eisenhardt theory–building process to test $\mathbf{H_2}$. The proposed model previews *the Monte-Carlo approach for the 50% sizing rule time sensitivity to eliminate resource contentions*. Data integration process consists in the creation of the researcher's integrator in step 3 (*50% sizing rule time sensitivity dimension* to eliminate resource contentions*)*. Other findings are related to the scoping review using the Christensen theory–building process to test $\mathbf{H_1}$ (see chapter 4, section 4.4).

7.3. Summary of Findings and Conclusions of the study

During the research, special attention was paid to Part 1 of the scoping review (or preliminary study) that fundamentally assessed the relationship between the CCRCS and PERT on the PM case study project and its project time. Part 1 was referenced to the Christensen theory–building concept. The scoping review consolidated the observation, categorisation and measurement in numbers and words, followed by the classification underlying categories, and the investigation between the categories and observations of their outcomes. An initial regression analysis for estimating the relationships among variables of $\mathbf{H_1}$ was evaluated for the research. Nuclear Project A was identified (refer to section 1.1) and was selected by the researcher as it has vast referencing empirical testing data.

Special attention was paid to Part 2 appraised the TOP and assays its effectiveness for critical chain scheduling on the PM case study project and its project time. Part 2 was referenced to Eisenhardt, et al. theory–building concepts. By combining the contributions of Eisenhardt (**Figure 18 – Eisenhardt Theory–Building Process)** and Eisenhardt, et al. (**Figure 28 – Developing Theory Through Simulation Methods**), it was revealed that *measurability* lies at the core of the theory–building concept. The researcher impulsively raised questions on *measurability*, which were used to formulate the research questions. Once research questions were refined, the PM case study was selected, and the measurement instruments formulated for the data collection process. Monte-Carlo simulation analyses for estimating the relationships among variables of $\mathbf{H_2}$ were evaluated for the research. Nuclear Project B was identified (refer to section 1.1) and selected by the researcher as it also had vast reference data for empirical testing.

In the end, special attention was paid to Part 3 of the research validation study was referenced to the Eisenhardt, et al. theory–building concept (**Figure 28**). This latest method of developing theory (through simulation) was adapted by the researcher after considering Eisenhardt former theory–building process (refer to **Figure 18 – Eisenhardt Theory–Building Process**). Simulation research strength lays in construct validity and subsequent accuracy of the specification and measurement of the constructs (Cook, 1979). Through the validity study the research problem is solved. The rigor underlying this validity study is outlined in more detail within Chapter 6. Three measurements validated the time sensitivity of tasks on the expected project time by correlation. These measurements were calculated by using Pearson's Product-Moment, Spearman's Rank and Kendall's Tau Rank Correlation. These correlations were used in the research study to display the degree of linear relationship between the *task time* and *expected project time*. Spearman's differs from Pearson's Correlation only in that the computations are performed after the values are converted to ranks (Lane, 1997b). Thereafter, the degree of similarity is further displayed between two sets (i.e. task time and expected project time) of ranks for the same set of objects by Kendall's Rank Correlation (Kendall, 1955). A visual representation of the correlation results are presented and discussed in chapter 6.

From the research study, the major result the researcher presented in this research is a revision of the critical chain project scheduling process model by Tukel et al. (2006) (see chapter 6) that allows the integration of *the 50% sizing rule time sensitivity to eliminate of resource contentions*. The proposed TOP model integrates the creation of the researcher's integrator in step 3 (*50% sizing rule time sensitivity dimension)*. The validation process was examined to determine whether the $\mathbf{H_2}$ theory–building results could be correctly represented in the real life practice. The results of the experiments were compared with the task time and expected project time by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher making the total of 900 simulations. It is confirmed that nine heterogeneous key tasks activities denote the likelihood of being critical on the case study (refer to section 5.3). The researcher confirms the TOP methodology by *using the Criticality Index concept for selection of the critical chain using Monte Carlo and validate the time sensitivity of the task time on the expected project time by correlation using 50% time sensitivity threshold sizing rule* (refer to section 6.3). The results deduct support for $\mathbf{H_2}$. Testing $\mathbf{H_2}$ theory on an existing Nuclear Project B and observing it across nine heterogeneous contexts, correlate with the outcomes as predicted. Project managers may now be aided to resolve resource contentions by following the researcher's 6–step critical chain project scheduling process (**Figure 84 – Theory of Optimisation for Projects**) to form the TOP methodology to reduce the risk of the *expected project time*.

7.4. Research Contributions

This thesis has demonstrated how a testable research question, simple theory, together with the discrete event approach and computational representation is used, for building theory in the nuclear arena. It is yet to be established that this research study can benefit the process that is currently running in nuclear project management at Koeberg. It is shown that implementing a methodology based on TOP will reduce the risk of the *expected project time* and is a supporting tool for structuring nuclear projects. Implementing CCPM the traditional way is complex and challenging for larger projects. Minimal efforts were made on the research of optimisation methods for projects (Penga & Huangb, 2013). The proposed TOP methodology presented in chapter 6 (**Figure 83 – Proposed Theory of Optimisation for Projects**), integrates different heterogeneous scenarios data sources to reduce the risk of the *expected project time*. By integrating the 50% sizing rule with the CCPM of Tukel et al. (2006) in step 3 we will be able to eliminate resource contentions.

7.4.1. Theoretical Contribution

The goal of the research described in this thesis was to propose a TOP through simulation to the nuclear project management arena in South Africa. The latest method of developing theory (through simulation) was adapted by the researcher (refer to **Figure 28**). The development of the TOP is data oriented and is not requirements oriented. As a result of the proposed TOP, delays are less likely when managing highly uncertain tasks. The methodology will provide a unique, integrated and placid source of information. It may provide a complete view of heterogeneous critical task activities. Accurate information for project managers to make decisions. Ability to validate the time sensitivity of the task time on the expected project time using 50% sizing rule for time sensitivity dimension (**Figure 84 – Theory of Optimisation for Projects**).

7.5. Recommendations

The recommendations are related to the empirical findings and to the proposed TOP. Nuclear project management will gain benefits in their decision-making process if the methodology is implemented. To minimize several potential limitations, finalize the process of defining the cost of human capital. Based on the proposed TOP, the researcher suggest that access be created for users and for several users to be educated for adopting the model. The proposed model will, facilitate the decision-making process, by providing coherent data to the decision makers. Other recommendations include the definition of the supporting tool for structuring nuclear projects to be implemented and designing the data model integration process to include the 50% sizing rule.

7.6. Further Research

As a result of the research study, the researcher had learned that more work can be done with the proposed TOP model, both organisational and in the academic arena. Given the novelty of the topics addressed in this study, future research is required to updating the theory-building process through simulation methods (refer to **Figure 28**). In general, research efforts are needed in the field of nuclear project management, since human resources are scarcely considered in the literature.

Appendix A: Monte-Carlo Simulation Scenario 1

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	5	8	8	Compile and submit EIA application (by applicant)
2	0	2	0	19	7	7	Authority accept application
3	0	7	0	14	12	8	Publicise Scoping Report including Plan of Study
4	0	7	0	2	4	3	Start public participation (by applicant)
5	0	1	0	17	21	11	Submit Scoping Report
6	0	10	0	9	13	9	Authority accept Scoping Report
7	0	7	0	3	9	7	Publicise EIA. Report including EMP
8	0	6	0	15	16	11	Public participation (by applicant)
9	0	10	0	20	17	11	Submit EIA Report including EMP
10	1	26	1	18	15	10	Authority accept EIA Report including EMP
11	0	5	0	20	12	8	Opportunity to Appeal
12	0	2	0	9	5	2	Compile and submit letter of intent (by applicant)

13	0	0	0	2	1	15	Compile and submit permit application for site establishment (by applicant)
14	0	1	0	13	6	6	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	10	0	1	11	8	Compile and submit application for a site license (by applicant)
16	20	59	35	15	8	8	Receipt of final safety case by NNR
17	2	29	2	7	12	9	NNR formal safety review phase
18	1	33	1	5	5	4	Stakeholder participation
19	0	18	0	4	1	1	Issuing NNR final safety evaluation report
20	0	0	0	1	3	10	NNR Board review and decision (issue NISL)
21	0	1	0	5	3	1	Conditions of authorisation will include mandatory hold and or witness points
22	0	2	0	13	12	9	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	20	0	1	5	3	Compile and submit application for a site license (by applicant)

24	30	63	56	33	31	24	Receipt of final safety case by NNR
25	0	31	0	20	21	14	NNR formal safety review phase
26	0	29	0	10	14	9	Stakeholder participation
27	0	22	0	1	9	7	Issuing NNR final safety evaluation report
28	0	0	0	6	6	7	NNR Board review and decision (issue NIL)
29	0	1	0	10	11	3	Conditions of authorisation will include mandatory hold and/or witness points
30	2	28	2	7	7	4	Authorisation to Design
31	2	28	2	7	7	4	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	1	0	11	12	11	Conditions of authorisation will include mandatory hold and or witness points
35	0	1	0	3	0	4	Conditions of authorisation will include mandatory hold and/or witness points
36	0	2	0	2	6	5	Compile and submit letter of intent (by applicant)

37	23	60	43	33	31	25	Application for a decontamination and decommissioning license (applicant)
38	0	18	0	2	1	0	Receipt of final safety case by NNR
39	21	67	35	44	37	29	NNR formal safety review phase
40	0	21	0	6	3	2	Issuing NNR final safety evaluation report
41	0	0	0	9	10	6	NNR Board review and decision (issue NIL)
42	0	1	0	11	10	10	Conditions of authorisation will include mandatory hold and/or witness points

I. Criticality Significance and Schedule Sensitivity Indices

All *criticality index (%)* tasks presented are below 30%. The probability of any task(s) being on the critical path is very low. No action is required as it does not exceed the sensitivity threshold of 50%. The *significance index (%)* tasks 39 (67%), and 37 (60%) exceeds the 50% sensitivity threshold.

II. Pearson's product-moment (CRI-Pearson)

In scenarios 1, non-critical and critical tasks were ahead. CRI-Pearson reports a weak positive correlation when the simulated tasks are *finishing earlier than planned*. When non-critical and critical tasks are ahead, the correlation is between 0 ≤ CRI-Pearson ≤ 0.44. . It is shown through the CRI-Pearson that the sensitivity values of the absolute tasks are below the sensitivity threshold (50%) for the crucially index.

III. **<u>Spearman's rank correlation (CRI-Spearman)</u>**

The crucially index based on CRI-Spearman reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier than planned*. When non-critical and critical tasks are ahead, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50. It is shown that only tasks 32 and 33 are sensitive as it equals the threshold of 50% on the crucially index.

IV. **<u>Kendell's tau rank correlation (CRI-Kendell)</u>**

CRI-Kendell reports a weak to moderate positive correlation when the simulated tasks are *finishing earlier than planned* except for task 32 (100%) and 33 (100%). Majority of tasks are insensitive and have a low potential impact.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 1** reported that no action is required for *Finishing Nuclear Project B Earlier than Planned.*

Appendix B: Monte-Carlo Simulation Scenario 2

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	0	100	100	Compile and submit EIA application (by applicant)
2	0	4	0	0	100	100	Authority accept application
3	0	12	0	0	100	100	Publicise Scoping Report including Plan of Study
4	0	12	0	0	100	100	Start public participation (by applicant)
5	0	1	0	0	100	100	Submit Scoping Report
6	0	17	0	0	100	100	Authority accept Scoping Report
7	0	12	0	0	100	100	Publicise EIA. Report including EMP
8	0	12	0	0	100	100	Public participation (by applicant)
9	0	18	0	0	100	100	Submit EIA Report including EMP
10	0	41	0	0	100	100	Authority accept EIA Report including EMP
11	0	8	0	0	100	100	Opportunity to Appeal
12	0	3	0	0	100	100	Compile and submit letter of intent (by applicant)

13	0	0	0	0	100	100	Compile and submit permit application for site establishment (by applicant)
14	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	15	0	0	100	100	Compile and submit application for a site license (by applicant)
16	100	100	0	0	100	100	Receipt of final safety case by NNR
17	0	50	0	0	100	100	NNR formal safety review phase
18	0	50	0	0	100	100	Stakeholder participation
19	0	33	0	0	100	100	Issuing NNR final safety evaluation report
20	0	0	0	0	100	100	NNR Board review and decision (issue NISL)
21	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
22	0	3	0	0	100	100	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	33	0	0	100	100	Compile and submit application for a site license (by applicant)

24	100	100	0	0	100	100	Receipt of final safety case by NNR
25	0	50	0	0	100	100	NNR formal safety review phase
26	0	50	0	0	100	100	Stakeholder participation
27	0	33	0	0	100	100	Issuing NNR final safety evaluation report
28	0	0	0	0	100	100	NNR Board review and decision (issue NIL)
29	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
30	0	46	0	0	100	100	Authorisation to Design
31	0	46	0	0	100	100	Authorisation to Design
32	0	0	0	0	100	100	Optional Authorisation to Manufacture
33	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
35	0	1	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
36	0	3	0	0	100	100	Compile and submit letter of intent (by applicant)

37	100	100	0	0	100	100	Application for a decontamination and decommissioning license (applicant)
38	0	33	0	0	100	100	Receipt of final safety case by NNR
39	100	100	0	0	100	100	NNR formal safety review phase
40	0	33	0	0	100	100	Issuing NNR final safety evaluation report
41	0	0	0	0	100	100	NNR Board review and decision (issue NIL)
42	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points

I. **Criticality Significance and Schedule Sensitivity Indices**

For the *criticality index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) probability of being on the critical path is very high at 100% for the project to finish earlier than scheduled. The *significance index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) exceeds the degree of sensitivity threshold (50%). These three tasks measure high and are extremely important tasks for project success. All *schedule sensitivity index (%)* task values are zero.

II. **Pearson's product-moment (CRI-Pearson)**

Other than the probability of tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) being relatively important, CRI-Pearson reports no correlation when the simulated tasks are *finishing earlier than planned*. All 42 tasks are insensitive and will not require any special attention from the PM as Nuclear Project B is progressing.

III. **Spearman's rank correlation (CRI-Spearman)**

Other than the probability of tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) being on the critical path, CRI-Spearman reports a near perfect positive correlation**.** It is shown that 98% of tasks are highly sensitive and should not deviate from their baseline values.

IV. **Kendell's tau rank correlation (CRI-Kendell)**

Other than the probability of tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) being on the critical path, CRI-Kendell reports a perfect positive correlation. It is shown that 100% of tasks are highly sensitive and must be under constant surveillance.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 2** reported a 100% probability that the NNR formal safety review phase, application for a decontamination and decommissioning license, and receipt of final safety case by NNR are important tasks on the critical path for reducing the risk of the *expected project time for Finishing Nuclear Project B Earlier than Planned:*

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;
- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time; and
- **Task 16 –** Receipt of final safety case by NNR for the applicant site license must be completed on time for the project to finish earlier than scheduled.

Appendix C: Monte-Carlo Simulation Scenario 3

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	60	57	36	Compile and submit EIA application (by applicant)
2	0	47	0	64	64	41	Authority accept application
3	20	65	13	78	87	63	Publicise Scoping Report including Plan of Study
4	0	56	0	67	68	46	Start public participation (by applicant)
5	0	52	0	59	61	41	Submit Scoping Report
6	0	53	0	65	67	46	Authority accept Scoping Report
7	0	45	0	61	58	37	Publicise EIA. Report including EMP
8	0	45	0	53	51	32	Public participation (by applicant)
9	0	47	0	66	59	38	Submit EIA Report including EMP
10	0	49	0	63	68	45	Authority accept EIA Report including EMP
11	20	63	13	70	78	57	Opportunity to Appeal
12	0	57	0	66	68	48	Compile and submit letter of intent (by applicant)

13	0	55	0	68	72	49	Compile and submit permit application for site establishment (by applicant)
14	0	52	0	69	69	48	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	47	0	51	50	33	Compile and submit application for a site license (by applicant)
16	0	49	0	64	60	40	Receipt of final safety case by NNR
17	0	55	0	69	75	49	NNR formal safety review phase
18	0	0	0	0	50	100	Stakeholder participation
19	0	0	0	0	50	100	Issuing NNR final safety evaluation report
20	0	51	0	62	58	38	NNR Board review and decision (issue NISL)
21	0	43	0	56	58	37	Conditions of authorisation will include mandatory hold and or witness points
22	0	48	0	70	69	45	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	20	65	14	71	81	59	Compile and submit application for a site license (by applicant)

24	0	48	0	61	60	37	Receipt of final safety case by NNR
25	20	65	14	71	81	58	NNR formal safety review phase
26	0	49	0	59	55	37	Stakeholder participation
27	0	45	0	65	63	41	Issuing NNR final safety evaluation report
28	0	49	0	67	63	43	NNR Board review and decision (issue NIL)
29	0	2	0	64	60	40	Conditions of authorisation will include mandatory hold and/or witness points
30	0	46	0	69	75	49	Authorisation to Design
31	0	46	0	0	50	100	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	58	38	Conditions of authorisation will include mandatory hold and/or witness points
34	0	51	0	62	58	37	Conditions of authorisation will include mandatory hold and or witness points
35	0	43	0	56	69	45	Conditions of authorisation will include mandatory hold and/or witness points
36	0	48	0	70	81	59	Compile and submit letter of intent (by applicant)

37	20	65	14	71	60	37	Application for a decontamination and decommissioning license (applicant)
38	0	48	0	61	81	58	Receipt of final safety case by NNR
39	20	65	14	71	55	37	NNR formal safety review phase
40	0	49	0	59	63	41	Issuing NNR final safety evaluation report
41	0	45	0	65	63	43	NNR Board review and decision (issue NIL)
42	0	49	0	67	63	43	Conditions of authorisation will include mandatory hold and/or witness points

I. Criticality Significance and Schedule Sensitivity Indices

The criticality index (%) tasks presented are all below 20%. The probability of any task(s) being on the critical path is very low. For the significance index (%), tasks 39 (65%), 37 (65%), 34 (51%), 25 (65%), 23 (65%), 20 (51%), 17 (55%), 14 (52%), 13 (55%), 11 (63%), 12 (57%), 11 (63%), 6 (53%), 4 (56%), 5 (52%), 4 (56%) and 3 (65%) exceeds the 50% sensitivity threshold. They measure high and are considered relatively important tasks for project success. Most tasks are low in the schedule sensitivity index (%).

II. Pearson's product-moment (CRI-Pearson)

In scenario 3, CRI-Pearson reports a moderate to perfect positive correlation when simulated tasks are earlier than planned. Majority of tasks are sensitive and have a high potential impact on Nuclear Project B. However, further analysis is required.

III. Spearman's rank correlation (CRI-Spearman)

Other than the low probability of tasks being on the critical path, CRI-Spearman reports a moderate to perfect positive correlation. It is shown that majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

IV. <u>Kendell's tau rank correlation (CRI-Kendell)</u>

Other than the low probability of tasks being on the critical path, CRI-Kendell reports a moderate to perfect positive correlation. It is shown that majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 3** reported that no action is required for *Finishing Nuclear Project B Earlier than Planned.*

Appendix D: Monte-Carlo Simulation Scenario 4

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	16	14	22	Compile and submit EIA application (by applicant)
2	0	2	0	16	17	13	Authority accept application
3	0	7	0	1	3	2	Publicise Scoping Report including Plan of Study
4	0	7	0	12	13	9	Start public participation (by applicant)
5	0	1	0	10	8	9	Submit Scoping Report
6	0	10	0	2	4	2	Authority accept Scoping Report
7	0	7	0	3	3	2	Publicise EIA. Report including EMP
8	0	7	0	6	7	4	Public participation (by applicant)
9	0	11	0	19	18	11	Submit EIA Report including EMP
10	0	27	0	6	6	3	Authority accept EIA Report including EMP
11	0	5	0	17	2	1	Opportunity to Appeal
12	0	2	0	1	18	1	Compile and submit letter of intent (by applicant)

13	0	2	0	1	6	1	Compile and submit permit application for site establishment (by applicant)
14	0	2	0	1	4	1	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	10	0	6	4	2	Compile and submit application for a site license (by applicant)
16	32	67	60	38	36	29	Receipt of final safety case by NNR
17	1	33	1	18	18	12	NNR formal safety review phase
18	0	31	0	9	14	9	Stakeholder participation
19	0	21	0	1	2	1	Issuing NNR final safety evaluation report
20	0	0	0	8	9	7	NNR Board review and decision (issue NISL)
21	0	1	0	26	23	14	Conditions of authorisation will include mandatory hold and or witness points
22	0	2	0	3	3	3	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	21	0	4	2	1	Compile and submit application for a site license (by applicant)

24	17	61	30	21	17	13	Receipt of final safety case by NNR
25	0	33	0	11	11	7	NNR formal safety review phase
26	2	32	2	4	4	13	Stakeholder participation
27	0	20	0	3	8	4	Issuing NNR final safety evaluation report
28	0	2	0	8	8	5	NNR Board review and decision (issue NIL)
29	0	0	0	7	5	15	Conditions of authorisation will include mandatory hold and/or witness points
30	0	1	0	3	3	10	Authorisation to Design
31	0	31	0	12	11	8	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	1	0	11	8	8	Conditions of authorisation will include mandatory hold and or witness points
35	0	2	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
36	0	2	0	5	4	50	Compile and submit letter of intent (by applicant)

37	26	63	54	42	43	32	Application for a decontamination and decommissioning license (applicant)
38	0	20	0	7	8	6	Receipt of final safety case by NNR
39	22	66	40	34	34	6	NNR formal safety review phase
40	0	20	0	9	8	7	Issuing NNR final safety evaluation report
41	0	0	0	7	6	16	NNR Board review and decision (issue NIL)
42	0	1	0	1	2	1	Conditions of authorisation will include mandatory hold and/or witness points

I. **Criticality Significance and Schedule Sensitivity Indices**

The *criticality index (%)* tasks presented are all below 32%. The probability of any task(s) being on the critical path is very low. As a result, no action is required as it does not exceed the sensitivity threshold of 50%. For the *significance index (%),* tasks 39 (66%), and 37 (63%), 24 (61%) and 16 (67%) exceeds the 50% sensitivity threshold. They measure high and are considered relatively important tasks for project success. Tasks 37 (54%) and 16 (60%) are merely presented on the *schedule sensitivity index (%)* as a relatively important task taking the CI into account.

II. **Pearson's product-moment (CRI-Pearson)**

In scenario 4, CRI-Pearson reports a weak to moderate positive correlation when simulated tasks are exactly on time. All tasks are insensitive and do not require any special attention.

III. **Spearman's rank correlation (CRI-Spearman)**

The crucially index based on CRI-Spearman reports a weak to moderate positive correlation when simulated tasks are exactly on time. Majority of tasks are insensitive and have a low potential impact on Nuclear Project B.

IV. <u>Kendell's tau rank correlation (CRI-Kendell)</u>

CRI-Kendell reports a weak to moderate positive correlation when simulated tasks are exactly on time. Majority of tasks are insensitive and have a low potential impact on except for tasks 32 (100%), 33 (100%) and 35 (100%).

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 4** reported that no action is required for *Finishing Nuclear Project B Exactly on Time.*

Appendix E: Monte-Carlo Simulation Scenario 5

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	0	100	100	Compile and submit EIA application (by applicant)
2	0	4	0	0	100	100	Authority accept application
3	0	12	0	0	100	100	Publicise Scoping Report including Plan of Study
4	0	1	0	0	100	100	Start public participation (by applicant)
5	0	1	0	0	100	100	Submit Scoping Report
6	0	17	0	0	100	100	Authority accept Scoping Report
7	0	12	0	0	100	100	Publicise EIA. Report including EMP
8	0	12	0	0	100	100	Public participation (by applicant)
9	0	18	0	0	100	100	Submit EIA Report including EMP
10	0	41	0	0	100	100	Authority accept EIA Report including EMP
11	0	8	0	0	100	100	Opportunity to Appeal
12	0	3	0	0	100	100	Compile and submit letter of intent (by applicant)

13	0	0	0	0	100	100	Compile and submit permit application for site establishment (by applicant)
14	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	2	0	0	100	100	Compile and submit application for a site license (by applicant)
16	0	15	0	0	100	100	Receipt of final safety case by NNR
17	100	100	0	0	100	100	NNR formal safety review phase
18	0	50	0	0	100	100	Stakeholder participation
19	0	50	0	0	100	100	Issuing NNR final safety evaluation report
20	0	33	0	0	100	100	NNR Board review and decision (issue NISL)
21	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
22	0	2	0	0	100	100	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	3	0	0	100	100	Compile and submit application for a site license (by applicant)

24	0	33	0	0	100	100	Receipt of final safety case by NNR
25	100	100	0	0	100	100	NNR formal safety review phase
26	0	50	0	0	100	100	Stakeholder participation
27	0	50	0	0	100	100	Issuing NNR final safety evaluation report
28	0	33	0	0	100	100	NNR Board review and decision (issue NIL)
29	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
30	0	2	0	0	100	100	Authorisation to Design
31	0	46	0	0	100	100	Authorisation to Design
32	0	0	0	0	100	100	Optional Authorisation to Manufacture
33	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
35	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
36	0	3	0	0	100	100	Compile and submit letter of intent (by applicant)

37	100	100	0	0	100	100	Application for a decontamination and decommissioning license (applicant)
38	0	33	0	0	100	100	Receipt of final safety case by NNR
39	100	100	0	0	100	100	NNR formal safety review phase
40	0	33	0	0	100	100	Issuing NNR final safety evaluation report
41	0	0	0	0	100	100	NNR Board review and decision (issue NIL)
42	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points

I. Criticality Significance and Schedule Sensitivity Indices

For the *criticality index (%)*, tasks 39 (100%), 37 (100%), 25 (100%) and 17 (100%) probability of being on the critical path is very high at 100% for the project to be completed on time. For the *significance index (%)*, tasks 39 (100%), 37 (100%), 25 (100%) and 17 (100%) exceeds the degree of sensitivity threshold (50%). These four tasks measure high and are extremely important tasks for project success. All *schedule sensitivity index (%)* task values for discernibility are zero.

II. Pearson's product-moment (CRI-Pearson)

In scenario 5, CRI-Pearson reports no correlation for 100% on time performance. All tasks are insensitive and do not require any special attention. However, further analysis is required for on time performance to be able to improvement the accuracy of the task sensitivity and to reduce potential impact on expected project time.

III. Spearman’s rank correlation (CRI-Spearman) and Kendell's tau rank correlation (CRI-Kendell)

Other than the probability of tasks 39 (100%), 37 (100%) and 25 (100%) being on the critical path, CRI-Spearman and CRI-

Kendell reports a perfect positive correlation. It is shown that 100% of tasks are highly sensitive and have a high potential impact on Nuclear Project B. Despite the tedious results observed, it was shown that the more effort dedicated to experimental simulations, the more the likelihood of reducing the risk of the *expected project time* in the case of 100% on time performance.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 5** reported a 100% that the NNR formal safety review phase, application for a decontamination and decommissioning license, NNR formal safety review phase (combined license), and NNR formal safety review phase (site license) are important tasks on the critical path for reducing the risk of the *expected project time* for *Finishing Nuclear Project B Exactly on Time:*

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;
- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time;
- **Task 25** – NNR formal safety review phase post combined license must be completed for the project finishes exactly on time; and
- **Task 17** – NNR formal safety review phase post application for a site license must be completed for the project finishes exactly on time.

Appendix F: Monte-Carlo Simulation Scenario 6

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	88	98	94	99	100	97	Compile and submit EIA application (by applicant)
2	0	44	0	65	65	46	Authority accept application
3	0	49	0	64	66	47	Publicise Scoping Report including Plan of Study
4	0	52	0	43	71	50	Start public participation (by applicant)
5	0	44	0	58	43	30	Submit Scoping Report
6	0	53	0	72	57	42	Authority accept Scoping Report
7	0	56	0	53	71	50	Publicise EIA. Report including EMP
8	0	46	0	56	50	37	Public participation (by applicant)
9	0	47	0	55	48	35	Submit EIA Report including EMP
10	0	48	0	58	57	39	Authority accept EIA Report including EMP
11	0	47	0	55	52	36	Opportunity to Appeal
12	0	49	0	55	57	40	Compile and submit letter of intent (by applicant)

13	0	49	0	58	55	39	Compile and submit permit application for site establishment (by applicant)
14	0	50	0	57	62	45	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	50	0	61	62	45	Compile and submit application for a site license (by applicant)
16	0	55	0	66	67	46	Receipt of final safety case by NNR
17	12	61	8	66	73	54	NNR formal safety review phase
18	0	54	0	61	62	45	Stakeholder participation
19	0	57	0	68	65	48	Issuing NNR final safety evaluation report
20	0	52	0	65	68	43	NNR Board review and decision (issue NISL)
21	0	47	0	59	61	42	Conditions of authorisation will include mandatory hold and or witness points
22	0	45	0	55	58	39	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	50	0	56	55	39	Compile and submit application for a site license (by applicant)

24	0	57	0	56	57	40	Receipt of final safety case by NNR
25	12	63	8	77	81	63	NNR formal safety review phase
26	0	52	0	56	57	42	Stakeholder participation
27	0	55	0	69	71	51	Issuing NNR final safety evaluation report
28	0	53	0	70	72	51	NNR Board review and decision (issue NIL)
29	0	51	0	66	66	47	Conditions of authorisation will include mandatory hold and/or witness points
30	0	51	0	59	59	42	Authorisation to Design
31	0	53	0	62	64	45	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	51	0	59	52	38	Conditions of authorisation will include mandatory hold and or witness points
35	0	44	0	58	56	40	Conditions of authorisation will include mandatory hold and/or witness points
36	0	50	0	60	59	42	Compile and submit letter of intent (by applicant)

37	12	58	8	70	79	61	Application for a decontamination and decommissioning license (applicant)
38	0	48	0	46	44	30	Receipt of final safety case by NNR
39	12	60	8	68	74	56	NNR formal safety review phase
40	0	47	0	55	54	37	Issuing NNR final safety evaluation report
41	0	49	0	59	56	40	NNR Board review and decision (issue NIL)
42	0	44	0	55	52	36	Conditions of authorisation will include mandatory hold and/or witness points

I. Criticality Significance and Schedule Sensitivity Indices

The criticality index (%) task 1 (88%) presented exceeds the 50% threshold. The probability of this task being on the critical path is very high. For the significance index (%), tasks 39 (60%), 37 (58%), 36 (50%), 34 (51), 31 (53), 30 (51%), 29 (51%), 28 (53%), 27, (55%), 26 (52%), 25 (63%), 24 (57%), 23 (50%), 20 (52%), 19 (57%), 18 (54%), 17 (61%), 16 (55%), 15 (50%), 14 (50%), 7 (56%), 6(53%), 4 (52%) and 1 (98%) exceeds the 50% sensitivity threshold. They measure high and are considered relatively important tasks for project success. Task 1 (94%) is merely presented on the schedule sensitivity index (%) as a relatively important task taking the CI into account. The schedule sensitivity index combines both the task time and project time standard deviations with the CI.

II. Pearson's product-moment (CRI-Pearson)

CRI-Pearson reports a moderate to perfect correlation when simulated tasks are exactly on time. Majority of tasks are sensitive and will require any special attention as Nuclear Project B is progressing.

III. **Spearman’s rank correlation (CRI-Spearman)**

The crucially index based on CRI-Spearman report a moderate to perfect positive correlation. Majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

IV. **Kendell's tau rank correlation (CRI-Kendell)**

Other than the probability of task 1 (88%) being on the critical path is high, CRI-Kendell reports a moderate to perfect positive correlation and will require special attention.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 6** reported 88% probability that the compilation and submission of the Environmental Impact Assessment (EIA) application is an important task on the critical path for reducing the risk of the *expected project time* for *Finishing Nuclear Project B Exactly on Time:*

- **Task 01** – Compilation and submission of the EIA application must be finish exactly on time not to delay the authority acceptance of the EIA application.

Appendix G: Monte-Carlo Simulation Scenario 7

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	0	50	100	Compile and submit EIA application (by applicant)
2	0	0	0	9	50	97	Authority accept application
3	0	0	0	1	41	91	Publicise Scoping Report including Plan of Study
4	0	0	0	4	35	82	Start public participation (by applicant)
5	0	0	0	0	50	100	Submit Scoping Report
6	0	1	0	11	41	78	Authority accept Scoping Report
7	0	0	0	14	39	93	Publicise EIA. Report including EMP
8	0	1	0	3	32	76	Public participation (by applicant)
9	0	1	0	1	31	65	Submit EIA Report including EMP
10	0	10	0	12	7	23	Authority accept EIA Report including EMP
11	0	0	0	2	37	83	Opportunity to Appeal
12	0	0	0	3	39	90	Compile and submit letter of intent (by applicant)

13	0	0	0	0	50	100	Compile and submit permit application for site establishment (by applicant)
14	0	0	0	8	50	97	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	1	0	2	25	64	Compile and submit application for a site license (by applicant)
16	97	97	0	35	92	92	Receipt of final safety case by NNR
17	0	16	0	17	19	16	NNR formal safety review phase
18	0	17	0	14	16	14	Stakeholder participation
19	0	3	0	24	6	66	Issuing NNR final safety evaluation report
20	0	0	0	0	50	100	NNR Board review and decision (issue NISL)
21	0	0	0	11	51	97	Conditions of authorisation will include mandatory hold and or witness points
22	0	0	0	1	49	95	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	6	0	13	1	46	Compile and submit application for a site license (by applicant)

24	3	79	0	48	61	47	Receipt of final safety case by NNR
25	0	13	0	32	29	35	NNR formal safety review phase
26	0	15	0	25	28	26	Stakeholder participation
27	0	5	0	7	16	34	Issuing NNR final safety evaluation report
28	0	0	0	6	47	99	NNR Board review and decision (issue NIL)
29	0	0	0	7	46	94	Conditions of authorisation will include mandatory hold and/or witness points
30	0	16	0	1	1	10	Authorisation to Design
31	0	0	0	0	50	100	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	0	0	4	48	98	Conditions of authorisation will include mandatory hold and or witness points
35	0	0	0	1	45	95	Conditions of authorisation will include mandatory hold and/or witness points
36	0	0	0	17	43	96	Compile and submit letter of intent (by applicant)

37	0	78	0	71	72	54	Application for a decontamination and decommissioning license (applicant)
38	0	7	0	28	14	53	Receipt of final safety case by NNR
39	0	79	0	59	59	44	NNR formal safety review phase
40	0	6	0	23	11	36	Issuing NNR final safety evaluation report
41	0	0	0	0	50	100	NNR Board review and decision (issue NIL)
42	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points

I. <u>Criticality Significance and Schedule Sensitivity Indices</u>

The *criticality index (%)* task 16 (97%) presented exceeds the 50% threshold. The probability of this task being on the critical path is very high. For the *significance index (%),* tasks 39 (79%), 37 (78%), 24 (79%) and 16 (97%) exceeds the 50% sensitivity threshold. They measure high and are considered relatively important tasks for project success. All schedule *sensitivity index (%)* task values on the bar chart for discernibility are zero.

II. <u>Pearson's product-moment (CRI-Pearson)</u>

In scenario 7, CRI-Pearson reports a weak to moderate positive correlation when the simulated tasks are later than planned. However, further analysis is required.

III. <u>Spearman’s rank correlation (CRI-Spearman) and Kendell's tau rank correlation (CRI-Kendell)</u>

Other than the probability of task 16 (97%) being on the critical path, CRI-Spearman and CRI-Kendell reports a moderate to perfect positive correlation. It is shown that most of tasks are sensitive and have a high potential impact on Nuclear Project B.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 7** reported 97% probability that the receipt of final safety case by NNR is an important task on the critical path for reducing the risk of the *expected project time for Finishing Nuclear Project B Later than Planned*:

- **Task 16** – Receipt of final safety case by NNR must be finished exactly on time not to delay the NNR formal safety review phase.

Appendix H: Monte-Carlo Simulation Scenario 8

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	0	100	100	Compile and submit EIA application (by applicant)
2	0	4	0	0	100	100	Authority accept application
3	0	12	0	0	100	100	Publicise Scoping Report including Plan of Study
4	0	12	0	0	100	100	Start public participation (by applicant)
5	0	1	0	0	100	100	Submit Scoping Report
6	0	17	0	0	100	100	Authority accept Scoping Report
7	0	12	0	0	100	100	Publicise EIA. Report including EMP
8	0	12	0	0	100	100	Public participation (by applicant)
9	0	18	0	0	100	100	Submit EIA Report including EMP
10	0	41	0	0	100	100	Authority accept EIA Report including EMP
11	0	8	0	0	100	100	Opportunity to Appeal
12	0	3	0	0	100	100	Compile and submit letter of intent (by applicant)

13	0	0	0	0	100	100	Compile and submit permit application for site establishment (by applicant)
14	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	0	0	0	100	100	Compile and submit application for a site license (by applicant)
16	100	100	0	0	100	100	Receipt of final safety case by NNR
17	0	50	0	0	100	100	NNR formal safety review phase
18	0	50	0	0	100	100	Stakeholder participation
19	0	50	0	0	100	100	Issuing NNR final safety evaluation report
20	0	33	0	0	100	100	NNR Board review and decision (issue NISL)
21	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
22	0	3	0	0	100	100	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	33	0	0	100	100	Compile and submit application for a site license (by applicant)

24	100	100	0	0	100	100	Receipt of final safety case by NNR
25	0	50	0	0	100	100	NNR formal safety review phase
26	0	50	0	0	50	100	Stakeholder participation
27	0	33	0	0	100	100	Issuing NNR final safety evaluation report
28	100	0	0	0	100	100	NNR Board review and decision (issue NIL)
29	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
30	100	46	0	0	100	100	Authorisation to Design
31	0	0	0	0	100	100	Authorisation to Design
32	0	0	0	0	100	100	Optional Authorisation to Manufacture
33	0	0	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and or witness points
35	0	3	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points
36	0	3	0	0	50	100	Compile and submit letter of intent (by applicant)

37	100	100	0	0	100	100	Application for a decontamination and decommissioning license (applicant)
38	0	33	0	0	100	100	Receipt of final safety case by NNR
39	100	100	0	0	100	100	NNR formal safety review phase
40	0	33	0	0	100	100	Issuing NNR final safety evaluation report
41	0	0	0	0	100	100	NNR Board review and decision (issue NIL)
42	0	2	0	0	100	100	Conditions of authorisation will include mandatory hold and/or witness points

I. <u>Criticality Significance and Schedule Sensitivity Indices</u>

The *criticality index (%)*, tasks 39 (100%), 37 (100%), 30 (100%), 28 (100%), 24 (100%) and 16 (100%) probability of being on the critical path is very high at 100% for the project to finish later than scheduled. For the *significance index (%)*, tasks 39 (100%), 37 (100%), 24 (100%) and 16 (100%) exceeds the degree of sensitivity threshold (50%). These three tasks measure high and are extremely important tasks for project success. All schedule *sensitivity index (%)* task values on the bar chart for discernibility are zero.

II. <u>Pearson's product-moment (CRI-Pearson)</u>

CRI-Pearson reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks are delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50. All tasks are insensitive and will not require any special attention from the PM when Nuclear Project B is progressing.

III. **Spearman's rank correlation (CRI-Spearman)**

The crucially index based on CRI-Spearman reports a near perfect positive correlation except for tasks 26 (50%) and 36 (50%). Majority of tasks are sensitive and have a high potential impact on Nuclear Project B.

IV. **Kendell's tau rank correlation (CRI-Kendell)**

Other than the probability of tasks 39 (100%), 37 (100%), 30 (100%), 28 (100%), 24 (100%) and 16 (100%) being on the critical path. The crucially index based on CRI-Kendell reports a perfect positive correlation when the simulated tasks are *finishing later than planned*. All tasks are sensitive and have a high potential impact on Nuclear Project B.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 8** reported a 100% probability that the NNR formal safety review phase, application for a decontamination and decommissioning license, and receipt of final safety case by NNR are important tasks on the critical path for reducing the risk of the *expected project time for Finishing Nuclear Project B Later than Planned*:

- **Task 39** – NNR formal safety review phase must be completed on time not to delay the issuing of the NNR final safety evaluation report;
- **Task 37** – Application for the decontamination and decommissioning license by the applicant must be submitted on time;
- **Task 30** – Authorisation to design must be completed on time before authorisation manufacture;
- **Task 28** – NNR Board review and decision (issue NIL) must be completed on time;
- **Task 24 & 16** – Receipt of final safety case by NNR for the applicant site license must be completed on time for the project to later than scheduled.

Appendix I: Monte-Carlo Simulation Scenario 9

Task	Critically Index (%)	Significance Index (%)	Schedule Sensitivity Index (%)	Crucially Index (CRI-r) (%)	Crucially Index (CRI-rho) (%)	Crucially Index (CRI-tau) (%)	Task Description
1	0	0	0	3	8	8	Compile and submit EIA application (by applicant)
2	0	3	0	15	14	8	Authority accept application
3	0	10	0	9	7	5	Publicise Scoping Report including Plan of Study
4	0	9	0	3	0	1	Start public participation (by applicant)
5	0	1	0	3	1	4	Submit Scoping Report
6	0	1	0	9	1	1	Authority accept Scoping Report
7	0	14	0	5	8	1	Publicise EIA. Report including EMP
8	0	10	0	1	2	6	Public participation (by applicant)
9	0	9	0	5	0	0	Submit EIA Report including EMP
10	0	15	0	2	5	1	Authority accept EIA Report including EMP
11	0	34	0	6	5	4	Opportunity to Appeal
12	0	6	0	9	7	3	Compile and submit letter of intent (by applicant)

13	0	3	0	7	11	7	Compile and submit permit application for site establishment (by applicant)
14	0	1	0	2	7	20	Conditions of authorisation will include mandatory hold and/or witness points (applicant)
15	0	1	0	7	7	1	Compile and submit application for a site license (by applicant)
16	0	13	0	14	18	11	Receipt of final safety case by NNR
17	0	81	37	40	35	26	NNR formal safety review phase
18	0	41	0	1	7	5	Stakeholder participation
19	0	41	0	0	3	2	Issuing NNR final safety evaluation report
20	0	26	0	3	5	3	NNR Board review and decision (issue NISL)
21	0	0	0	3	5	9	Conditions of authorisation will include mandatory hold and or witness points
22	0	2	0	6	7	6	Compile and submit letter of intent (Combined License for Construction and Operation) (by applicant)
23	0	3	0	24	17	10	Compile and submit application for a site license (by applicant)

24	0	27	0	6	1	2	Receipt of final safety case by NNR
25	27	83	53	28	31	22	NNR formal safety review phase
26	0	41	0	5	5	3	Stakeholder participation
27	0	42	0	18	19	12	Issuing NNR final safety evaluation report
28	0	27	0	9	9	6	NNR Board review and decision (issue NIL)
29	0	0	0	7	6	9	Conditions of authorisation will include mandatory hold and/or witness points
30	0	2	0	29	26	14	Authorisation to Design
31	0	39	0	9	6	5	Authorisation to Design
32	0	0	0	0	50	100	Optional Authorisation to Manufacture
33	0	0	0	0	50	100	Conditions of authorisation will include mandatory hold and/or witness points
34	0	2	0	4	5	6	Conditions of authorisation will include mandatory hold and or witness points
35	0	2	0	17	17	14	Conditions of authorisation will include mandatory hold and/or witness points
36	0	3	0	9	11	8	Compile and submit letter of intent (by applicant)

37	28	85	0	46	48	35	Application for a decontamination and decommissioning license (applicant)
38	0	27	0	10	10	7	Receipt of final safety case by NNR
39	27	84	55	30	25	20	NNR formal safety review phase
40	0	26	0	1	3	2	Issuing NNR final safety evaluation report
41	0	0	0	11	10	21	NNR Board review and decision (issue NIL)
42	0	2	0	15	13	11	Conditions of authorisation will include mandatory hold and/or witness points

I. <u>Criticality Significance and Schedule Sensitivity Indices</u>

The *criticality index (%)* tasks presented are all below 30%. The probability of any task(s) being on the critical path is very low. As a result, no action is required as it does not exceed the sensitivity threshold of 50%. The *significance index (%)*, tasks 39 (84%), 37 (85%), 25 (83%) and 17 (81%) exceeds the degree of sensitivity threshold (50%). These three tasks measure high and are extremely important tasks for project success. Task 39 (55%) and 25 (53%) are merely presented on the *schedule sensitivity index (%)* and are relatively important task taking the CI into account.

II. <u>Pearson's product-moment (CRI-Pearson)</u>

CRI-Pearson reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks are delayed, the correlation is between $0 \leq$ CRI-Pearson ≤ 0.50. All tasks are insensitive and will not require any special attention from the PM when Nuclear Project B is progressing).

III. <u>Spearman's rank correlation (CRI-Spearman)</u>

CRI-Spearman reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks were delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.50**.** It is shown that 98% of tasks are insensitive.

IV. <u>Kendell's tau rank correlation (CRI-Kendell)</u>

CRI-Kendell reports a weak to moderate positive correlation when the simulated tasks are *finishing later than planned*. When non-critical and critical tasks were delayed, the correlation is between 0 ≤ CRI-Pearson ≤ 0.35 except for task 33 (100%) and 32 (100%)**.** It is shown that 95% of tasks are insensitive.

In summary, the results of the experiments were compared with the *task time* and *expected project time* by correlation. The validity of simulation results increases with a higher number of simulation runs. For Nuclear Project B, 100 simulation runs were performed by the researcher. **Scenario 9** reported that no action is required for *Finishing Nuclear Project B Later than Planned.*

Appendix J: Results of Correlations for Monte-Carlo Simulation Scenario 1 – 3

Scenario 1 Non-critical & critical tasks are ahead	Scenario 2 Non-critical tasks are on plan & critical tasks are ahead	Scenario 3 Non-critical are delayed & critical activities are ahead
• Pearson reports a weak positive correlation	• Pearson reports no correlation	• Pearson reports a moderate to perfect positive correlation
• Spearman reports a weak to moderate positive correlation	• Spearman reports a near perfect positive correlation	• Spearman reports a moderate to perfect positive correlation
• Kendell reports a weak to moderate positive correlation	• Kendell reports a perfect positive correlation	• Kendell reports a moderate to perfect positive correlation

Appendix K: Results of Correlations for Monte-Carlo Simulation Scenario 4 – 6

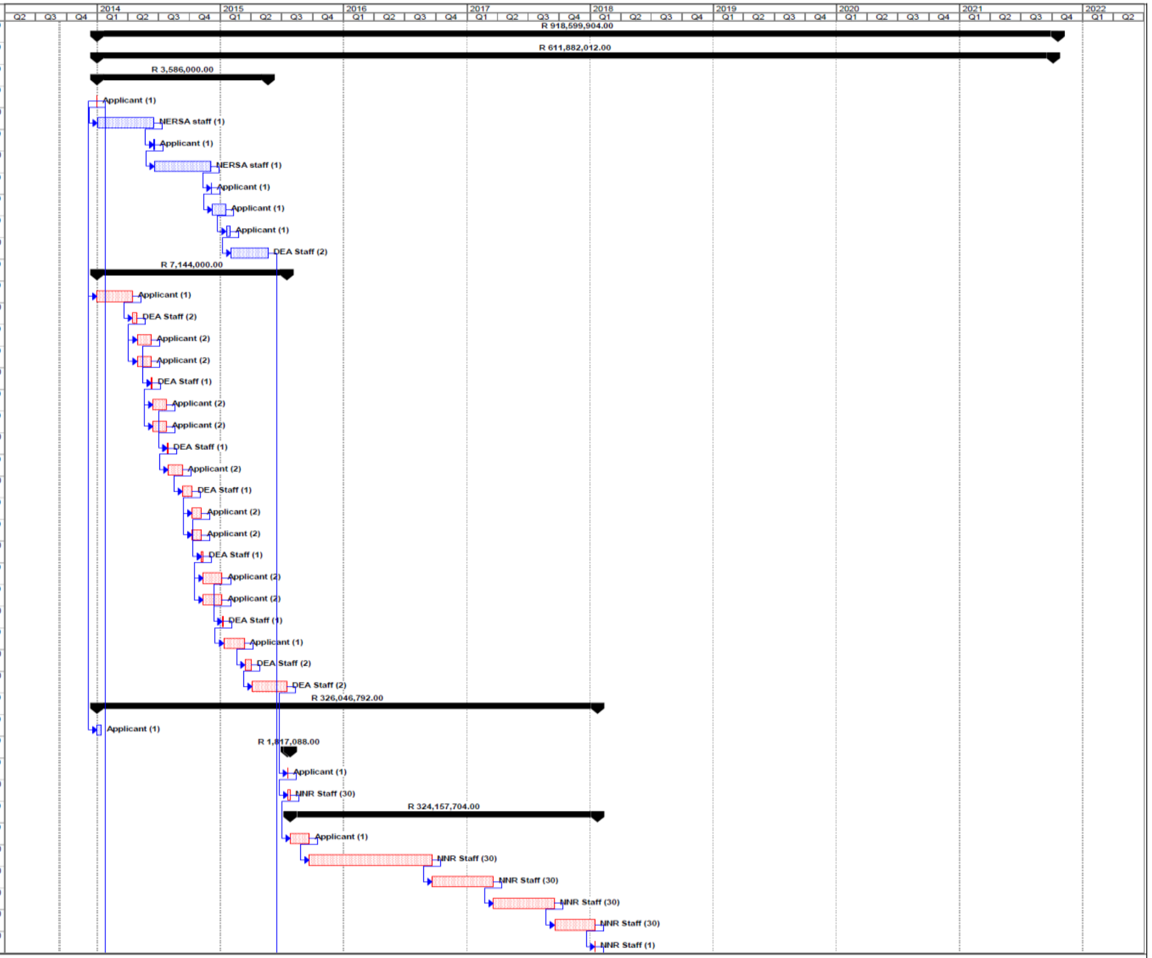
Scenario 4 Non-critical tasks are ahead & critical tasks are on plan	Scenario 5 100% on time performance	Scenario 6 Non-critical tasks are delayed & critical tasks are on plan
• Pearson reports a weak to moderate positive correlation	• Pearson reports no correlation	• Pearson reports a moderate to perfect positive correlation
• Spearman reports a weak to moderate positive correlation	• Spearman reports perfect positive correlation	• Spearman reports a moderate to perfect positive correlation
• Kendell reports a weak to moderate positive correlation	• Kendell reports a perfect positive correlation	• Kendell reports a moderate to perfect positive correlation

Appendix L: Results of Correlations for Monte-Carlo Simulation Scenario 7 – 9

Scenario 7 Non-critical activities are ahead & critical activities are delayed	Scenario 8 Non-critical & critical tasks are on plan	Scenario 9 Non-critical and critical tasks are delayed
• Pearson reports a weak to moderate positive correlation	• Pearson reports no correlation	• Pearson reports a weak to moderate positive correlation
• Spearman reports a weak to moderate positive correlation	• Spearman reports a near perfect positive correlation	• Spearman reports a weak to moderate positive correlation
• Kendell reports a moderate to perfect positive correlation	• Kendell reports a perfect positive correlation	• Kendell reports a weak to moderate positive correlation

Appendix M: Nuclear Project B - A licensing plan for coupling a nuclear energy source to a chemical process plant – SASOL Secunda as a case study

ID	Task Name	Duration	Start	Finish	Cost
1	A licencing plan for coupling a nuclear energy source to a chemical process plant - SASOL Secunda as a case study	2035 days	Wed 14/01/01	Tue 21/10/19	R 918,599,904.00
2	Pre-operational	2025 days	Wed 14/01/01	Tue 21/10/05	R 611,882,012.00
3	NERSA Licensing	363 days	Wed 14/01/01	Fri 15/05/22	R 3,586,000.00
4	Application for a Construction license by the applicant for Electricity Generation (by applicant)	1 day	Wed 14/01/01	Wed 14/01/01	R 8,000.00
5	NERSA formal review and decision	120 days	Thu 14/01/02	Wed 14/06/18	R 960,000.00
6	Application for an Operation license by the applicant for Electricity Generation (by applicant)	1 day	Thu 14/06/19	Thu 14/06/19	R 8,000.00
7	NERSA formal review and decision	120 days	Fri 14/06/20	Thu 14/12/04	R 960,000.00
8	Application for a Distribution license by the applicant for the Electricity (Co-generation) (by applicant)	1 day	Fri 14/12/05	Fri 14/12/05	R 8,000.00
9	Application advertisement by applicant and return to NERSA (by applicant)	30 days	Mon 14/12/08	Fri 15/01/16	R 282,000.00
10	Completion and return of the Inspection in the loco questionnaire (by applicant)	10 days	Mon 15/01/19	Fri 15/01/30	R 80,000.00
11	NERSA formal review and decision	80 days	Mon 15/02/02	Fri 15/05/22	R 1,280,000.00
12	EIA Process	403 days	Wed 14/01/01	Fri 15/07/17	R 7,144,000.00
13	Compile and submit EIA application (by applicant)	75 days	Wed 14/01/01	Tue 14/04/15	R 600,000.00
14	DEA reviews application; accepts or rejects	10 days	Wed 14/04/16	Tue 14/04/29	R 160,000.00
15	Compile and submit Draft SR, POS (by applicant)	30 days	Wed 14/04/30	Tue 14/06/10	R 480,000.00
16	Start public participation (by applicant)	30 days	Wed 14/04/30	Tue 14/06/10	R 480,000.00
17	DEA requests comments from State Departments	3 days	Wed 14/06/11	Fri 14/06/13	R 24,000.00
18	State Departments comment (by applicant)	30 days	Mon 14/06/16	Fri 14/07/25	R 480,000.00
19	Public participation (by applicant)	30 days	Mon 14/06/16	Fri 14/07/25	R 480,000.00
20	DEA sends comments to Applicant's EAP	3 days	Mon 14/07/28	Wed 14/07/30	R 24,000.00
21	Compile and submit Final SR and POS (by applicant)	30 days	Thu 14/07/31	Wed 14/09/10	R 480,000.00
22	DEA accepts or rejects Final SR and POS	21 days	Thu 14/09/11	Thu 14/10/09	R 168,000.00
23	Compile and submit Draft EIR, EMP (by applicant)	20 days	Fri 14/10/10	Thu 14/11/06	R 320,000.00
24	Start public participation (by applicant)	20 days	Fri 14/10/10	Thu 14/11/06	R 320,000.00
25	DEA requests comments from State Departments	3 days	Fri 14/11/07	Tue 14/11/11	R 24,000.00
26	State Departments comment (by applicant)	40 days	Wed 14/11/12	Tue 15/01/06	R 640,000.00
27	Public participation (by applicant)	40 days	Wed 14/11/12	Tue 15/01/06	R 640,000.00
28	DEA sends comments to Applicant's EAP	3 days	Wed 15/01/07	Fri 15/01/09	R 24,000.00
29	Compile and submit Final EIR and EMP (by applicant)	45 days	Mon 15/01/12	Fri 15/03/13	R 360,000.00
30	DEA considers completeness of reports	15 days	Mon 15/03/16	Fri 15/04/03	R 240,000.00
31	DEA issues decision (Environmental Authorisation)	75 days	Mon 15/04/06	Fri 15/07/17	R 1,200,000.00
32	Nuclear Installation Site License (NISL)	1060 days	Wed 14/01/01	Tue 18/01/23	R 326,046,792.00
33	Compile and submit letter of intent (by applicant)	9 days	Wed 14/01/01	Mon 14/01/13	R 72,000.00
34	MANDATORY Stage 1 (a) Site establishment	6 days	Mon 15/07/20	Mon 15/07/27	R 1,817,088.00
35	Compile and submit permit application for site establishment (by applicant)	1 day	Mon 15/07/20	Mon 15/07/20	R 8,000.00
36	Conditions of authorisation will include mandatory hold and/or witness points	5 days	Tue 15/07/21	Mon 15/07/27	R 1,809,088.00
37	MANDATORY Stage 1 (b) Early Site Activities	651 days	Tue 15/07/28	Tue 18/01/23	R 324,157,704.00
38	Compile and submit application for a site license (by applicant)	40 days	Tue 15/07/28	Mon 15/09/21	R 320,000.00
39	Receipt of final safety case by NNR	260 days	Tue 15/09/22	Mon 16/09/19	R 94,072,576.00
40	NNR formal safety review phase	130 days	Tue 16/09/20	Mon 17/03/20	R 47,036,288.00
41	Stakeholder participation	130 days	Tue 17/03/21	Mon 17/09/18	R 47,036,288.00
42	Issuing NNR final safety evaluation report	85 days	Tue 17/09/19	Mon 18/01/15	R 30,754,496.00
43	NNR Board review and decision (issue NISL)	1 day	Tue 18/01/16	Tue 18/01/16	R 103,128,968.00



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Date: Mon 13/09/09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline | Critical

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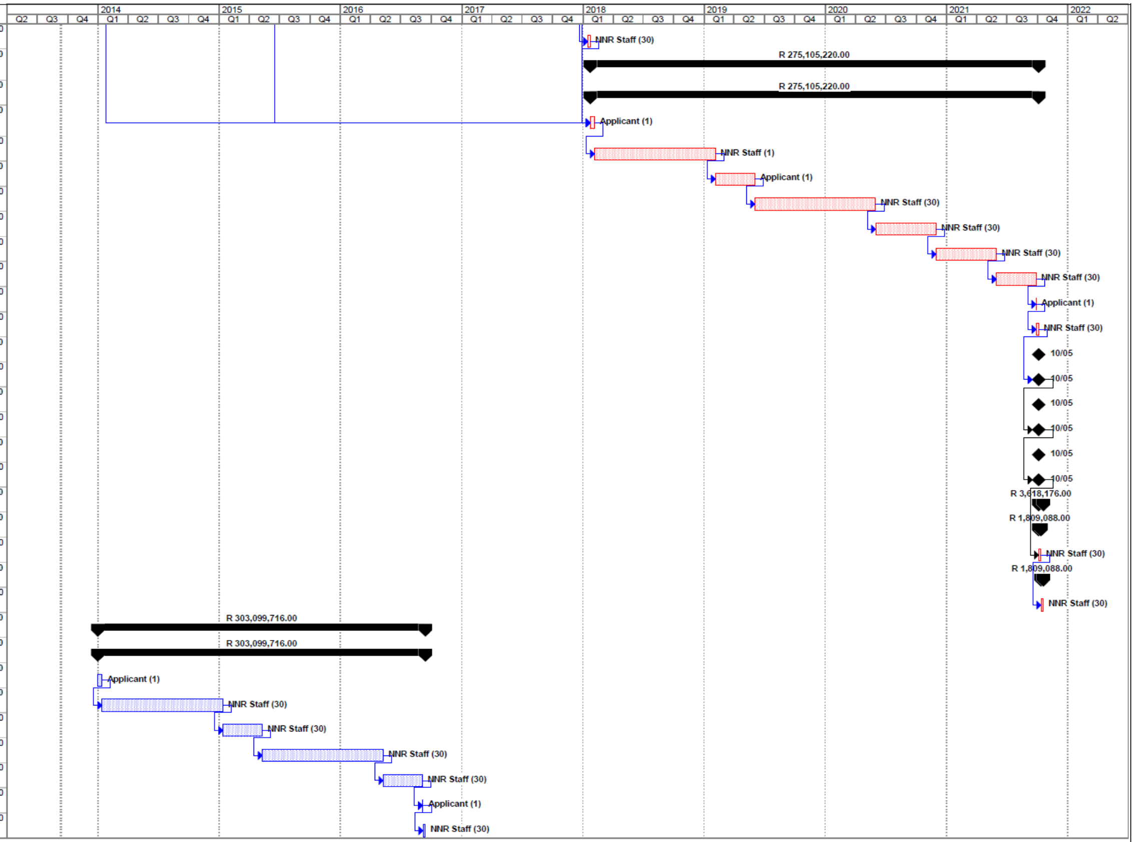
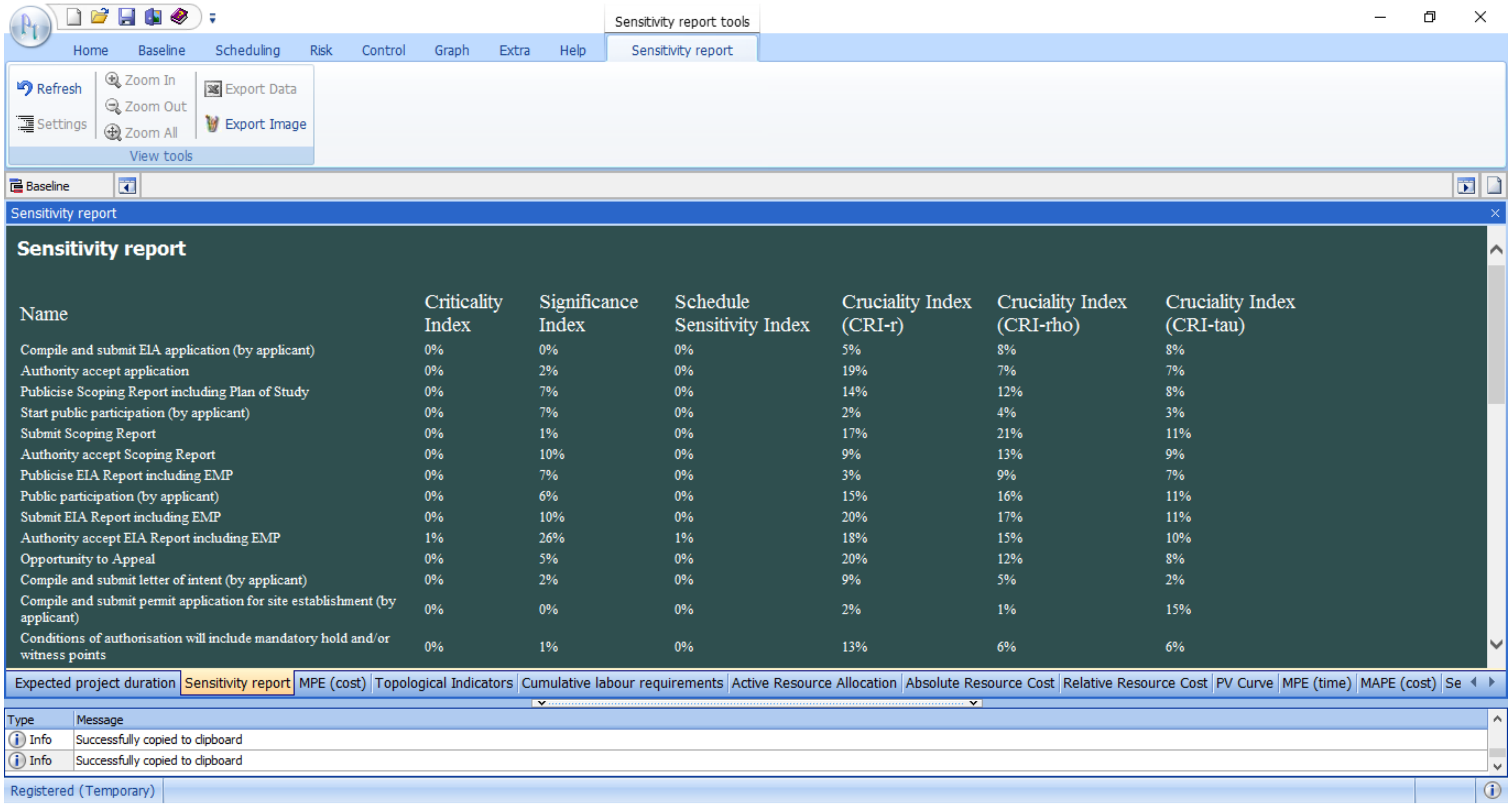
ID	Task Name	Duration	Start	Finish	Cost
44	Conditions of authorisation will include mandatory hold and/or witness points	5 days	Wed 18/01/17	Tue 18/01/23	R 1,809,088.00
45	**Nuclear Installation License (NIL via NISL) (Combined license for Construction and Operation)**	**965 days**	**Wed 18/01/24**	**Tue 21/10/05**	**R 275,105,220.00**
46	**MANDATORY Stage 1 (c) Early Construction Activities**	**965 days**	**Wed 18/01/24**	**Tue 21/10/05**	**R 275,105,220.00**
47	**Compile and submit letter of intent (Combined license for Construction and Operation) (by applicant)**	**9 days**	**Wed 18/01/24**	**Mon 18/02/05**	**R 72,000.00**
48	NNR secure local and international technical co-operation and support (Only once)	260 days	Tue 18/02/06	Mon 19/02/04	R 2,080,000.00
49	**Compile and submit application for a site license (by applicant)**	**85 days**	**Tue 19/02/05**	**Mon 19/06/03**	**R 680,000.00**
50	Receipt of final safety case by NNR	260 days	Tue 19/06/04	Mon 20/06/01	R 94,072,576.00
51	NNR formal safety review phase	130 days	Tue 20/06/02	Mon 20/11/30	R 47,036,288.00
52	Stakeholder participation	130 days	Tue 20/12/01	Mon 21/05/31	R 47,036,288.00
53	Issuing NNR final safety evaluation report	85 days	Tue 21/06/01	Mon 21/09/27	R 30,754,496.00
54	NNR Board review and decision (issue NIL)	1 day	Tue 21/09/28	Tue 21/09/28	R 51,564,484.00
55	Conditions of authorisation will include mandatory hold and/or witness points	5 days	Wed 21/09/29	Tue 21/10/05	R 1,809,088.00
56	**Optional Stage 2 (a) Authorisation to Design**	**0 days**	**Tue 21/10/05**	**Tue 21/10/05**	**R 0.00**
57	Optional for Authorisation to Design	0 days	Tue 21/10/05	Tue 21/10/05	R 0.00
58	**Optional and Mandatory Stage 2 (b) Authorisation to Manufacture**	**0 days**	**Tue 21/10/05**	**Tue 21/10/05**	**R 0.00**
59	Optional Authorisation to Manufacture	0 days	Tue 21/10/05	Tue 21/10/05	R 0.00
60	**Mandatory for long lead item manufacturing**	**0 days**	**Tue 21/10/05**	**Tue 21/10/05**	**R 0.00**
61	Conditions of authorisation will include mandatory hold and/or witness points	0 days	Tue 21/10/05	Tue 21/10/05	R 0.00
62	**Commissioning**	**10 days**	**Wed 21/10/06**	**Tue 21/10/19**	**R 3,618,176.00**
63	**MANDATORY Stage 3 NIL for the construction of the installation**	**5 days**	**Wed 21/10/06**	**Tue 21/10/12**	**R 1,809,088.00**
64	Conditions of authorisation will include mandatory hold and/or witness points	5 days	Wed 21/10/06	Tue 21/10/12	R 1,809,088.00
65	**MANDATORY Stage 4 NIL for the operation of the installation**	**5 days**	**Wed 21/10/13**	**Tue 21/10/19**	**R 1,809,088.00**
66	Conditions of authorisation will include mandatory hold and/or witness points	5 days	Wed 21/10/13	Tue 21/10/19	R 1,809,088.00
67	**Decommissioning (After Life-Time of Plant)**	**705 days**			**R 303,099,716.00**
68	**MANDATORY Stage 5 NIL for the decontamination and decommissioning of the installation**	**705 days**			**R 303,099,716.00**
69	**Compile and submit letter of intent (by applicant)**	**9 days**			**R 72,000.00**
70	**Application for a decontamination and decommissioning license (by applicant)**	**260 days**			**R 94,072,576.00**
71	Receipt of final safety case by NNR	85 days			R 30,754,496.00
72	NNR formal safety review phase	260 days			R 94,072,576.00
73	Issuing NNR final safety evaluation report	85 days			R 30,754,496.00
74	NNR Board review and decision (issue NIL)	1 day			R 51,564,484.00
75	Conditions of authorisation will include mandatory hold and/or witness points	5 days			R 1,809,088.00



Project: AUG 2013_A licencing plan fo
Date: Mon 13/09/09

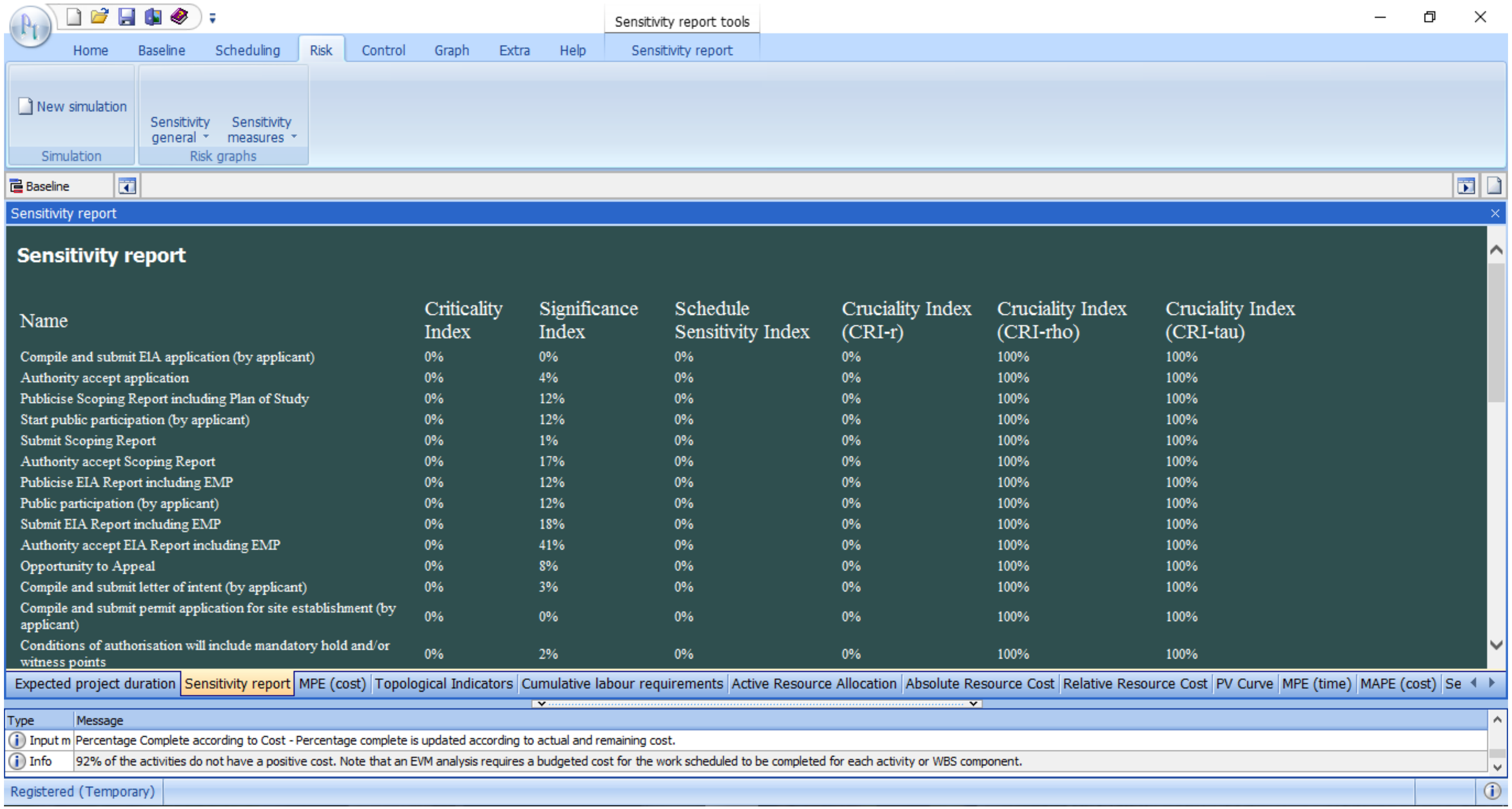
Task	Progress	Summary	External Tasks	Deadline	
Split	Milestone	Project Summary	External Milestone	Critical	

Appendix N: Scenario 1 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	5%	8%	8%
Authority accept application	0%	2%	0%	19%	7%	7%
Publicise Scoping Report including Plan of Study	0%	7%	0%	14%	12%	8%
Start public participation (by applicant)	0%	7%	0%	2%	4%	3%
Submit Scoping Report	0%	1%	0%	17%	21%	11%
Authority accept Scoping Report	0%	10%	0%	9%	13%	9%
Publicise EIA Report including EMP	0%	7%	0%	3%	9%	7%
Public participation (by applicant)	0%	6%	0%	15%	16%	11%
Submit EIA Report including EMP	0%	10%	0%	20%	17%	11%
Authority accept EIA Report including EMP	1%	26%	1%	18%	15%	10%
Opportunity to Appeal	0%	5%	0%	20%	12%	8%
Compile and submit letter of intent (by applicant)	0%	2%	0%	9%	5%	2%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	2%	1%	15%
Conditions of authorisation will include mandatory hold and/or witness points	0%	1%	0%	13%	6%	6%

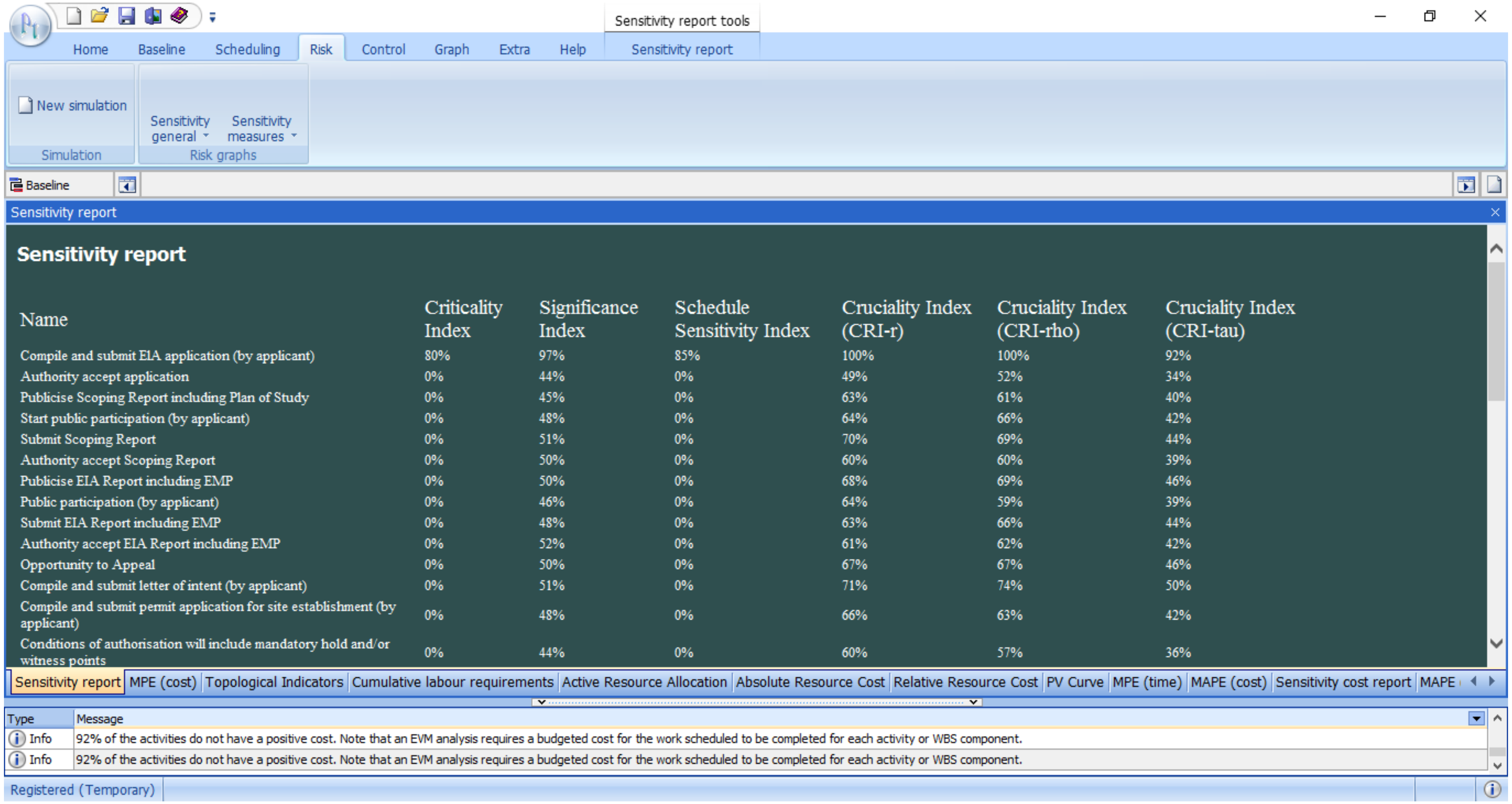
Appendix O: Scenario 2 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Sensitivity report

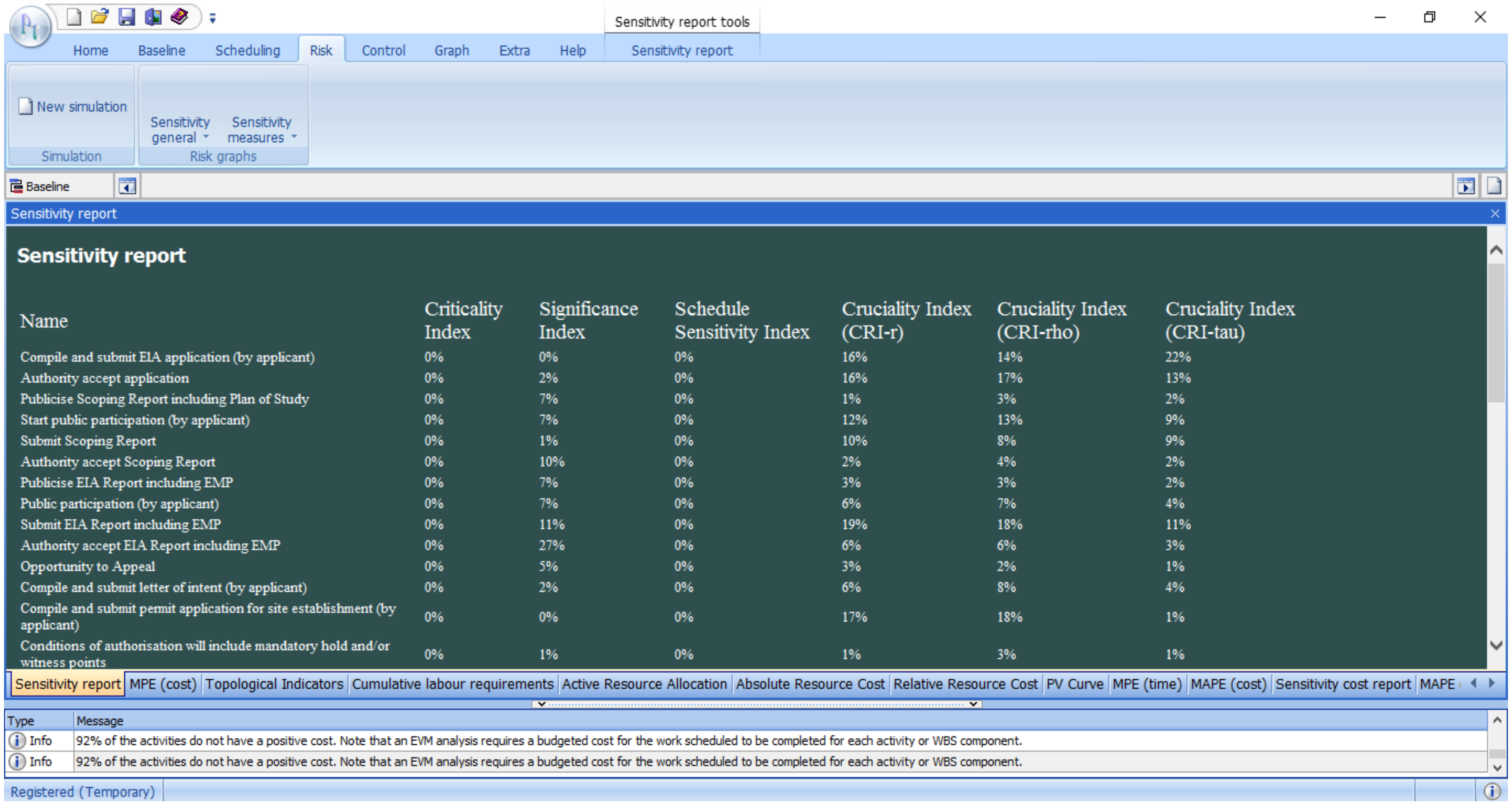
Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	0%	100%	100%
Authority accept application	0%	4%	0%	0%	100%	100%
Publicise Scoping Report including Plan of Study	0%	12%	0%	0%	100%	100%
Start public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit Scoping Report	0%	1%	0%	0%	100%	100%
Authority accept Scoping Report	0%	17%	0%	0%	100%	100%
Publicise EIA Report including EMP	0%	12%	0%	0%	100%	100%
Public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit EIA Report including EMP	0%	18%	0%	0%	100%	100%
Authority accept EIA Report including EMP	0%	41%	0%	0%	100%	100%
Opportunity to Appeal	0%	8%	0%	0%	100%	100%
Compile and submit letter of intent (by applicant)	0%	3%	0%	0%	100%	100%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	0%	100%	100%
Conditions of authorisation will include mandatory hold and/or witness points	0%	2%	0%	0%	100%	100%

Appendix P: Scenario 3 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	80%	97%	85%	100%	100%	92%
Authority accept application	0%	44%	0%	49%	52%	34%
Publicise Scoping Report including Plan of Study	0%	45%	0%	63%	61%	40%
Start public participation (by applicant)	0%	48%	0%	64%	66%	42%
Submit Scoping Report	0%	51%	0%	70%	69%	44%
Authority accept Scoping Report	0%	50%	0%	60%	60%	39%
Publicise EIA Report including EMP	0%	50%	0%	68%	69%	46%
Public participation (by applicant)	0%	46%	0%	64%	59%	39%
Submit EIA Report including EMP	0%	48%	0%	63%	66%	44%
Authority accept EIA Report including EMP	0%	52%	0%	61%	62%	42%
Opportunity to Appeal	0%	50%	0%	67%	67%	46%
Compile and submit letter of intent (by applicant)	0%	51%	0%	71%	74%	50%
Compile and submit permit application for site establishment (by applicant)	0%	48%	0%	66%	63%	42%
Conditions of authorisation will include mandatory hold and/or witness points	0%	44%	0%	60%	57%	36%

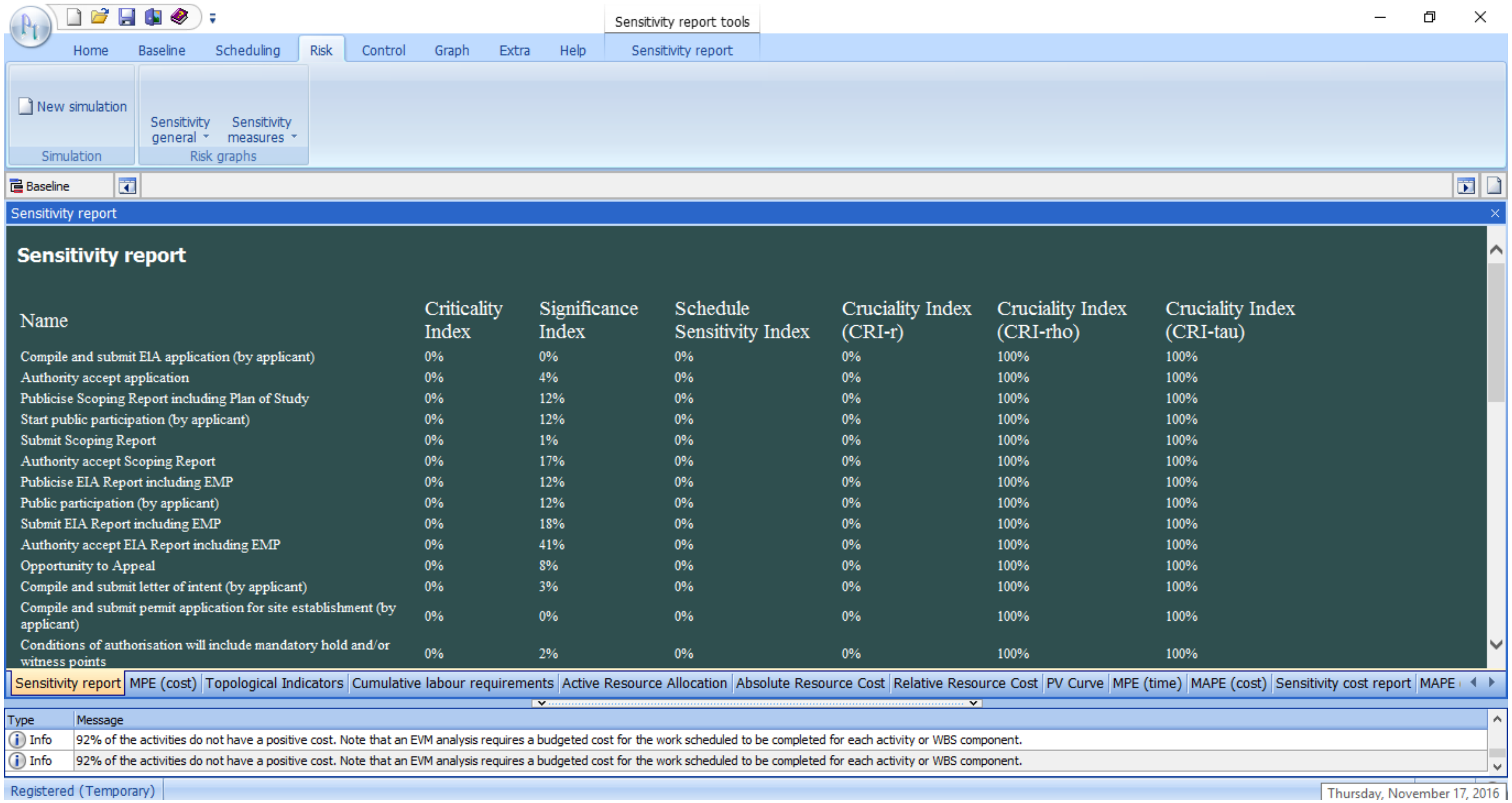
Appendix Q: Scenario 4 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Sensitivity report

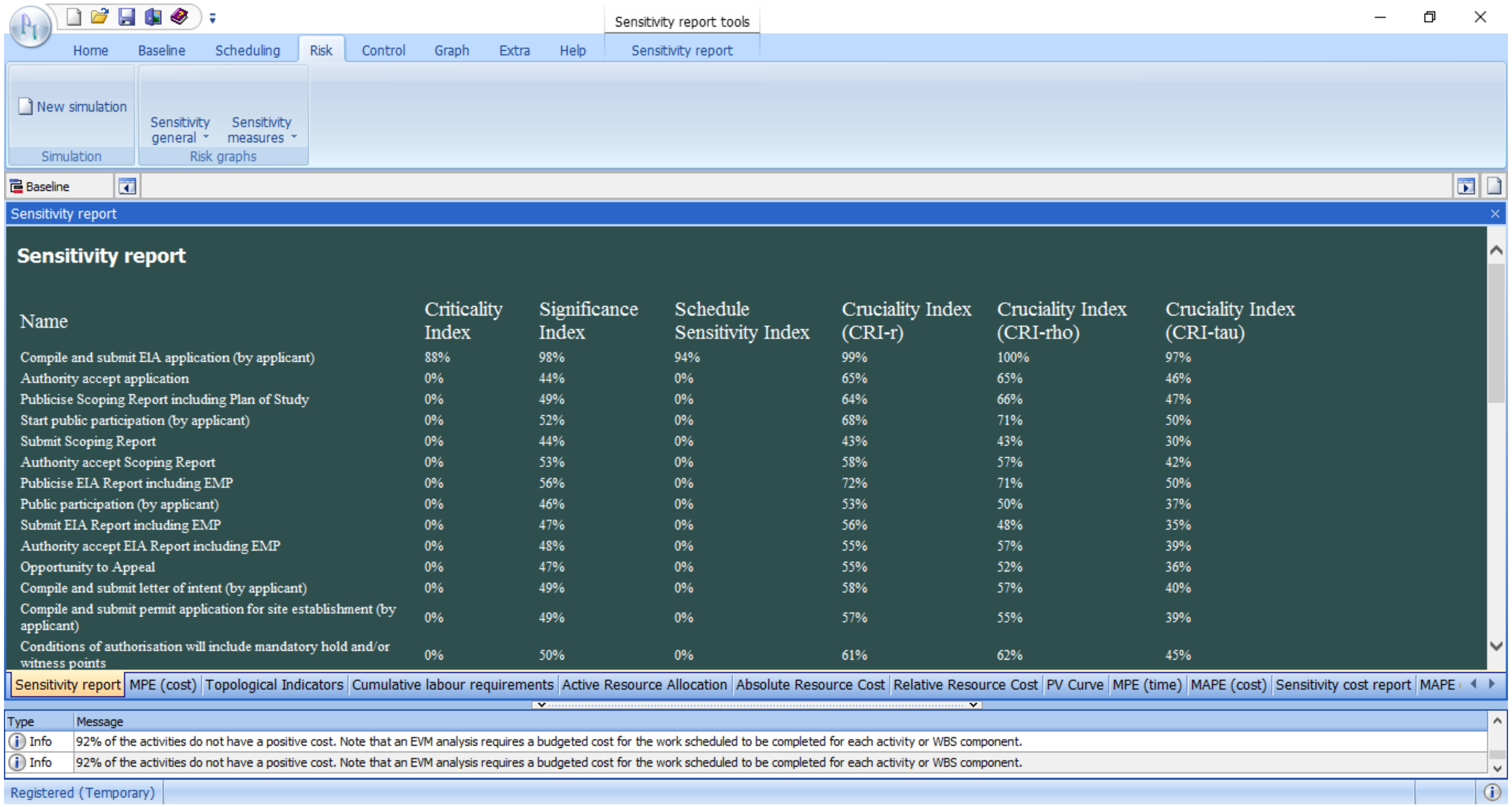
Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	16%	14%	22%
Authority accept application	0%	2%	0%	16%	17%	13%
Publicise Scoping Report including Plan of Study	0%	7%	0%	1%	3%	2%
Start public participation (by applicant)	0%	7%	0%	12%	13%	9%
Submit Scoping Report	0%	1%	0%	10%	8%	9%
Authority accept Scoping Report	0%	10%	0%	2%	4%	2%
Publicise EIA Report including EMP	0%	7%	0%	3%	3%	2%
Public participation (by applicant)	0%	7%	0%	6%	7%	4%
Submit EIA Report including EMP	0%	11%	0%	19%	18%	11%
Authority accept EIA Report including EMP	0%	27%	0%	6%	6%	3%
Opportunity to Appeal	0%	5%	0%	3%	2%	1%
Compile and submit letter of intent (by applicant)	0%	2%	0%	6%	8%	4%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	17%	18%	1%
Conditions of authorisation will include mandatory hold and/or witness points	0%	1%	0%	1%	3%	1%

Appendix R: Scenario 5 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



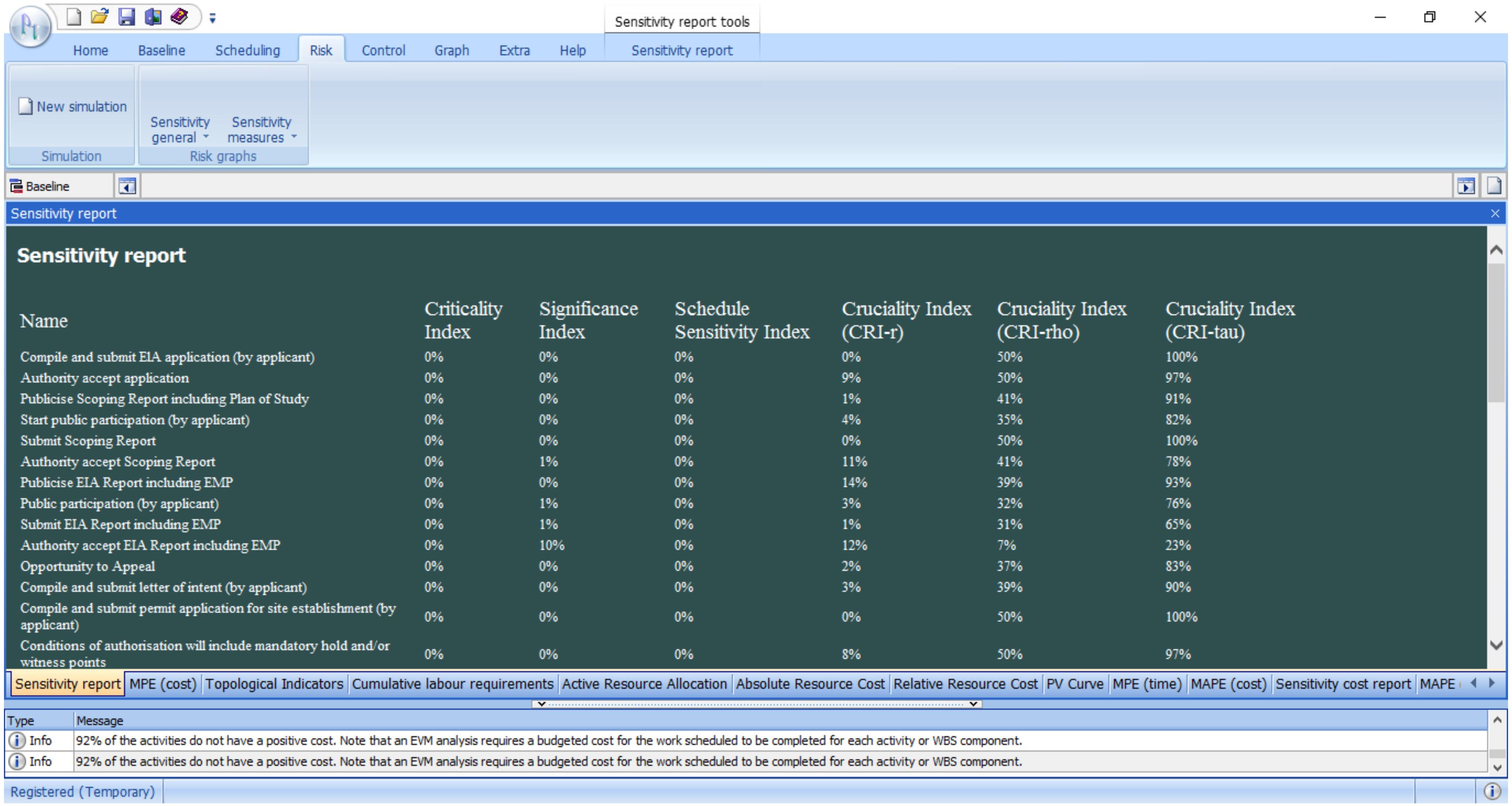
Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	0%	100%	100%
Authority accept application	0%	4%	0%	0%	100%	100%
Publicise Scoping Report including Plan of Study	0%	12%	0%	0%	100%	100%
Start public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit Scoping Report	0%	1%	0%	0%	100%	100%
Authority accept Scoping Report	0%	17%	0%	0%	100%	100%
Publicise EIA Report including EMP	0%	12%	0%	0%	100%	100%
Public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit EIA Report including EMP	0%	18%	0%	0%	100%	100%
Authority accept EIA Report including EMP	0%	41%	0%	0%	100%	100%
Opportunity to Appeal	0%	8%	0%	0%	100%	100%
Compile and submit letter of intent (by applicant)	0%	3%	0%	0%	100%	100%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	0%	100%	100%
Conditions of authorisation will include mandatory hold and/or witness points	0%	2%	0%	0%	100%	100%

Appendix S: Scenario 6 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	88%	98%	94%	99%	100%	97%
Authority accept application	0%	44%	0%	65%	65%	46%
Publicise Scoping Report including Plan of Study	0%	49%	0%	64%	66%	47%
Start public participation (by applicant)	0%	52%	0%	68%	71%	50%
Submit Scoping Report	0%	44%	0%	43%	43%	30%
Authority accept Scoping Report	0%	53%	0%	58%	57%	42%
Publicise EIA Report including EMP	0%	56%	0%	72%	71%	50%
Public participation (by applicant)	0%	46%	0%	53%	50%	37%
Submit EIA Report including EMP	0%	47%	0%	56%	48%	35%
Authority accept EIA Report including EMP	0%	48%	0%	55%	57%	39%
Opportunity to Appeal	0%	47%	0%	55%	52%	36%
Compile and submit letter of intent (by applicant)	0%	49%	0%	58%	57%	40%
Compile and submit permit application for site establishment (by applicant)	0%	49%	0%	57%	55%	39%
Conditions of authorisation will include mandatory hold and/or witness points	0%	50%	0%	61%	62%	45%

Appendix T: Scenario 7 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B

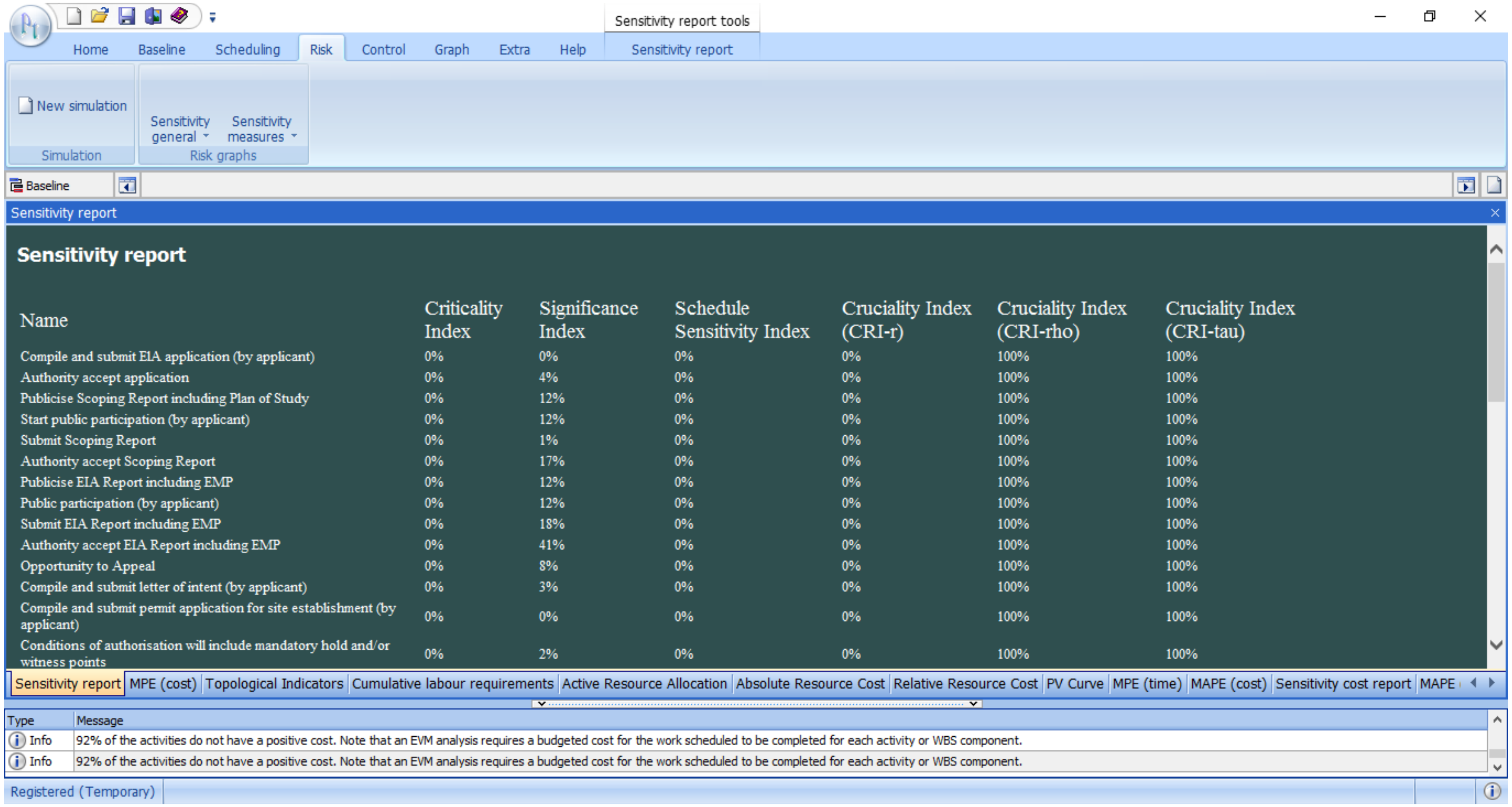


Sensitivity report

Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	0%	50%	100%
Authority accept application	0%	0%	0%	9%	50%	97%
Publicise Scoping Report including Plan of Study	0%	0%	0%	1%	41%	91%
Start public participation (by applicant)	0%	0%	0%	4%	35%	82%
Submit Scoping Report	0%	0%	0%	0%	50%	100%
Authority accept Scoping Report	0%	1%	0%	11%	41%	78%
Publicise EIA Report including EMP	0%	0%	0%	14%	39%	93%
Public participation (by applicant)	0%	1%	0%	3%	32%	76%
Submit EIA Report including EMP	0%	1%	0%	1%	31%	65%
Authority accept EIA Report including EMP	0%	10%	0%	12%	7%	23%
Opportunity to Appeal	0%	0%	0%	2%	37%	83%
Compile and submit letter of intent (by applicant)	0%	0%	0%	3%	39%	90%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	0%	50%	100%
Conditions of authorisation will include mandatory hold and/or witness points	0%	0%	0%	8%	50%	97%

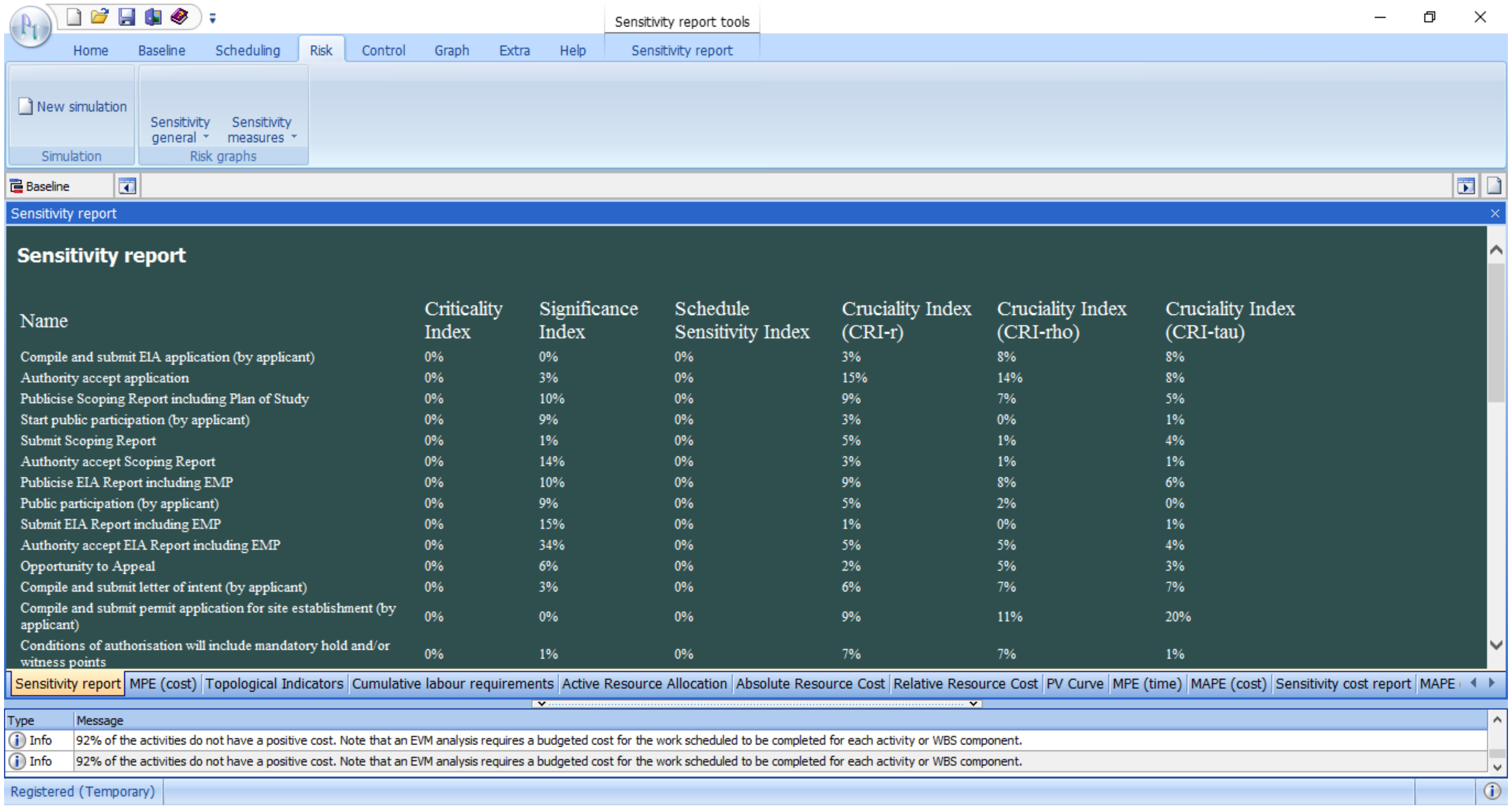
Type	Message
Info	92% of the activities do not have a positive cost. Note that an EVM analysis requires a budgeted cost for the work scheduled to be completed for each activity or WBS component.
Info	92% of the activities do not have a positive cost. Note that an EVM analysis requires a budgeted cost for the work scheduled to be completed for each activity or WBS component.

Appendix U: Scenario 8 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	0%	100%	100%
Authority accept application	0%	4%	0%	0%	100%	100%
Publicise Scoping Report including Plan of Study	0%	12%	0%	0%	100%	100%
Start public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit Scoping Report	0%	1%	0%	0%	100%	100%
Authority accept Scoping Report	0%	17%	0%	0%	100%	100%
Publicise EIA Report including EMP	0%	12%	0%	0%	100%	100%
Public participation (by applicant)	0%	12%	0%	0%	100%	100%
Submit EIA Report including EMP	0%	18%	0%	0%	100%	100%
Authority accept EIA Report including EMP	0%	41%	0%	0%	100%	100%
Opportunity to Appeal	0%	8%	0%	0%	100%	100%
Compile and submit letter of intent (by applicant)	0%	3%	0%	0%	100%	100%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	0%	100%	100%
Conditions of authorisation will include mandatory hold and/or witness points	0%	2%	0%	0%	100%	100%

Appendix V: Scenario 9 - Extract of Sensitivity Report from ProTrack V3 for Nuclear Project B



Sensitivity report

Name	Criticality Index	Significance Index	Schedule Sensitivity Index	Cruciality Index (CRI-r)	Cruciality Index (CRI-rho)	Cruciality Index (CRI-tau)
Compile and submit EIA application (by applicant)	0%	0%	0%	3%	8%	8%
Authority accept application	0%	3%	0%	15%	14%	8%
Publicise Scoping Report including Plan of Study	0%	10%	0%	9%	7%	5%
Start public participation (by applicant)	0%	9%	0%	3%	0%	1%
Submit Scoping Report	0%	1%	0%	5%	1%	4%
Authority accept Scoping Report	0%	14%	0%	3%	1%	1%
Publicise EIA Report including EMP	0%	10%	0%	9%	8%	6%
Public participation (by applicant)	0%	9%	0%	5%	2%	0%
Submit EIA Report including EMP	0%	15%	0%	1%	0%	1%
Authority accept EIA Report including EMP	0%	34%	0%	5%	5%	4%
Opportunity to Appeal	0%	6%	0%	2%	5%	3%
Compile and submit letter of intent (by applicant)	0%	3%	0%	6%	7%	7%
Compile and submit permit application for site establishment (by applicant)	0%	0%	0%	9%	11%	20%
Conditions of authorisation will include mandatory hold and/or witness points	0%	1%	0%	7%	7%	1%

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