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BPJ 420: Final Project Report
Tool for Support Concept Evaluation for Missile A

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Abstract

Over the years, post production support has become more specific to the user. Streamlining a support concept so that it best fits the user requirement eliminates unnecessary costs, thereby reducing the overall life cycle cost of the product system. Integrated Logistics Support and more especially, the Level of Repair Analysis has played a significant role in this respect, managing processes in order to meet specific requirements within the capabilities of the company and the user.

A global supplier of defence equipment, Denel Dynamics has been one of the game changers in the local and global defence industry. The company has consistently worked toward providing innovative solutions for their clients, building and maintaining strong relations based on their commitment to improving both products and processes within the company.

Denel Dynamics is currently experiencing a problem in their Integrated Logistics Support Division, whereby clients have differing requirements for support. The support concept already created for a particular client cannot be generally applied to another client's requirement- a tailored concept must be created for each client. However, the current Excel-based method of support concept generation and evaluation is rigid and does not allow quick manipulations to make each one specific to a particular client's needs. It is time consuming and often leads to one single concept being chosen based on the experience of personnel and presented as the best solution to meet the requirement- with no comparisons being made between options to validate the decision.

This report explores the project effort to create an improved, more dynamic and flexible method of evaluating the support concepts, allowing Denel Dynamics to make informed decisions regarding the support options made available to users. A literature review included gives a brief overview of the methods and processes in the Integrated Logistics Support field. Studies conducted to solve similar problems have also been presented in the literature review. These studies contribute to the concept design of the problem solution. A simulation-based approach was employed on AnyLogic PLE, as opposed to the current Excel-based approach. The model design has been presented, along with the data analysis, providing information that was used in the simulation model, as well as the results analysis of the base case and alternative scenario concepts. Finally, conclusions are drawn to indicate that this is a valuable solution to the problem faced by the company, giving recommendations that may be implemented in the future to improve the model.

Disclaimer

Please take note that from an ethical perspective, this project does not infringe on laws, regulations or conditions outlined by Denel SOC, the Republic of South Africa or the partner companies, both local and foreign. All data that has been used (and that which will be used later on) was cleared for use in all published documents of this project. Any information that is deemed sensitive or confidential has been omitted or replaced with adjusted hypothetical, but realistic information to protect the interests of Denel SOC and that of the Republic of South Africa and all associated parties.

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Chapter 1

Introduction

Denel Dynamics, formerly known as Kentron, is a state owned company, specializing in defence and aerospace solutions. Founded in 1991, Denel Dynamics is not only responsible for designing and developing products, but also integration of such products in their intended environment of use and providing support throughout the lifetime of the product. Denel SOC (2015) defined their objectives in the Denel Integrated Report 2014/15; one of which is to build and sustain strong relationships with customers and stakeholders, while nurturing new and existing revenue streams. To that end, the company as a whole is trying to shift from methods they have always employed to solve their problems to new practices that could be considered state of the art in order to improve on their offerings to the client. This project is one of the initiatives currently being run to specifically improve the way their Integrated Logistics Support department works.

As part of supportability engineering, one of the essential functions Denel Dynamics serves involves designing and implementing innovative and capable support solutions to their clients: through integrated logistics support. Integrated Logistics Support (ILS) is a management approach that integrates support development with systems engineering. This assists in maintaining Denel's competitiveness in the international market while maintaining good relations with users. This ILS division at Denel Dynamics works on how best to provide a post production service to the user that is suitable to their needs and capabilities, as well as the company's capabilities.

Weapon systems normally have a life cycle of approximately 20 years and during this time, they are subject to maintenance and repairs. Clients purchase both the product and the support capability from the company. Exploiting this opportunity creates revenue streams for the company, but this is not possible without the appropriate structured methods and tools to do so.

1.1 Background of the problem

Missile A, produced by Denel Dynamics, is subject to regular maintenance and/or repair during its lifetime. Currently, three levels of support exist for this missile: Operational-level, Intermediate-level and Depot-level (henceforth referred to as O-, I- and D-level respectively). D-level support can be further divided into User D-level and Original Equipment Manufacturer (OEM) D-level; the former being the responsibility of the user and the latter at the Denel Dynamics premises. Each one exists to perform certain maintenance and repair tasks. The hierarchy of maintenance levels are illustrated in Figure 1.1 below.

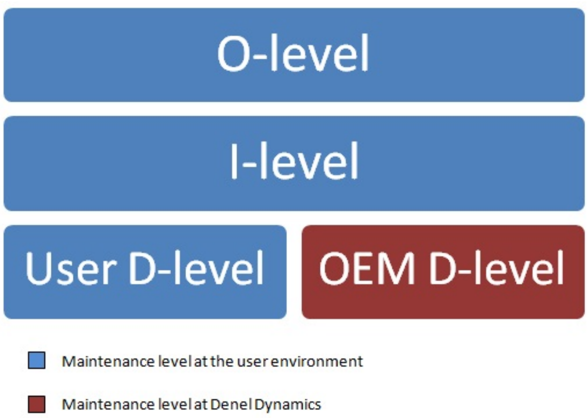

Figure 1.1: Maintenance levels

O-level tasks are performed by the user at the squadron level, with tasks limited to cleaning and inspections. I-level tasks are also performed by the user, including cleaning, inspections and diagnostic testing. Quick removal and repair of some parts, such as the missile fins, can also take place at the user environment. D-level tasks are performed at the user or Denel Dynamics. Tasks include fault identification, repair or replacement of external parts having suffered major physical damage and repair and replacement of whole functional subsystems of the missile. The missile has a 300 flight hour lifespan; should the user wish to extend the life of the missile, it must be returned to Depot level for mandatory life extension maintenance. Missiles are also transported between I-level and D-level as fully assembled (all-up round) or separated into the front and rear sections (split round). However, splitting the missile requires special equipment and trained personnel for splitting and mating, integration and testing. This scenario is only applicable when the user has the capability to carry out this task. Shown below in 1.2 is an example of movement from level to level for a local context.

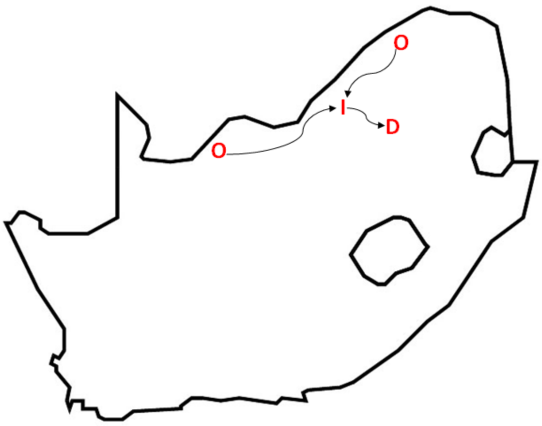

Figure 1.2: Example of support levels for local client

Support concepts are developed that best provide post production logistic support to the user. The support concept is a strategic plan that allocates tasks and support elements to the required points- to the O-, I- and D-levels in this case. Support elements include, but are not limited to: spares, personnel, training, documentation, consumables, testing and ground support equipment (Ministry of Defense, 2014). Support concepts also take into consideration whether the missile will be split before transportation.

In general, high volume manufactured products have support concepts for a broad spectrum of users; concepts are independent of the user. However, for low volume manufactured products, support concepts are developed with specific consideration of the user's requirements and capabilities. Low volume manufactured items may be produced in varying quantities but are usually highly specialized. This is the motivational factor behind tailor made support solutions specific to user requirements. Missile A is a complex product and therefore low volume manufactured; special attention should be focused on the support concepts that meet the user's requirements while being mindful of the user's environment capabilities.

Currently, support concept generation and evaluation is carried out by personnel with experience-based knowledge. A single scenario or concept is generated based on the user requirements, some logistic support analysis and prior knowledge derived from other projects; with Excel being the primary tool for analysis. This is illustrated in Figure 1.3 below using a hypothetical spreadsheet:

	Price Spare 1 (per unit)	Spares 2	Qnty of Spare 2	Price Spare 2 (per unit)	Spares 3	Qnty of Spare 3	Price Spare 3 (per unit)	Spares Price for LC	Total Price
O/I-Level Operating Tasks									
I-Level test with ILTE									R 192,000
O-Level test with OLTE									R 549,000
Maintenance of ILTE									
Maintenance of OLTE									
O/I-Level Corrective Maintenance Tasks									
Corrective Maintenance Task 1	R 51	Spares Kit 2	12	R 2,502	Pin 1	3	R 81	R 3,637,018	R 3,643,524
Corrective Maintenance Task 2	R 72	Pin 2	12	R 92	Pin 2	2	R 92	R 26,041	R 27,310
Corrective Maintenance Task 3	R 1,501	Spares Kit 1	12	R 1,501	Spares Kit 1	2	R 1,501	R 421,501	R 421,682
O/I-Level Scheduled/Preventive Maint Tasks									
Scheduled Maintenance Task 1	R 81	Pin 1	12	R 15	Screw 1	3	R 51	R 59,400	R 85,400
Scheduled Maintenance Task 2	R 1,501	Pin 2	12	R 25	Screw 2	2	R 72	R 68,920	R 92,920
Scheduled Maintenance Task 3	R 2,502	Spares Kit 1	12	R 25	Pin 1	2	R 81	R 58,079	R 199,840
Preventive Maintenance Task 1									
Preventive Maintenance Task 2									
Preventive Maintenance Task 3									

Figure 1.3: Support Concept Example on Excel Spreadsheet

The different support tasks for one concept are entered on the extreme left column of the spreadsheet, with their associated cost to calculate the total cost of that particular task. Personnel and spares required to complete the task are also included. However, acquisition costs such as infrastructure, are not included on this spreadsheet; this indicates that the entire life cycle cost is not being addressed. The concept is then presented to the user as the best possible solution.

This presents a huge problem for the company, as there is no formal way of quantifying whether that decision is the best for the client and for the company. This is an indication that the concept chosen could potentially be the most wasteful of resources.

1.2 Problem statement

Denel Dynamics currently has a support concept for Missile A that was created for Client Z. Client Z has an O- and I-level support for Missile A, with D-level support at Denel Dynamics. Client X also requires a support concept with O-, I- and D-level support, but has different support requirements as compared to Client Z. The support concept should be tailor made to Client X's requirements: these may include moving a D-level task to I-level, splitting the missile at I-level before transporting it to D-level, etc.

The company cannot use the same concept for Client X as that used for Client Z, but must now explore different concepts that will be better for both Client X and Denel Dynamics. However, the current method of support concept evaluation is problematic: it is done on Excel, with only one concept generated at a time. Introducing new concepts will require creating a new spreadsheet, and this ultimately wastes time. Therefore, effort is not made to generate several concepts due to the inconvenience and lack of available time to do so. The decision made to use the concept is based on experience of personnel working on the concept, not on comparisons with other concepts.

As mentioned, there are numerous issues with this method, equally contributing to the requirement for a formal, improved method of analysis and evaluation; as summarised below:

- The experience-based knowledge disappears once personnel leave the company;
- multiple support concepts are not being generated;
- lack of concept options to compare will mean that the single concept being generated may not be the optimal solution for Denel Dynamics;

- lack of options to compare also makes it difficult to convince the user that the best solution is being chosen;
- the Excel spreadsheet does not include all possible scenarios. If a new concept is to be used, a new spreadsheet must be created to include any deviations from the previous concept;
- the current method does not include all costs that make up the life cycle cost; and
- it is time consuming, tedious and allows much room for human error, therefore it is not the most effective analysis.

Additionally, should the company acquire multiple large orders the current informal method is not fast or reliable enough to carry out a logistic support analysis or support concept evaluation. This compromises the capabilities of D-level support of Denel Dynamics if the proper steps have not been taken to plan for an influx of maintenance activities. The ripple effect is compromised quality of support offered to customers, thus having an adverse effect on strategies aimed at meeting the objectives of the company.

1.3 Objective of project

The objective of the project was to create a model that makes evaluating and comparing support concepts easier: by moving the support concept evaluation from being Excel-based to model-based. The model assists with decision making concerning which support concept best suits the client and Denel Dynamics, by minimising the life cycle cost. It also enables support element planning for the different levels of support. Attributes of reliability, availability and maintainability are considered. The missile must ultimately be available for use for the most part of its lifespan; this means that it should be reliable and easy to repair or support during its life to ensure that it remain operational.

As previously mentioned in the problem statement, the Excel-based approach is inefficient and allows large room for human error since new spreadsheets must be created and filled in for every new support concept. The whole life cycle cost is comprised of different support elements, all of which are not currently addressed in this method of analysis. To ensure that the model is appropriate and value adding, different support concepts were generated and then modelled. Concepts were then evaluated by comparing them to each other: assessing them in terms of the life cycle cost (LCC) (which must be minimised), and time taken to return the missile to use (which must be minimised to maximise the total availability of the missile). Sensitivity analysis was conducted with LCC data derived from the model, providing quantifiable proof for the choice of support concept applicable to the user's needs. Denel Dynamics prides itself on being a technologically advanced company, employing state-of-the-art, formal methods of solving problems. Therefore, creating a model provides an innovative platform whereby the concepts can be easily manipulated and assessed; as compared to Excel, which is more rigid. It is clear that a formal support concept evaluation method is required that will consequently form part of the formal processes at Denel Dynamics.

1.4 Research design

Missile A is produced in three variations: operational, acquisition and practice inert. This project will focus on the operational missile variant. Denel Dynamics does not repair or replace any explosive material on their own premises, therefore the associated explosive sub systems will only be considered so far as the time and cost concerned with transporting the explosive sub components to the Somerset West branch of Rheinmetal Denel Munition (RDM). Missile A can also be transported to the support level as an all-up round (the fully assembled missile) or as a split round (separated into the front and rear sections).

The scope of this project includes the following:

- Partial logistic support analysis

A hardware breakdown structure, as well as information regarding the assembly failure rates, mean time between failures and other associated information has been compiled using data provided by Denel Dynamics. Once this was completed, the concept design was created.

- Model Concept Design

  The concept of the simulation model was created to guide the development of the model later in the project.

- Development of a simulation model

  The simulation model was developed and used to represent a baseline support concept and test the proposed support concepts. It encompasses the relevant logistic elements and costs and is used to determine the LCC of each concept.

- Proposing support concepts to test on the model

  These were developed based on existing scenarios and data collected from the LSA. Proposed concepts include a scenario for both local and international clients and for both all-up and split round configurations. All three levels of support (i.e. O-, I-, D-levels) are addressed.

- Support concept evaluation

  Evaluation was performed to determine the effect of different concepts on availability, turnaround time and life cycle cost of the weapon.

- Discussion of results and recommendations

Proposed deliverable:

- A simulation-based model used to simulate proposed support concepts; and
- support concept evaluation report (Level of Repair Analysis or LORA report).

  This report describes the findings of the support concept evaluation, recommending the best concept.

1.5 Document Structure

In the chapters to follow, the action taken to solve the problem has been discussed. The literature review in Chapter 2 of this document provides background for the project as a whole: background on ILS, motivation for tailored support concepts and previous studies to solve similar problems. Following that is the research methodology in Chapter 3, followed by the data analysis included in Chapter 4. The design of model is described in Chapter 5. Chapter 6 describes the base case and Chapter 7 includes the analysis of the base case results. Alternative concepts are described and the results analysed in Chapter 8. Chapter 9 concludes this document.

Chapter 2

Literature review

The following literature review has been conducted to give a brief overview of the studies and methods currently or previously used to solve similar problems. It encompasses information from several articles, which together, make up the scope of the project that will be done. This includes information concerning the following:

- Integrated Logistics Support: a brief overview is given on this topic as it serves as a banner under which similar studies fall;
- Logistics Support Analysis: this is branch of integrated logistics support and is the primary method of gathering information to generate support concepts;
- Key Considerations: the important RAM factors that have been focused on in previous studies have been identified and presented here. Life cycle cost has also been introduced;
- Motivation for Different User Specific Support Concepts: Denel Dynamics currently uses a single concept based on the experience of individuals working in the division. However, with increasing and differing demands, a need arises for tailor made solutions. The motivation for this has been addressed before in a military context and included in this review;
- Previous Studies: included are similar studies conducted previously which are used as a guide for conducting this project; and
- Simulation models: insight into the relevance and appropriateness of simulation models for projects of this nature.

2.1 Introduction to Integrated logistics support

Integrated logistics support (ILS) defines the objectives relating to the performance and reliability of a product in different stages of its lifecycle. In their paper on an Integrated Logistics System for Indigenous Fighter Aircraft Development Program, Shukla et al. (2014) refer to ILS as an iterative process. They go on to say that it seeks to optimize a system's functional support, reducing costs, by leveraging the existing resources. Streamlining the product's logistic support facilitates the proper planning of support elements, and thus the associated costs, for the duration of its serviceable life. Herewith, it can be said that one of the goals of ILS is to assess the life cycle cost of the product.

The Italian Ministry of Defence recognized that their naval integrated combat system's key performance indicators were embedded in two domains: systems engineering (SE) and logistics support (Solazzi et al., 2012). This agrees with the shift from sequential engineering to concurrent engineering, illustrated below in Figure 2.1 and Figure 2.2. Using a SE approach, the functional system's life cycle is managed- the system effectiveness is indicated by the capability to perform the task required. However the system effectiveness is of little importance if the probability of the system being available to perform the task is slim to none. This is where logistics support fits in, defining a relationship between ILS and systems view for the lifetime of the system.

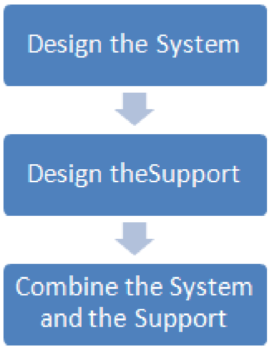

Figure 2.1: Sequential Engineering

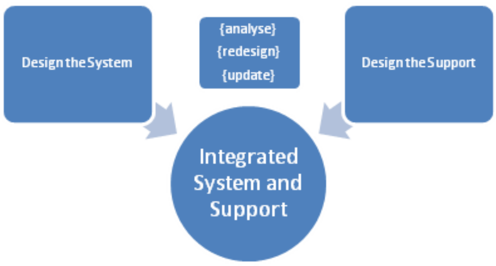

Figure 2.2: Concurrent Engineering

2.2 Logistic support analysis

A branch of ILS widely used in the Aerospace and Defence (A&D) industry is Logistic Support Analysis (LSA). The LSA process was developed in response to several issues with the ILS practice; unsuccessful coordination of information during weapon systems design being one of them (Jones, 1987). Four goals of LSA as stated in the Integrated Logistics Support Handbook:

- Find ways to make the system easier to support;
- identify cost drivers of support early in the design process and change the design to correct or eliminate the support problems;
- establish the logistic support resource requirement for system life cycle; and
- establish a single database for all analyses.

Thus, an LSA program would only be considered successful if the above mentioned goals are achievable.

If one were to perform LSA at the post production stage of the weapon life cycle, the objectives would be an overlap of ILS element level LSA and supportability assessment and verification, as illustrated in the System Equipment Life Cycle (Jones, 1987), included in Appendix A. The overlap includes:

- Post production support analysis;
- supportability assessment plans and criteria;
- support concept verification;
- verification of logistic support resource requirement, and
- identification and correction of supportability problems.

Narrowed down further, LSA process at post production support level includes:

- Creating a hardware breakdown structure;
- Failure mode analysis;
- Support task identification:

  Support task identification involves determining which tasks must be performed. These include operator tasks, failure detection tasks, fault location tasks, corrective tasks and preventative tasks, to name but a few. A task library is used to compile the records of the tasks, describing all the details that may be required to repeat it;
- Support Task Allocation;
- Support Task Analysis:

  Once the appropriate tasks are identified and allocated the relevant levels, the tasks or support activities themselves need to be fully defined, in terms of the requirements. A complete detailed description of procedures must be developed; it can later be used as work instructions, for planning or training purposes; and
- Support Resources Definition:

  In order to perform the tasks, a number of resources are required which is derived from the Support task analysis. In addition to trained personnel (and additional training if required) and replacement spares, tools, consumables and equipment needed for failure detection, measurement and testing are also required. Appropriate facilities and documents, such as work instructions, are imperative for effective support. A cost is also attached to each of these resources, prompting the need for proper planning to enable efficient use of resources.

2.2.1 Failure mode and effects analysis

The Failure Mode and Effect Analysis (FMEA) is conducted to identify the failure modes for all components within a system. In their paper, Integrated Appproach & Decision Making Algorithms for Complex Systems Effectiveness Evaluation, Solazzi et al. (2012) identify that the analysis uses a bottom-up approach. It analyses the effect that failure of even the smallest components have on the hierarchy of sub systems and eventually the whole functional system. The severity of the failure, the effect it has on the next level of the system and the average probability of the failure occurring per flight hour must all be used to class the failure mode. They go on further to suggest that an additional step should be added to evaluate how the failure can propagate to affect the entire system. Therefore, the failure of a component is assessed based on the effect it has on the functional node on the upper level of the hardware breakdown structure.

FMECA is similar to FMEA but includes a Criticality Analysis. Based on the probability that the failure will occur, a failure probability code is selected. The severity of the failure must be assessed, thereafter giving the failure a safety hazard severity code. These codes are shown below in Table 2.1. Using the aforementioned codes, a criticality matrix can be generated plotting the failure probability against the severity.

	Failure Probability Code		Safety Hazard Code
5	Frequent ($p > 0.2$)	4	Catastrophic
4	Reasonably Probably ($0.1 < p < 0.2$)		
3	Occasional ($0.01 < p < 0.1$)	3	Critical
2	Remote ($0.001 < p < 0.01$)	2	Marginal
1	Unlikely ($p < 0.001$)	1	Minor

Table 2.1: Failure Probability and Safety Hazard Severity Codes

Reliability centered maintenance (RCM) analysis is also done in combination with the FMECA, in order to minimise inconsistencies between data that either one could produce. RCM is an analysis that assesses maintenance tasks based on the cost effectiveness (Ministry of Defense, 2014). In his paper on Development of Instructions for Continuing Airworthiness and Aircraft Logistics Support Analysis, Petrov (2014) states that scheduled maintenance analysis is usually employed to address latent or 'hidden' failures. It involves providing a detailed work up of the potential failures that are anticipated, their causes and effects. The objective is to schedule maintenance or replacement of a part in anticipation of failure; takes a proactive stance.

2.2.2 Support task allocation

While support task identification is used to determine what must be done when failure is detected, support task allocation refers to where the task will be performed- should one be required. Once the financial impact of replacement and repair is ascertained, the decision to discard or repair must be made. If the option to repair is chosen, a Level of Repair Analysis (LORA) must take place. LORA identifies the optimal prerequisites of repair and maintenance facilities and aims to reduce the cost of the repair service without compromising the availability of the system. This enables decision making pertaining to the most favorable level of repair. A well known strategy of the A& D industry, as described by Shukla et al. (2014) , is the use of three levels of support maintenance: Operational-level, Intermediate-level and Depot-level.

- O-level

  Also referred to as Organizational-level, the maintenance tasks allocated to this level are usually located at the user environment, such as a local squadron. The tasks approved to be performed at this level are usually preventative tasks, cleaning and inspection tasks and testing the weapon/aircraft serviceability.

- I-level

  This level also falls under the responsibility of the user. Tasks to be performed at this level are more specialized and time consuming, involving use of I-level Test Equipment (ILTE) to test the weapon/aircraft. Failed items from O-level are usually removed and sent to I-level for more intensive diagnostic tests and approved repair activities. Otherwise, they are sent to D-level.

- D-level

  D-level is usually at the OEM and includes tasks such as full replacement of inoperable parts, extensive diagnostic and repair activities, modifications, testing and calibration. Scheduled inspections also take place at D-level.

Allocation of tasks to different levels based on capabilities and resources involves the creation of support concepts. Influences on support concepts include the mode of transportation between levels, the configuration of the weapon/aircraft for transport and/or testing and support tasks. Level of expertise of personnel and the need for additional specialized training also influences support concepts.

2.3 Key considerations

From the perspective of missile support, the attributes to be considered are reliability, availability and maintainability (RAM). According to the American Department of Defence (DoD), these are considered the "essential elements of mission capability". Reliability refers to the probability that an item remains functioning as required for a certain amount of time under specific operating conditions. Maintainability refers to the ease at which an item can be restored to its proper functioning state after a failure occurs, within a reasonable amount of time. The availability of the missile depends on the factors of reliability and maintainability of the missile. For example, the availability of the missile increases if the missile is more reliable and experiences fewer failures. The ability to maintain the missile also improves the availability- if it can be repaired, it can still be used. Contributors to availability are illustrated below in Figure 2.3.

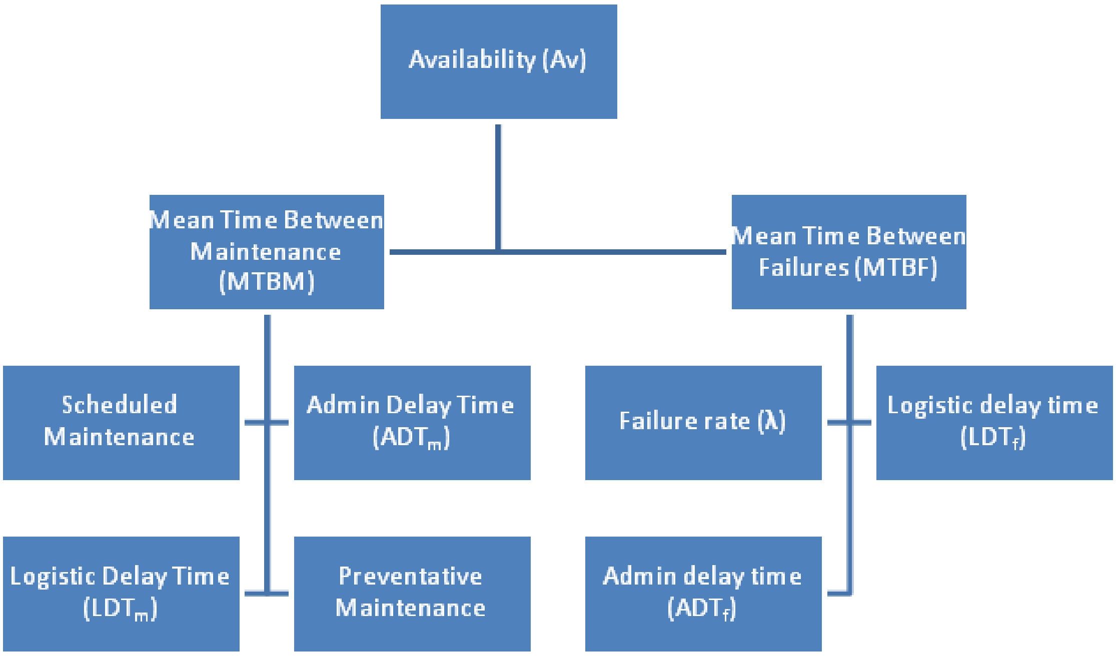

Figure 2.3: Contributors to Availability

Where,

$$Failure\ Rate = \lambda = \frac{1}{MTBF} \tag{2.1}$$

$$Mean\ Time\ to\ Repair = MTTR = ADT + LDT \tag{2.2}$$

$$Availability = Av = \frac{MTBF + MTBM}{MTBM + MTTR + MTBF} \tag{2.3}$$

Reliability can be given by $R = e^{-\lambda t}$, however this formula is only applicable when the failure rate is constant.

In addition to the above, the turnaround time for the failed item must be considered and within acceptable limits to both the user and customer. This is the period of time commencing when the weapon is submitted for maintenance or repair and ending once the weapon has been returned to the customer with full functionality.

The life cycle cost (LCC) is an important metric to consider- like most costs, it should preferably be minimised. The life cycle cost analysis (LCCA) is used to determine the effect of maintenance costs on the LCC. Data obtained from LCCA is thus used to identify support cost drivers and assess the cost impact of levels of repair and support resources. LCCA can be carried out as follows:

- Step 1: Create the Hardware Breakdown Structure;
- Step 2: Perform a LCC breakdown, in terms of recurring and initial costs. Further break down the costs in terms of the resources they are allocated to (eg. spares, support equipment);
- Step 3: Perform a sensitivity analysis, and
- Step 4: Perform a trade-off analysis between different support concepts.

All three metrics, availability, turnaround time and LCC, are measured using different units. This makes comparing concepts across these metrics difficult. A simple method called Multi-Attribute Utility Theory (MAUT), is often utilised to evaluate a set of alternatives against a set of weighted selection criteria (Kossiakoff et al., 2011). Due to its ease of implementation, MAUT is extensively used across engineering fields. The utility function, U(m_i), translates the attributes m_i (or selection criteria) to unitless measure of of utility. The weighted sum of the utilities is then used to choose the best alternative.

The utility is calculated as follows:
Let,
$i \in I\{1, 2, ..., k\}$ be the set of attributes,
$j \in J\{1, 2, ..., n\}$ be the set of concept alternatives,
$m_i \triangleq$ utility of each attribute, where $i \in I$,
$a_{ij} \triangleq$ magnitude of the j^{th} alternative on the i^{th} attribute, where $j \in J$ and $i \in I$, and
$U(j) \triangleq$ overall utility of concept alternative j, where $j \in J$

Then,

$$U(j) = \sum_{i=1}^{k} m_i a_{ij}, \tag{2.4}$$

This method of decision analysis allows the combination of different selection criteria, eliminating the units of measure and presenting only a single value that determines the most attractive option.

2.4 Motivation for different user specific support concepts

Galloway (1996) identified that, motivated by the global recession in the 1900s and diminishing demand for military services, well advanced defence nations began budget cuts. The periods of relative peace lead to increased in-service time for defence systems and equipment, implying the need for better control over the in-service support cost, thus the cost of ownership. The American DoD has been on the forefront of advanced military systems. Imminent war meant that their systems, although complex and cutting edge technology, were also heavily maintenance reliant: they resulted in large costs to support in the operations and support phase of the life cycle. The British National Audit Office stated that 1 billion pounds was spent in the 1989-1990 financial year- on unscheduled maintenance and repairs alone. That being said, the support costs were found to be critical for any reduction in LCC and this notion persisted into the current era.

Civilian companies also recognized the need to dedicate more effort into improving and streamlining the support phase of their operations. This is seen in common customer care centers, whereby the original equipment manufacturer provides a support centre for repairs and other related support services. The need for a specific support concept is illustrated by an example of the new Samsung Smart Care Centre. Owing to the lengthy process, inconvenience and cost associated with returning all malfunctioning products to a single support facility, Samsung South Africa created three support centers- strategically positioned in the country's three most popular cities. The additional level of support exploits an opportunity to improve the company's service delivery standing. It also lessens reliance on outsourcing; giving the company an opportunity to expand their business area.

In this respect, we see congruence between A&D and civil companies. The American DoD and British military alike adopted this so called management approach in an attempt to manage project sustenance (Galloway, 1996). User specific support concepts are employed, not only to improve customer satisfaction but to curb the costs of an overly generalized support system that is ultimately wasteful.

2.5 Previous studies

2.5.1 Study 1

In their study, "2 Level vs 3 Level of Maintenance: The Cost", Hughes et al. (1989) describe the Level of Repair analysis for four army weapons and communication systems; one of which was a HAWK guided missile system. The objective was to achieve a target operational availability at a decreased life cycle cost. Using Optimum Supply and Maintenance Model (OSAMM) to determine at which level tasks should be performed and their resource requirements, different support structures were compared with respect to their cost, the readiness of the system and the operational availability they resulted in.

The OSAMM has three modes. The first determines which echelon of support to station a single support task concept. The second mode tests multiple support concept alternatives and determines how and where each repair should be performed. The third mode involves screening to test if failure has occurred before sending it to the next level- only one repair scenario be input therefore the purpose of the third mode is simply to check the cost effectiveness of screening. The Selected Essential-Item Stockage for Availability Method (SESAME) algorithm was used in conjunction with OSAMM. The algorithm obtained "stockage criteria" with costs for each maintenance concept. Once the cost was ascertained, OSAMM used mixed integer programming to find the optimum maintenance structure for minimized cost which met the availability goals.

A simplistic project approach was used, involving identifying a suitable army system to study, setting up the OSAMM with the baseline case under the current maintenance concepts to determine the cost to compare with the excursions to be modeled. For the HAWK, three levels of support were considered: Depot level, General Support and Direct Support. The focus of the study was to determine where the Integrated Family of Test Equipment (IFTE) should be stationed, and whether it should be dedicated (i.e specific to the HAWK) or not dedicated thereby allowing it to be used to test other systems. As a result of the study, it was found that a two level maintenance policy was the optimum solution for the HAWK guided missile, when the Integrated Family of Test Equipment was not dedicated at all levels.

Applicability:
In this project screening via O-level test equipment, I-level test equipment and D-level test equipment will be implemented. This ensures that faults are detected at a high level and will be funneled to the correct level for repair, avoiding unnecessary expenditure and negative impact on the availability of the missile. The baseline case will also be modeled first, against which other support concept options will be compared. A mixed integer linear programme was initially considered, however this method gives one optimal solution which may or may not be realistic. This results in a substantial trial and error effort, which is not at all efficient.

2.5.2 Study 2

In their paper on an Integrated Logistics Model of Spare Parts Maintenance Planning within the Aviation Industry, Fritzsche and Lasch (2012) present a model to be used as decision support for maintenance and ordering cost reduction. It aims to optimize different network levels to ensure that the right resources are available, at reduced total costs.

Recognising the need to change unscheduled maintenance or repair tasks to scheduled preventative maintenance, Fritzsche and Lasch created a model that uses the failure rate and remaining useful life of a component to properly plan for repairs, maintenance tasks and the allocation of spare parts. A three-level model is used, each with its own support elements for the tasks to be performed at that level. At the first level, all items of the aircraft are checked to determine their remaining useful lifetime. If it is less than the acceptable remaining useful lifetime, it is sent to the nearest reparation station, which is the second level. Level three is simply a logistics network responsible for delivering spare parts to the reparation stations based the failure rate recorded by level one and the inventory level of parts at reparation stations. Separation of the levels was also justified as it reduced the complexity of the logistic network.

A simulation-based optimization was identified to be the most effective tool of representing and evaluating the different design options. It is inexpensive and useful when the system to be modeled is complex. It also avoids re-planning between different alternatives- the simulation can be easily manipulated.

Fritzsche and Lasch went on to explain the objective of the model: to minimise the total cost of the airline by applying the preventative maintenance strategy described above.

$$C_{Tot} = \sum_{j}(c_I \cdot S_j + c_T \cdot T_j + c_D \cdot U_j) \rightarrow min \tag{2.5}$$

Where: C_{Tot} = Total cost; c_I = Inventory cost; S_j = Inventory level at station j; c_T = Transportation cost; T_j = Expected number of transportation to station j; c_D = Downtime cost, and U_j = Downtime at station j.

Inventory, transportation and downtime costs are given to be constant, therefore the remaining variables have an effect on the total cost.

Fritzsche and Lasch identify two economic benefits as a result of this model. The first is the ability to plan for the inventory required to perform the maintenance activities. The second is the reduced cost of maintaining the system as the model helps plan for maintenance only when it is required. Additionally, the model assists in increasing the availability of the aircraft as unscheduled maintenance is reduced, allowing for more operational hours of the aircraft.

Applicability:
In this project, a 3 level model will be simulated: O-level, I-level and D-level. Screening at each level for failure will be included as well as additional screening for life extension requirement, as mentioned in Study 1. Based on the capability of each level, the fault will be fixed at the level the missile is currently in or it will be moved to a lower level. A simulation based model will be used; due to the complex nature and expense that could potentially be incurred via a trial and error method, a simulation model would be most appropriate to evaluate different design options. One of the objectives of the simulation is to minimise the lifecycle cost of the missile. All cost elements will be taken into consideration to choose the best support concept for the company and the client. The fixed cost of each repair task will remain constant and only increased on an incremental basis- once the task is completed, the counter for that task will be incremented by one and multiplied by the fixed cost to give a total cost of that task.

2.5.3 Study 3

The aim of the study by Jentsch and Boukhtouta (2015) was to maximize the level of equipment availability for training and deployed operational fleets while maintaining a low cost, as described in their paper: A Simulation Study of Military Land Equipment Available Under Corrective and Preventative Maintenance Regimes. Logistic and support factors influence availability levels- identifying, understanding and analyzing these influences helps understand how they can be effectively and efficiently employed in the relative supply chains and logistics networks.

Using the Canadian Armed Forces Land Equipment as the basis of the study, the impact of different maintenance regimes on the operational availability was simulated- with maintenance cost considered an imperative simulation metric. The discrete event simulation model was implemented in ARENA software, simulating the Corrective Maintenance, Scheduled Preventative Maintenance and Condition Based Maintenance maintenance regimes. Corrective maintenance is triggered by system failures- when the system fails, a diagnostic test is carried out to pinpoint the exact fault which is then repaired. Scheduled Preventative Maintenance involves repair tasks that take place at scheduled intervals to reduce the likelihood that failure will occur. Triggered by a decision making system, the likelihood of failure of particular parts are predicted. This prediction is based on the current state of the system if maintenance has not taken place within a certain period of time. This is the basis of the Condition Based Maintenance regime.

Several contributors of operational availability were taken into consideration and are listed below:

- TSS: time to supply spares;
- TFD: time for failure diagnostics;
- TMT: time on mission tasks;

- NOT: non-operating time;
- TTR: time to repair;
- SBT: standby time;
- DWT: downtime; and
- TCT: task cycle time.

Figure 2.4 has been included below to illustrate the time hierarchy of operation availability in Jentsch and Boukhtouta's study:

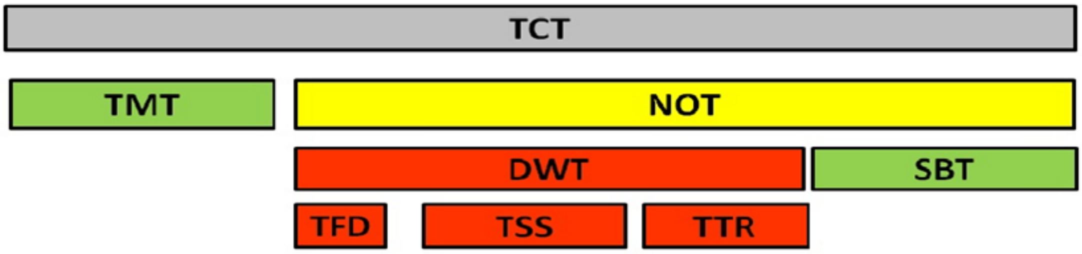

Figure 2.4: Time Subdivision Hierarchy for Vehicle Operational Availability Measurements

Operational availability was calculated as follows:

$$Ao = \frac{uptime}{uptime + downtime} = \frac{TMT + SBT}{TMT + SBT + TSS + TTR} \tag{2.6}$$

Two levels of support were identified: task and base levels. Task level comprised of only Corrective Maintenance tasks, with base level consisting of Scheduled Preventative Maintenance and Condition Based Maintenance tasks. The cost metric was implemented in an incremental fashion. A task was allocated a fixed cost. Each time the task was completed, the simulation incremented the total cost by one and multiplied it by the fixed cost. For example, if the fixed cost of Task A was R50 and Task A was performed three times, the total cost would be R150.

Time was treated as a stochastic variable in the simulation model. System wear, a linear function of the time spent performing a task, was evaluated against a threshold value. If the system wear was found to be less than the threshold value, the vehicle would complete its current task and go in for maintenance. Once repaired, the system wear resets and the simulation will continue to run, adjusting system wear continuously. The task duration was set to 0.1 days. Probability distributions were allocated to each activity in the simulation, given by P_x. The mean and standard deviations of these distributions were given by M_x and S_x respectively. The subscript x refers to different activities:

- $x = t$: task;
- $x = n$: non-operating;
- $x = r$: repair;
- $x = s$: supply; and
- $x = f$: system wear.

The operational availability was plotted against the time between replacements, adjusting the Mean Task Duration to study the influence it has on the Wear Rate. Additionally, the operational availability was plotted as a function of time between replacements and the thresholds of Condition Based

Maintenance. Jentsch and Boukhtouta (2015) concluded that when the time between replacements increased, the need for Scheduled Preventative Maintenance lessened. The most effective and efficient regime was Condition Based Maintenance as most maintenance takes place when a failure occurs; it also saves time and money that may be wasted on unnecessary scheduled maintenance where failure could occur during the maintenance task itself. Scheduled Preventative Maintenance can increase the operational availability of equipment but this will require a significant cost growth.

Applicability:
Probability of failure of different assemblies of the missile will be used to predict the need for repair/life extension maintenance. Another objective of the simulation model is to maximise the availability of the missile: clients require a product that is operational for most of its life therefore long maintenance/repair duration will be undesirable. The breakdown for availability used in the study above will be adapted to this project to determine turnaround time and overall availability of Missile A.

Chapter 3

Research methodology

Due to the complexity of the system, a methodical approach was employed to complete this project. The primary method of data collection was through existing documentation (work packs and reports) and interaction with logistic support personnel involved with this project at Denel Dynamics ILS division.

3.1 Logistic support analysis

1. Preparation of the hardware breakdown structure for the missile using design information that was available.

2. Obtained information from FMECA and RCM analysis for the missile and identified current support tasks.

3. Complete the support task definition.

4. Determined the logistics resources required and their associated cost to complete each task.

3.2 Model development

There are 3 different methodologies currently employed to simulate models: system dynamics, discrete event and the more recent agent-based. The system dynamics approach is top down, utilised to address strategic issues when only information about the global dependencies of the system are available. Discrete event simulation is often used when a system can be described as a process by using a system level view. Agent based models are generally used when the focus is on individual entities and there is data available for these individual entities. This is referred to as the bottom down approach (AnyLogic, 2016).

Decision support systems often utilise simulations as tools, the most common being a discrete event simulation. Examples of this can be seen in warehouse planning. The physical implementation of solutions to large scale problems may be extremely costly and may take years to generate usable results. Simulation provides a platform whereby the system can be modeled and tested multiple times, allowing variation, in a low cost, time efficient method (Albrecht and Az, 2010). This provides the motivation behind the use of a discrete event simulation.

The concept design for the simulation model has been addressed in the preliminary report and served as a guide for the development of the simulation model. The model was programmed on AnyLogic PLE. It follows a similar thought process as the three level model described earlier in the literature review, with some changes to make it more specific to Denel Dynamics requirements.

3.3 Support concept development

Based on the results from the LSA process, a baseline concept and possible support concepts were developed for the following proposed scenarios:

1. All-up Round;

2. Split Round;

3. Local Client, and

4. Internationally based Client.

3.4 Support concept evaluation

This assisted in determining where (O-, I- or D-level) a support task can best be performed in order to decrease the LCC and increase the turnaround time of the missile. This makes up the most important part of the LORA.

1. Perform sensitivity analysis to determine the effect of variables in the modeled support concepts on LCC.
2. Compare each concept option based on their percentage difference in LCC.
3. Evaluate concepts based on the RAM attributes, making a comparison between options, to determine which concept yields the best availability of the weapon.
4. Consideration of overall turnaround time of the missile.
5. Recommendations made for the best support concept and suggestions for future study if necessary.

Chapter 4
Data analysis

4.1 Hardware breakdown

Missile A is comprised of a front section (MFS) and rear section (MRS), with each section comprised of several sub assemblies. Figure 4.1 below shows a schematic sketch of Missile A, indicating the important sub assemblies that will be included in this study:

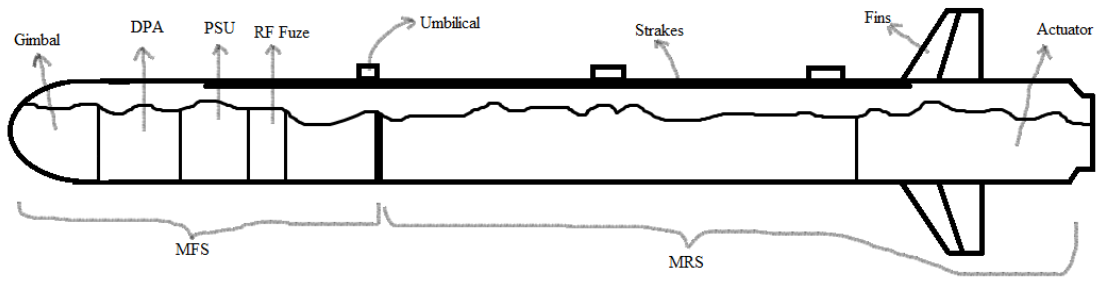

Figure 4.1: Missile A Sketch

Since the scope of this project is limited only up until Indenture level 2 sub assemblies of the missile, the following breakdown structure is applicable, as shown below in Figure 4.2:

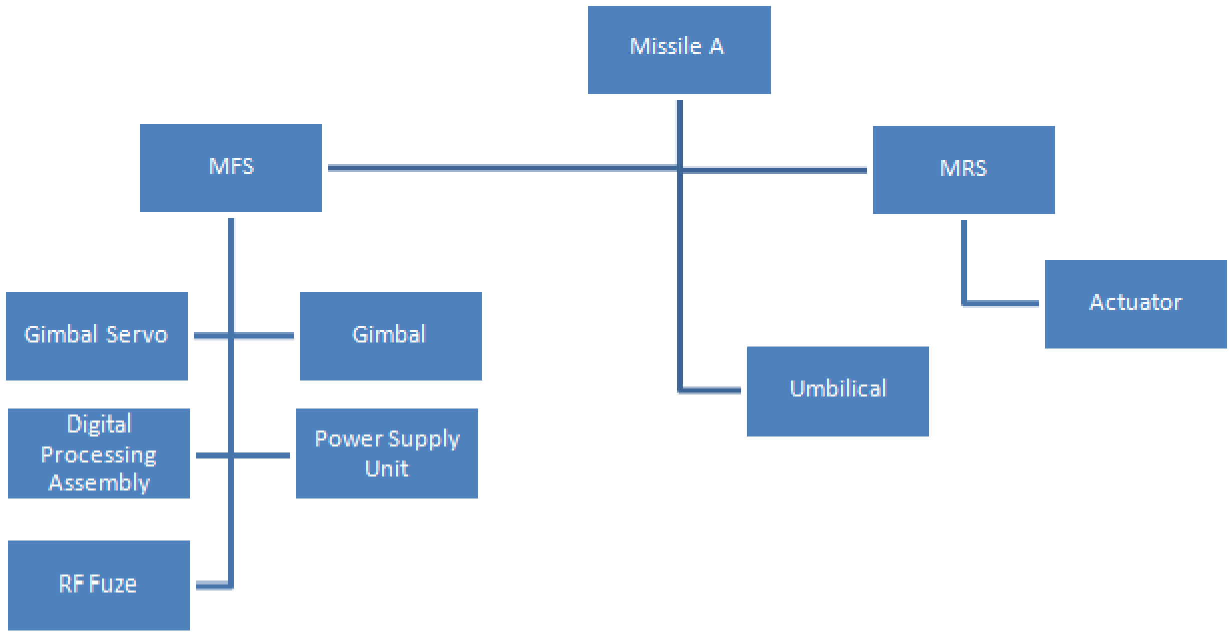

Figure 4.2: Hardware Breakdown Structure

4.2 Failure mode analysis

The following data was extracted from the work packages of Missile A, using a sample fleet of 41 operational missiles.

Table 4.1 below provides the failure rates and MTBF of the different elements of Missile A. The failure rate is given as follows: $\frac{1}{MTBF} \times 1000000$.

Indenture Level	System Element	Failure Rate	MTBF (hrs)
0	Missile A Round	3642.7333	275
1	Missile Front Section (MFS)	1493.5920	670
2	Gimbal Servo Assy	46.3972	21553
2	Gimballed Assy	534.1858	1872
2	Digital Processing Assy (DPA)	289.8687	3450
2	Fuze Assy	85.4217	11707
2	MFS Power Supply Assy (PSU)	503.7076	1985
1	Missile Rear Section (MRS)	2148.141	466
2	Warhead Assy	500	2000
2	Motor Assy	518	1931
2	Actuator Assy	677.2840	1476
1	Umbilical	1	1000000

Table 4.1: Reliability Forecast Data

Annual missile hours are calculated using the aircraft flying hours- there are 2 missiles on each aircraft:

$$Missile\ hours = Aircraft\ hours \times 2 \tag{4.1}$$

Since missiles are removed from the aircraft every 3 sorties (a sortie is one full flight), the installation/removal cycles are calculated as follows:

$$Install/remove\ cycle = number\ of\ sorties \times \frac{2}{3} \tag{4.2}$$

Therefore, the missile hours and installation/removal cycles are calculated and given in Table 4.2:

Aircraft Type	Missile Hours	Missile Install/Remove Cycles
Hawk	$4 \times 2 = 8$	$8 \times \frac{2}{3} = 5.333 \approx 5$
Gripen	$240 \times 2 = 480$	$151 \times \frac{2}{3} = 100.667 \approx 100$

Table 4.2: Annual Missile Hours and Installation Cycles

4.2.1 Failure forecast calculations

Using the information provided in Table 4.1 and Table 4.2, the following failure forecasts were calculations.

1. In-Use Failure: Operational Missile Failure per annum:

$$\frac{Missile\ Hours}{MTBF} = \frac{488}{275} = 1.775 \approx 1.8 \tag{4.3}$$

2. Handling Damage: This failure relates to the umbilicals, strakes, strakelets, launch shoes and missile airframe damage, such as scratches and indentations. Assuming damage occurs once per 500 handling cycles:

$$\frac{Missile\ Install/Remove\ Cycles}{500\ Handling\ Cycles} = 0.21\ per\ annum \tag{4.4}$$

$$Probability\ of\ failure = \lambda e^{-\lambda} = 0.21e^{-0.21} = 0.1702 (Poisson\ distributed) \tag{4.5}$$

3. Fatigue Life: The missile life is 300 hours, therefore the fatigue life:

$$Fatigue\ Life = \frac{488}{300} = 1.6727 \approx 1.6 \tag{4.6}$$

With a fleet of 41 missiles: $\frac{41}{1.6} = 25.625$ Since the life cycle of Missile A is expected to be 20 years, it is expected that there will be no potential fatigue life failure.

4. Sub-Assembly Failure Forecast: These are failures that require return to D-level for repair or replacement. It is calculated as follows: $\frac{Missile\ Hours}{MTBF}$. The sub-assemblies and their failure forecast are given below in Table 4.3:

Sub-Assembly	Failure Forecast
Gimbal Servo	0.0226
Gimbal	0.2607
PSU	0.2458
RF Fuze	0.0417
Actuator	0.3306
DPA	0.1414

Table 4.3: Sub-Assembly Failure Forecast

Using historical data, it was found that the MFS module of the missile has an 80% chance of being repaired as compared to the R&R option. Every effort is taken to repair the components. However, if it is found that the module is beyond repair, the R&R option will be chosen instead. The same applies for the actuator, however there is a higher possibility that it will be repaired; the chance of R&R is only 10%.

4.3 Support task identification

The support tasks that are currently required for the maintenance/repair for Missile A are:

- Fault identification;
- physical damage;
- remove and replace Umbilical cords;
- remove and replace fins;
- missile life extension;
- repair/replace MFS; and
- repair/replace Gimbal, PSU, DPA, RF Fuze and Actuator Assemblies.

Any pyrotechnic faults (or failure related to the explosive modules of the missile) are referred to Rheinmetal Denel Munition (Somerset West) for maintenance and are not handled by Denel Dynamics directly.

4.4 Support task definition

The support tasks mentioned above are further expanded, by the level at which they were originally performed. Below are the tasks currently allocated to **O-Level**:

- O-Level testing: The equipment used for this task has already been purchased and the cost accounted for with the support equipment costs. Therefore, the only additional attribute to this cost is labour, the O-Level technician.

- R&R for physical damage: The spares required for the umbilical are the umbilical itself and the 4 screws required to fasten the cord to the missile frame. The labour involved includes the O-Level technician and a worker.
- Storage: The storage costs include cost to keep the bunker environment controlled (eg. temperature control), insurance and security services.
- Transport to I-Level: This cost varies depending on where the O-Level and I-Level facilities are located. In addition to the actual cost of transportation, insurance is also taken into consideration.

Below are the tasks currently allocated to **I-Level**:

- I-Level testing: As with the O-Level testing equipment, the I-Level testing equipment has been purchased and the cost accounted for in the support equipment cost. The labour cost associated with this task is the cost of the I-Level technician and worker that will perform the testing.
- Split: The missile can be split before moving to D-Level from I-Level. The equipment required for this task has been purchased and the cost is included in the support equipment cost. Labour cost is included for the I-Level technician and a worker.
- R&R for physical damage: The spares required for the umbilical are the umbilical itself and the 4 screws required to fasten the cord to the missile frame. The labour involved includes the I-Level technician and a worker.
- Storage: The storage costs include cost to keep the bunker environment controlled (eg. temperature control), insurance and security services.
- Transport to D-Level: This cost varies depending on where the I-Level and D-Level facilities are located. In addition to the actual cost of transportation, insurance is also taken into consideration.

Below are the tasks currently allocated to **D-Level**:

- D-Level testing: As with the O- and I-Level testing equipment, the D-Level testing equipment has been purchased and the cost accounted for in the support equipment cost. The labour cost associated with this task is the cost of the D-Level technician and worker that will perform the testing.
- Life extension: This task requires launch shoes spares and penetration dye. The personnel involved includes: design/development engineer, support engineer, and a worker.
- Split: The missile must be split before moving to RDM from D-Level, as only the pyrotechnical components are sent to RDM, while the rest of the missile is kept in storage. The equipment required for this task has been purchased and the cost is included in the support equipment cost. However labour cost is charged for the support technician and worker.
- Move to RDM: The mode of transport used here is air travel as the missile pyrotechnical components must be flown to the Somerset West branch of Rheinmetal Denel Munition, in the Western Cape. Transportation by road may be risky as the components would be kept in an unstable environment for an extended period of time. If a vehicle with a controlled environment is utilised, the cost could be far more and will most likely increase the insurance cost too. Using a local airline, there is a standard charge for cargo, as well as an additional cost per kg charged for dangerous goods.
- RDM: An insurance cost is charged in addition to the actual cost of repairs.
- Move to back D-Level: Same cost involved as that moving the components to RDM.

- Combine: Reassembling the missile costs the same as a the splitting task as the same equipment ans personnel are used.
- Storage: The storage costs include cost to keep the bunker environment at D-Level controlled (eg. temperature control), insurance and security services.
- R&R for physical damage: The spares required for the umbilical are the umbilical itself and the 4 screws required to fasten the cord to the missile frame. The labour involved includes the D-Level support technician and a worker.
- Gimbal repair: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the physical repair cost, which is normally taken as 75% of the procurement cost of the module.
- R&R of Gimbal: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the cost of module spares.
- PSU repair: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the physical repair cost, which is normally taken as 75% of the procurement cost of the module.
- R&R of PSU: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the cost of module spares.
- RF Fuze repair: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the physical repair cost, which is normally taken as 75% of the procurement cost of the module.
- R&R of RF Fuze: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the cost of module spares.
- DPA repair: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the physical repair cost, which is normally taken as 75% of the procurement cost of the module.
- R&R of DPA: The labour cost for this task is made up of the specialist engineer, support engineer, D-Level technician and a worker. This is in addition to the cost of module spares.
- Actuator repair: The labour cost for this task is made up of the specialist engineer, support engineer, support technician and a worker. This is in addition to the physical repair cost, which is normally taken as 75% of the procurement cost of the module.
- R&R of actuator: The labour cost for this task is made up of the specialist engineer, support engineer, support technician and a worker. This is in addition to the cost of module spares.
- Integration: The integration equipment has been purchased and the cost accounted for in the support equipment cost. The labour cost associated with this task is the cost of the D-Level support engineer and a worker.
- Storage: The storage costs include cost to keep the bunker environment controlled (eg. temperature control), insurance and security services.

4.5 Support resource definition

Missile acquisition costs are initial costs incurred, such as the cost of the missiles. These costs are given below in Table 4.4:

Item	Unit Cost (Rands)
Operational Missile	3000000
Initial Spares Provisioning	3000000
Initial Staff Training Cost	500000
Total	**6500000**

Table 4.4: Missile Acquisition Costs

Facility level costs make up the total life cycle cost and are given below, in Table 4.5:

Item	Unit Cost (Rands)
Base O- and I-level establishment of infrastructure	3000000
Initial Documentation, Software and Data	2250000
General Support Equipment	1000000
Total	**12500000**

Table 4.5: Infrastructure Establishment Costs

All-up round and split round support equipment costs are shown below in Table 4.6 and Table 4.7 respectively:

Item	Unit Cost (Rands)
Functional All-Up Tester	800000
MFS Container	30000
MRS Container	35000
Missile (Integration) Bench	2500000
Integration Bench Staff Training	100000

Table 4.6: All-Up Round Support Equipment Costs

Item	Unit Cost (Rands)
MFS Bench	300000
Additional Documentation for Split Round	500000
MRS Bench	500000
Missile (Integration) Bench	2500000
MFS Container	30000
MRS Container	35000
Transport Containers for Modules	3000
Integration Bench Staff Training	100000

Table 4.7: Split Round Support Equipment Costs

Recurring Costs Over 20 Years:
Recurring costs are, as a rule, calculated as a percentage of the initial cost. Since the expected lifetime of the missile is 20 years, the costs are calculated as follows: $Initial\ Cost \times \% \times 20$, as seen below in Table 4.8.

Item	Annual Recurring Cost (%)	All-Up Round	Split Round
Base O- and I-level Infrastructure Maintenance	5	3 000 000	3 000 000
Documentation, Software and Data Support	5	2 250 000	2 250 000
Additional Documentation for Split Round	5		500 000
General Support Equipment Maintenance	5	1 000 000	1 000 000
Functional All-Up Tester	6	960 000	960 000
MFS Container Maintenance	10		600 000
MRS Container Maintenance	10		700 000
Module Transport Container Maintenance	10		270 000
MFS Bench Maintenance	6		360 000
MRS Bench Maintenance	6		600 000
Missile Integration Bench Maintenance	6		3 000 000
Maintenance Staff Training	7	700 000	700 000
Integration Bench Staff Training	7		140 000
	Total	**7 910 000**	**14 080 000**

Table 4.8: Recurring Costs

Personnel costs vary depending on the maintenance level as well as the skill level of the employee. Table 4.9 below summarises the cost generated by individual classes of labour:

Personnel	Cost (R/hr)
O-Level Technician	400
I-Level Technician	500
O- and I-Level Worker	75
D-Level Worker	75
Support Technician	400
Production Technician	350
Support Engineer	450
Design/Development Engineer	500
Specialist Engineer	650
D-Level Technician	680

Table 4.9: Personnel Costs

Transportation is required to move the missiles between levels and between Denel Dynamics and RDM. This influences the total cost of support concepts as large distances are often covered, with air travel being the primary mode of transport in most cases and transport by road for shorter distances. Cruise speed of the cargo aircraft is given to be approximately 300mph, while road travel is an approximate 25m/s. The cost for road travel is calculated as R40/km and air travel is R239.10 plus an additional R46.46 per kg of dangerous goods. Table 4.10 below presents these transport costs:

From	To	Approx. Distance (km)	Approx. Speed (m/s)	Approx. Time (hrs)
Local O-Level	Local I-Level	180	25	2
Local I-Level	D-Level	540	25	6
International client O-Level	International client I-Level	415	25	4.617
International client I-Level	D-Level	6000	140	11.9
D-Level	RDM	1092	140	2.167

Table 4.10: Transportation Costs

Spares costs are summarised below in Table 4.11:

Task	Spares cost (Rands)
R&R of umbilical	80200
Life extension	1020
RDM	300000
Gimbal R&R	65500
Gimbal repair	49125
PSU R&R	110000
PSU repair	82500
DPA R&R	96000
DPA repair	72000
RF Fuse R&R	57000
RF Fuse repair	42750
Actuator repair	47500
Actuator R&R	95000

Table 4.11: Spares costs for tasks

Sundry expenses are also taken into account. Insurance for storage is calculated for goods worth R15 million or more. The insurance for storage is charged at 0.0325% of the value of the goods. The insurance on goods in transit differs, depending on the mode and distance traveled. The storage facility cost is R35/sqm, and the I- and D-Level storage facilities are an estimated 100sqm each. The O-Level storage facility is an estimated 50sqm. For the purpose of this project, it is assumed that insurance is always charged. given in Table 4.12 below:

Task	Cost (Rands)
O-Level Storage (Facility cost and Insurance + Security)	$5800 + 100 * 24hr = 8200$
Transport to I-level (Insurance)	$500 * 2hr = 1000$
I-Level Storage (Facility cost and Insurance + Security)	$6100 + (120 * 24hr) = 8980$
Transport to D-level (Insurance)	$500 * 6hr = 3000$
Insurance for components sent to RDM	$250 * 72hr = 18000$
Storage at D-Level (Facility cost and Insurance + Security)	$2500 + 1500 = 4000$

Table 4.12: Sundry expenses

The approximate task duration addressed in the simulation are shown below in Table 4.13:

Task	Duration (the mode given in hours)
O-Level testing	0.5
R&R for physical damage at O-Level	0.5
O-Level storage	24
Transport to I-Level	2 (Local client), 4.617 (International client)
I-Level testing	0.5
I-Level split	1
R&R for physical damage at I-Level	1
I-Level storage	24
Transport to D-Level	6 (Local client), 11.9 (International client)
D-Level testing	1
Life extension	20
D-Level split	1
Move to RDM	2.69
Pyro repair at RDM	72
Move to back D-Level	2.69
Combine	1
D-Level storage	24
R&R for physical damage at D-Level	1
Gimbal repair	12
R&R of Gimbal	8
PSU repair	14
R&R of PSU	8
DPA repair	14
R&R of DPA	8
RF Fuse repair	10
R&R of RF Fuse	8
Actuator repair	20
R&R of actuator	15
Integration	1.5

Table 4.13: Task duration

Chapter 5

Model design

A discrete event simulation-based model was employed and programmed on AnyLogic PLE version 7.3.5 software to represent the support system of Denel Dynamics. A similar thought process as the three level model described earlier in the literature review forms the basis of the model; the logical flow of the missile through the different levels of support was modeled. The process model library was utilised to achieve the closest possible resemblance to the actual maintenance system. A general flow diagram is given below in Figure 5.1 to indicate the flow between levels.

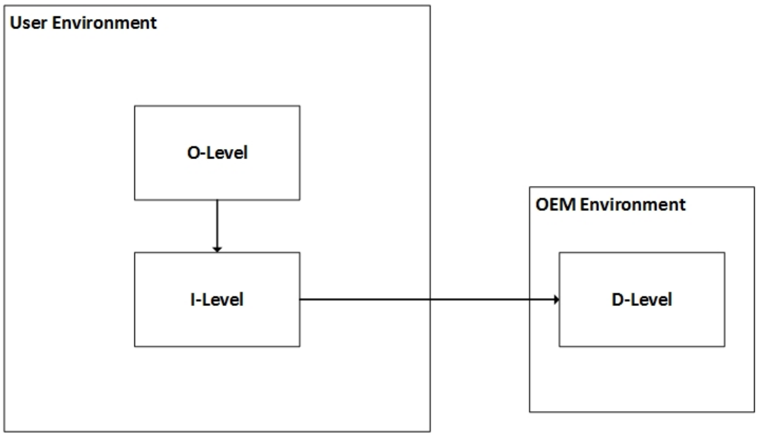

Figure 5.1: General Flow of Missile Between Support Levels

Refer to Appendix B and Appendix C for the detailed flow diagrams for O-, I- and D-level. The legend for these diagrams can be found in Appendix D.

Level 1 represents O-level, Level 2 represents I-level and Level 3 represents D-level. The levels are further distinguished by coloured space markups. Please refer to Appendix E to view the model. O-Level begins with the source block that injects agents (refers to the missiles) into the model. The interarrival time corresponds with the sortie duration that each missile flies; the missile is tested between every sortie. Agents can also be manually injected into the system with the use of a button. A parameter is used to track the number of missiles that are in the maintenance system at any given time. This assists is calculating the availability of the missiles for the user. The agent then passes through the timeMeasureStart block. This enables tracking of how long the missile remains in the level, with the help of a corresponding timeMeasureEnd block located just before the missile leaves the level.

The agent then moves to the selectOutput block which evaluates the availability of tasks at O-Level, with the use of a decision variable. The user utilises a tick box to indicate whether they would prefer for O-Level to be available or not. This effectively switches the level on or off. If O-Level is available, the agent moves to a delay block, representing the O-Level Testing Equipment. The delay (and all other delay blocks used in this model) is preceded by a queue block. This provides a buffer, which is inevitably required and serves to make the model more realistic.

Another selectOutput is encountered, which evaluates the condition for whether a fault is detected in the missile. If the condition returns true, the missile moves to the conveyor bloc which simulates the movement from O-Level to I-Level. The distance and speed of the conveyors in the model are input by the user in the allocated edit boxes. This enables the user to adjust the scenario for different clients, where the movement between levels will differ due to different locations. The agent then leaves O-Level through the exit block that routes the agent to the next level. If a fault is not detected, the agent will move to the selectOutput block to determine if there is physical damage on the missile. If the condition returns true, the model checks if the remove and replace (R&R) task is available at this level. If the condition returns false, the agent will move directly to the conveyor to be transported to the next level where the task can be completed; otherwise it moves to the remove and replace task delay block. Thereafter it moves to storage (modeled using a wait block) before moving to the sink. If no damage is detected, the agent moves immediately to the storage.

I-Level begins with the enter block, linked to the exit block from O-Level. The process in I-Level is similar to that of O-Level with one exception: a splitting task is included before moving the agent to the conveyor that simulates the movement from I-Level to D-Level. A selectOutput is included to allow the user to specify if the missile is split at I-Level or not.

D-Level begins with an enter block that corresponds with the exit block from I-level. The agent goes through the D-Level testing equipment to ascertain that fault does indeed exist. The first selectOutput block determines whether the missile requires life extension. The condition relies on the 300 flight hour rule. If life extension is required, the task is carried out (modeled as a delay block); thereafter the agent moves to another selectOutput to check for pyrotechnical failure. If not, the agent moves directly to the selectOutput block to check for pyrotechnical failures.

If the condition evaluates to true, the agent passes to the split block. This block simply makes a copy of the agent and sends them through two separate ports. Since specific characteristics have not been allocated to agents, this method does not conflict with the logic of the model. One agent moves to storage (a wait block) and the other to the process involved with sending the missile to RDM for pyrotechnical support. This is modeled using a delay block that resembles the task time taken to correct the problem, preceded and succeeded by conveyors (simulating the movement between the D-Level facility and the RDM facility in Somerset West). Once the agent arrives back at D-Level via the second conveyor, the corresponding agent from the wait block is released and they are combined again via the combine block.

The agent passes through a selectOutput block that detects physical damage. If true, it moves through the R&R delay block and then checks for other faults via another selectOutput. Otherwise, the agent will move directly to check for other faults. Other faults that could occur are the MFS component failures and the actuator failure. For both these scenarios, two options exist and have been modeled: repair or remove and replace the whole component. After the repair or R&R task has been completed, the missile is integrated, represented by a delay block and sent to the storage wait block.

Although the delay blocks have been programmed to have a duration that ranges from a specified minimum and maximum with a mode (triangularly distributed), it is important to calculate the exact time taken by each task. This data was used to calculate the turnaround time of the missile. It was also used to calculate costs in instances where cost depends on the duration of the task. An example of this is the labour cost associated with the tasks, which are calculated in terms of some rate of Rands per hour. Each task was given a cost, modeled using a parameter. If the task was performed, the cost was calculated and added to a total life cycle cost.

An animation was created to accompany the process model, shown in Appendix F.

Chapter 6

Base case

The base case is for the local client, making use of a three level, all-up round support concept. O-Level comprises of O-Level testing and the R&R task for physical damage. I-Level comprises of I-Level testing and the R&R task for physical damage, while the splitting task is unavailable for I-Level. D-Level remains with standard capabilities.

The task duration for the base case is the same as that given in Table 4.13, keeping in mind that I-Level splitting is unavailable for this concept.

The life cycle cost is calculated as follows:

$$LCC = Acquisition + Infrastructure + Support\,equipment + Recurring\,cost + Individual\,task\,cost \tag{6.1}$$

The individual task cost encompasses the total cost of the task- the inventory (spares), labour and transportation required by each level. Total LCC is calculated and presented in Table 6.1. An allowable error of 5% was specified for comparison with the results from the simulation.

Activity	**Calculation**	**No. of missiles**	**Total cost (Rands)**
Acquisition	$6500000 * 41$		266500000
Infrastructure establishment	$[(3000000 + 2250000 + 1000000) * 2]$		12500000
All-up round support equipment	$(800000*2)+[(30000+35000)*41]+2500000+100000$		6865000
Recurring cost	refer to Table 4.8		7910000
Individual task costs			
O-Level:			
OLTE	$400 * 0.5$	41	8200
R&R	$80200 + (400 * 0.5) + (75 * 0.5)$	2	160875
Storage	$5800 + (100 * 24)$	9	73800
Transport to I-Level	$(40 * 180) + (500 * 2)$	32	262400
I-Level:			
ILTE	$(500 * 0.5) + (75 * 0.5)$	32	9200
Split	$(500 * 1) + (75 * 1)$	0	0
R&R	$80200 + (500 * 1) + (75 * 1)$	1	80775
Storage	$6100 + (120 * 24)$	4	35920
Transport to D-Level	$(40 * 540) + (500 * 6)$	28	688800
D-Level:			
DLTE	$(400 * 1) + (75 * 1)$	28	13300
Life Extension	$1020 + (500 * 20) + (450 * 20) + (75 * 20)$	23	494960
Move to RDM	$239.10 + (46.46 * 89)$	5	21870.2
RDM	$300000 + (250 * 72)$	5	1590000
Move to D-Level	$239.10 + (46.46 * 89)$	5	21870.2
Split	$(400 * 1) + (75 * 1)$	5	2375
Combine	$(400 * 1) + (75 * 1)$	5	2375
Storage	$2500 + 1500$	5	20000
R&R for physical damage	$80200 + (400 * 1) + (75 * 1)$	4	322700
Repair Gimbal	$49125 + (680 * 12) + (650 * 12) + (450 * 12) + (75 * 12)$	2	142770
R&R for Gimbal	$65500 + (680 * 8) + (650 * 8) + (450 * 8) + (75 * 8)$	1	80340
Repair PSU	$82500 + (680 * 14) + (650 * 14) + (450 * 14) + (75 * 14)$	3	325410
R&R for PSU	$110000 + (680 * 8) + (650 * 8) + (450 * 8) + (75 * 8)$	1	124840
Repair RF Fuse	$42750 + (680 * 10) + (650 * 10) + (450 * 10) + (75 * 10)$	1	61300
R&R for RF Fuse	$57000 + (680 * 8) + (650 * 8) + (450 * 8) + (75 * 8)$	1	71840
Repair DPA	$72000 + (680 * 14) + (650 * 14) + (450 * 14) + (75 * 14)$	1	97970
R&R for DPA	$96000 + (680 * 8) + (650 * 8) + (450 * 8) + (75 * 8)$	1	110840
Repair Actuator	$47500 + (650 * 20) + (450 * 20) + (400 * 20) + (75 * 20)$	3	237000
R&R Actuator	$95000 + (650 * 15) + (450 * 15) + (400 * 15) + (75 * 15)$	1	118625
Integration	$(450 * 1.5) + (75 * 1.5)$	28	22050
Storage	$6100 + (200 * 24)$	28	305200
Total			**297670735.2**

Table 6.1: Life cycle cost for base case

Chapter 7

Analysis of base case results

After running the base case in the simulation multiple times to ensure all 41 missiles in the fleet were sent in for maintenance once, five runs were chosen that best represented the various results produced, shown in Table 7.1:

Run 1	R297 968 453.031
Run 2	R298 184 916.052
Run 3	R299 112 540.328
Run 4	R299 277 247.66
Run 5	R298 858 521.267

Table 7.1: Base case results from simulation

The average is R298 680 335.7 which, as compared to the base case hand calculations, is R1 009 600.5 more than that which was expected. The percentage error is therefore:

$$\%Error = abs[\frac{1009600.5}{297670735.2}] \times 100 = 0.3392 \quad (7.1)$$

This error is acceptable and within the specified allowable deviation.

The individual task duration calculated in the simulation yield results that are consistent with the base case model and shown in Table 7.2 below. It is important to mention that the R&R tasks for the RF Fuze and actuator were each only performed once in the five runs. This is not unusual as there is only a 20% and 10% possibility that the RF Fuze and actuator respectively would be replaced completely. The R&R task at I-Level was also only performed once in the five runs; this is justified as it is unlikely that the physical damage will not be detected and handled at O-Level if O-Level is available.

Task	Run 1	Run 2	Run 3	Run 4	Run 5	Average
OLTE	0.583	0.503	0.517	0.52	0.551	0.5348
O-Level R&R for physical damage	0.421	0.435	0.41	0.461		0.4318
Move to I-Level	2	2	2	2	2	2
O-Level storage	24	24	24	24	24	24
ILTE	0.491	0.512	0.505	0.498	0.657	0.5326
I-Level R&R for physical damage				1.244		1.244
Move to D-Level	6	6	6	6	6	6
I-Level storage	24	24	24	24	24	24
DLTE	1.09	0.987	0.986	1.047	0.889	0.9998
Life Extension	18.702	19.342	17.32	18.271	19.074	18.542
Move to RDM	2.69	2.69	2.69	2.69	2.69	2.69
RDM	72.425	83.08	61.595	91.799	71.975	76.175
Move to back to D-Level	2.69	2.69	2.69	2.69	2.69	2.69
D-Level Split	2.1	2	1.78	2.1	1.88	1.972
D-Level Combine	1.662	1.62	2.2	2.11	1.97	1.912
D-Level R&R for physical damage	1.053	1.036	0.937	1.014	0.779	0.9638
Gimbal Repair	11.786	12.751	13.323	11.428	11.412	12.14
Gimbal R&R		7.9	5.576		6.783	6.753
PSU Repair	16.487	16.727	15.428	14.001	13.363	15.2012
PSU R&R	6.575	9.009	8.495	8.065		8.036
RF Fuze Repair		12.592		12.174	12.056	12.274
RF Fuze R&R					6.222	6.222
DPA Repair	14.156	13.362		14.413	16.185	14.529
DPA R&R	8.905		7.306			8.1055
Actuator Repair	19.568	21.732	20.716	22.545	20.184	20.949
Actuator R&R		12.347				12.347
Integration	1.247	1.473	1.755	1.413	1.806	1.5388
D-Level storage	24	24	24	24	24	24

Table 7.2: Duration of tasks from simulation

The time taken by the missiles at each level are also plotted, and included in Appendix G, to determine the average time that a missile spends at a particular level. With the duration that the particular missile spent in the level plotted on the Y-axis (given in hours) and time that the missile entered the level plotted on the X-axis (in model units), the scatter plot feeds data directly to the frequency distribution or Histogram plot. This helps assess what duration of time was the most frequently spent at a particular level. As seen from the graphs, missiles spend an average of 0.5 to 0.6 hours at O-Level, 6.5 to 6.6 hours at I-Level and between 20 to 35 hours at D-Level. This does not include the storage time.

It can be concluded from this that the model yields results consistent with the current method of support concept evaluation. This implies that the model is calibrated.

To understand the impact of this concept over the entire lifetime of the missile fleet, the simulation was run for a period of 20 years. The results generated showed an LCC of R378 042 736.56 of the 20 year life span, with the availability of missiles ranging between 37 and 41 at any given time. The turnaround time per missile was 48.4 hours, consistent with that of the analysis done above.

A general time study was also conducted to evaluate the impact that the simulation would have in terms of the amount of time required to test a concept. Running the base case in the simulation as opposed to creating a spreadsheet in Excel results in just over a 3 hour difference; this is a significant efficiency factor, with the percentage difference given below:

$$\frac{4.76 - 1.52}{4.76} \times 100 = 68.067\% \tag{7.2}$$

Chapter 8

Alternative concepts

Multiple concepts were tested over a 3 year time period on the model to evaluate solutions for different client requirements. Normal delays were not taken into consideration in the model, but a total delay of 8 weeks can be experienced due to unforeseen circumstances. Using the MAUT decision analysis, attributes and utility weighting (between 1 and 5) shown in Table 8.1 were used to choose appropriate concepts. The range and weighting of the three attributes are also shown in Table 8.2, Table 8.3 and Table 8.4.

Attribute	Weighting
LCC	4
Availability	4
Turnaround Time	3

Table 8.1: Attribute weighting

Range (Rands)	Weighting
250000000 - 279999999	5
280000000 - 309999999	4
310000000 - 339999999	3
340000000 - 369999999	2
370000000 - 399999999	1
$\geq$ 400000000	0

Table 8.2: LCC weighting

Range (No. of missiles)	Weighting
41 - 39	5
38 - 36	4
35 - 33	3
32 - 30	2
29 - 27	1
$\leq$ 26	0

Table 8.3: Availability weighting

Range (hours)	Weighting
$\leq$ 49	5
50 - 53	4
54 - 57	3
58 - 61	2
62 - 65	1
$\geq$ 65	0

Table 8.4: Turnaround time weighting

8.1 Local Client

The local Client Z has the following requirements:

- The split round method must be adopted if there is an I-Level, whereby the missile is split at I-Level before moving to D-Level.
- The R&R tasks must be available at every level.
- The stock of missiles must not be less than 35 at any given time.

Two concepts were tested. The first was a three level, split round concept. The second was a two level, all up round concept. Since only O-Level and D-Levels were available and the O-Level at the user environment lacks capabilities to split the missile before moving it to a different level, splitting the missile between levels is not possible.

Local three level split round concept: The model yielded an LCC of R307 107 045.4, with the stock of missiles hovering around an average of 33 missiles at any given time. This means that the user has 33 missiles available, while 8 missiles are away for maintenance and/or repair at any given time. As indicated by the graphs given in Figure 8.1, the majority portion of missiles spend approximately 0.5294 hours at O-Level, 7.475 hours at I-Level and 47.06 hours at D-Level. This results in an average turnaround time of 55.06 hours per missile.

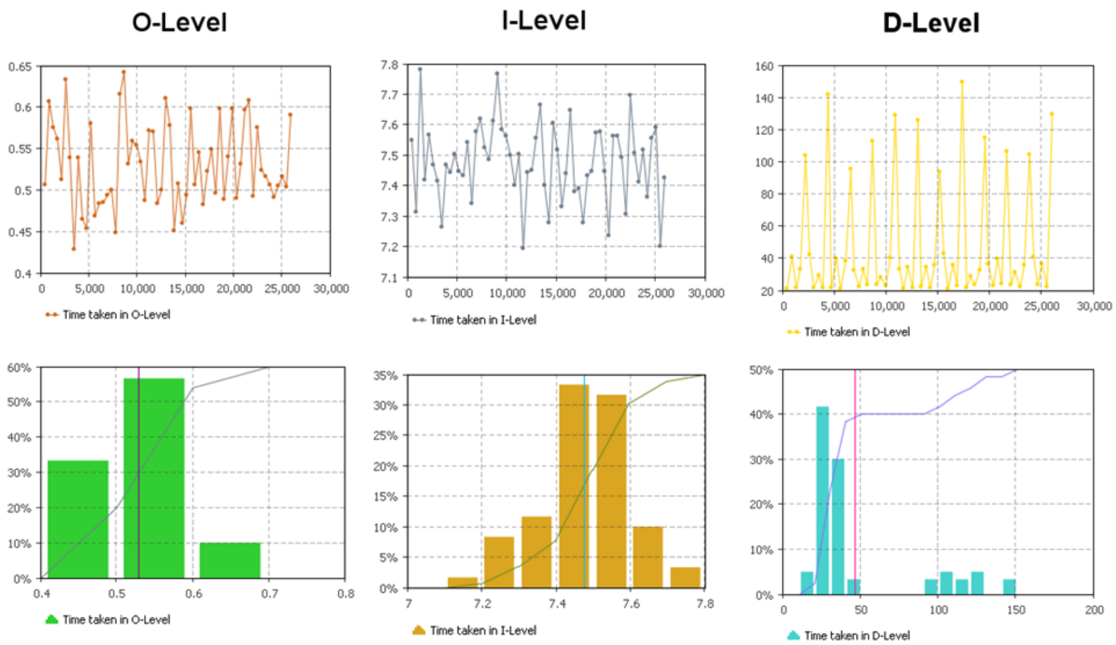

Figure 8.1: Local three level split round concept results for time

Local two level all-up round concept: The model yielded an LCC of R301 598 727.3, with the stock of missiles hovering around an average of 36 missiles at any given time. This means that the user has 36 missiles available, while 5 missiles are away for maintenance and/or repair at any given time. As indicated by the graphs given in Figure 8.2, the majority portion of missiles spend approximately 0.5294 hours at O-Level and 47.06 hours at D-Level, bypassing the I-Level. This results in a decreased average time of 47.585 hours for the missile to return to the user.

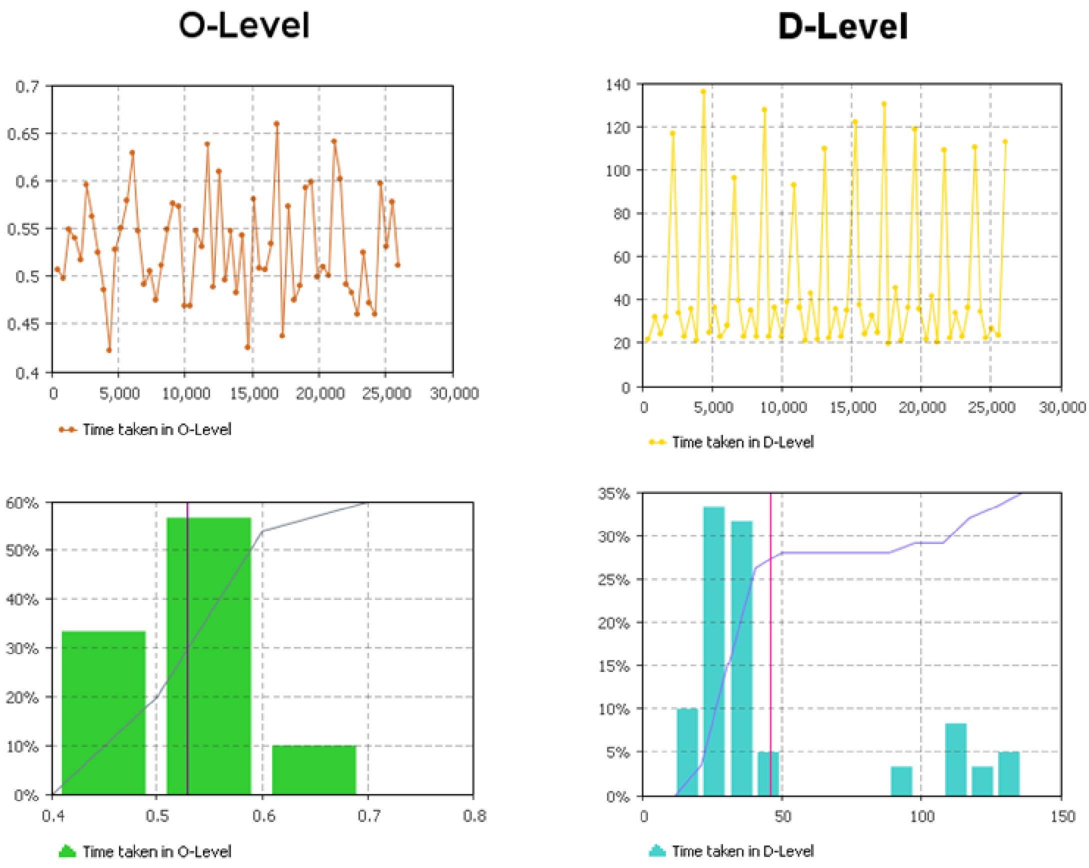

Figure 8.2: Local two level all-up round concept results for time

The difference in LCC between the two concepts is given below:

$$\frac{307107045.4 - 301598727.3}{307107045.4} \times 100 = 1.794\% \qquad (8.1)$$

The difference in availability of the fleet is calculated as:

$$\frac{36 - 31}{36} \times 100 = 13.89\% \qquad (8.2)$$

The MAUT analysis for the alternatives produces the following results. Let 1 be the three level split round concept and 2 be the two level all-up round concept.

$$U(1) = (4 \times 4) + (3 \times 4) + (3 \times 3) = 37U(2) = (4 \times 4) + (4 \times 4) + (5 \times 3) = 47 \qquad (8.3)$$

The difference in results, along with the MAUT analysis results, indicates that the second concept (two level all-up round concept) would be more suitable for Client Z, as it complies with the availability requirement and the LCC is lower than that of the first concept. The turnaround time of the second concept is also more favourable than that of the first concept and the MAUT score is 27.02% more than that of the first concept.

8.2 International Client

The international Client X has the following requirements:

- A three level support concept that can either be all-up round or split round.
- The fleet should not reduce to less than 35 at any given time.
- R&R tasks must be available at every level.

The all-up round and split round concepts were both tested on the model.

All-up round concept: The model produced a life cycle cost of R320 111 286. The stock size ranged between 34 and 37, implying that at any given time, between 4 to 7 missiles were in maintenance. As indicated by the graphs given in Figure 8.3, missiles spent approximately 0.5412 hours at O-Level, 12.43 hours at I-Level and 42.85 hours at D-Level. This results in an average turnaround time of 55.8212 hours per missile.

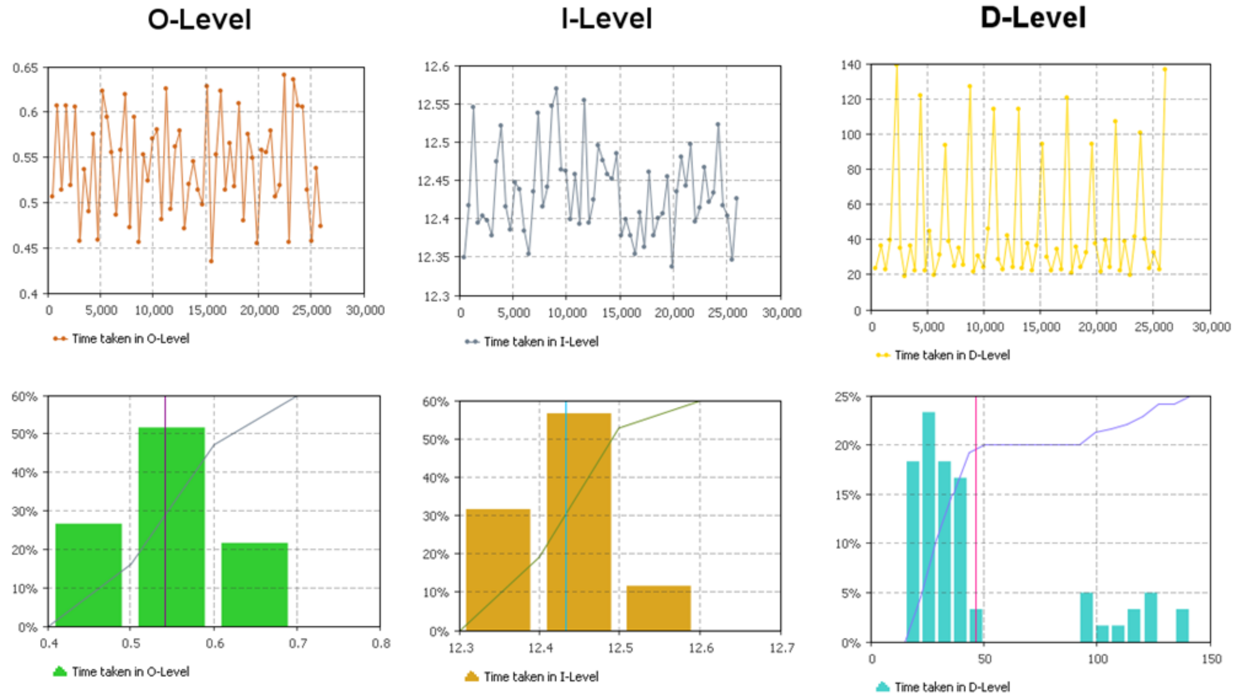

Figure 8.3: International all-up round concept results for time

Split round concept: The only difference between this concept and the all-up round concept is that the splitting task is available at I-Level in the Split round concept. The life cycle cost produced by the model is R319 436 771.04, with a stock of 34 missiles at any given time. The turnaround time was calculated to be 59.39 hours, following from the results shown in Figure 8.4. The average time spent in O-Level is 0.5412 hours, 13.4 hours in I-Level and 45.45 hours in D-Level.

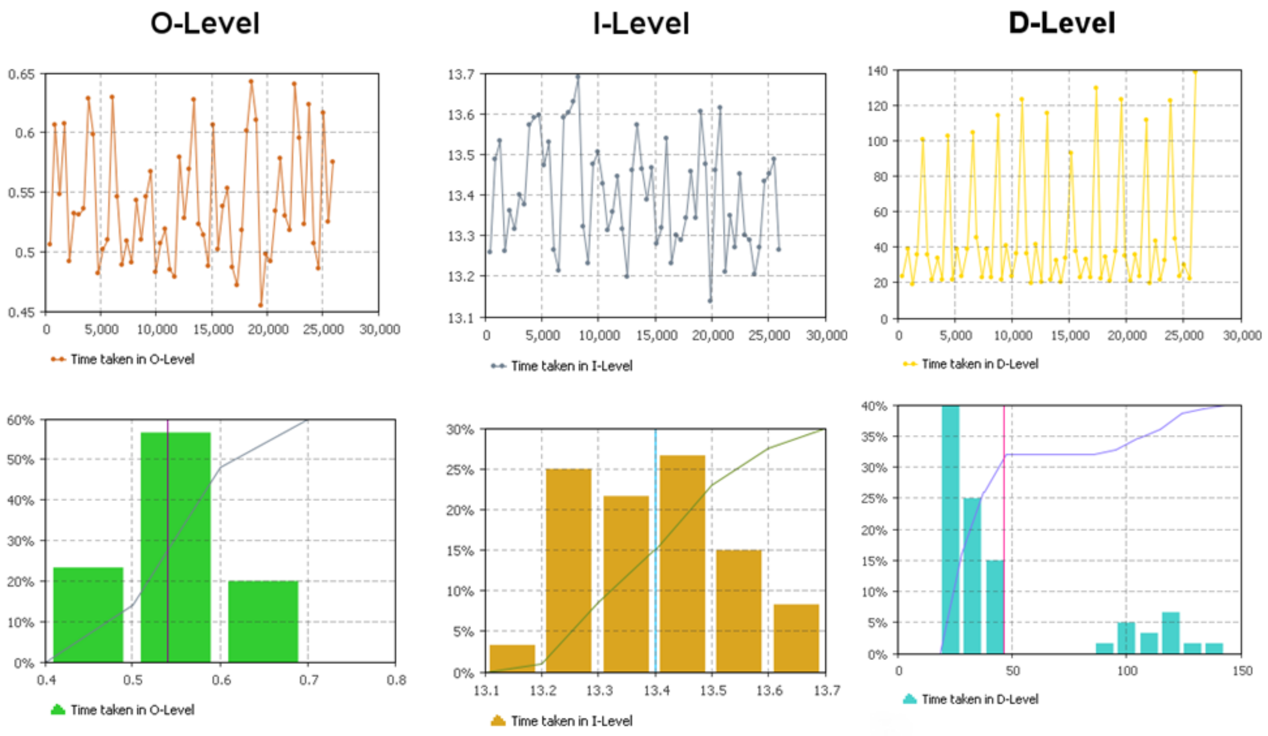

Figure 8.4: International split round concept results for time

The MAUT analysis for the alternatives produces the following results. Let 1 be the all-up round concept and 2 be the split round concept.

$$U(1) = (3 \times 4) + (4 \times 4) + (3 \times 3) = 37U(2) = (3 \times 4) + (3 \times 4) + (2 \times 3) = 30 \quad (8.4)$$

The MAUT score of the all-up round concept is 23.33% more than that of the split round concept. It is therefore more prudent for Client X to choose the all-up round concept, rather than the split round concept. Although the life cycle cost incurred by the all-up round concept is R674 514.96 more than the split round concept, the turnaround time for the split round concept is more than that of the all-up round concept. This outweighs the LCC difference, which is only 0.2114%. The availability of missiles for the all-up round concept does vary about the given required availability, however, this variation can be reduced by improving the efficiency at the user's O-Level or I-Level.

Chapter 9

Conclusion

The ILS division of a company can prove to be a valuable strategy in order to improve processes internally. Externally, the increased capability of the company to provide post production services to clients improves their ability to reach company goals. The service cannot just be compliant with user requirements; it must also be a viable and realistic option for Denel Dynamics. With operations and support making up approximately two thirds of the total life cycle cost of the weapon (Shukla et al., 2014), it is imperative to manage these processes, formalize them and continually improve them using advanced technology and more in depth analyses.

That being said, the goal of this project was to create a model that will assist with key decision making regarding support concepts, providing an innovative approach to ILS within the company. It allows the supportability engineers to study different support concepts, identify opportunity to reduce the life cycle cost, evaluate the RAM of the weapon and identify improvement areas to be addressed in the future.

From the literature review, it was concluded that the best solution was to develop a discrete event simulation model that represents the three level support system of Denel Dynamics. The data for the model was been extracted using the logistic support analysis methodology. The model built in AnyLogic allows for quick manipulation of the support concept to simulate different options. The model generates a total life cycle cost and turnaround time as an output, to evaluate the concepts against each other, with a small, acceptable degree of error when compared to the baseline case. From the analysis of the results, it can be concluded that the simulation will be a valuable and efficient tool for use in the ILS department.

The proposed scenarios simulated reveal that the most promising concept for the local client is the two level, all-up round concept. The three level, all-up round concept was recommended for an international client. These decisions were based on the comparison between the turnaround time, availability and LCC results of the alternatives run in the simulation.

For future expansion of this project, it would be beneficial to add all the D-Level tasks to O- and I-Level to allow increased flexibility and a wider variety of concept alternatives to be tested. The normal delay time caused by administration and logistics should be addressed in the model to improve accuracy and provide a better view of the turnaround time and availability of the missile. Furthermore, the practice inert and acquisition missile variants should also be addressed to include the entire product range.

The output of this project will improve the service offered to clients, improving current relations with clients, assisting in growing the client base and ultimately stimulating growth potential of the company. Taking into consideration that Denel Dynamics is a state owned company, any growth of the company concludes in the growth of the South African economy.

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Appendix A

System equipment life cycle

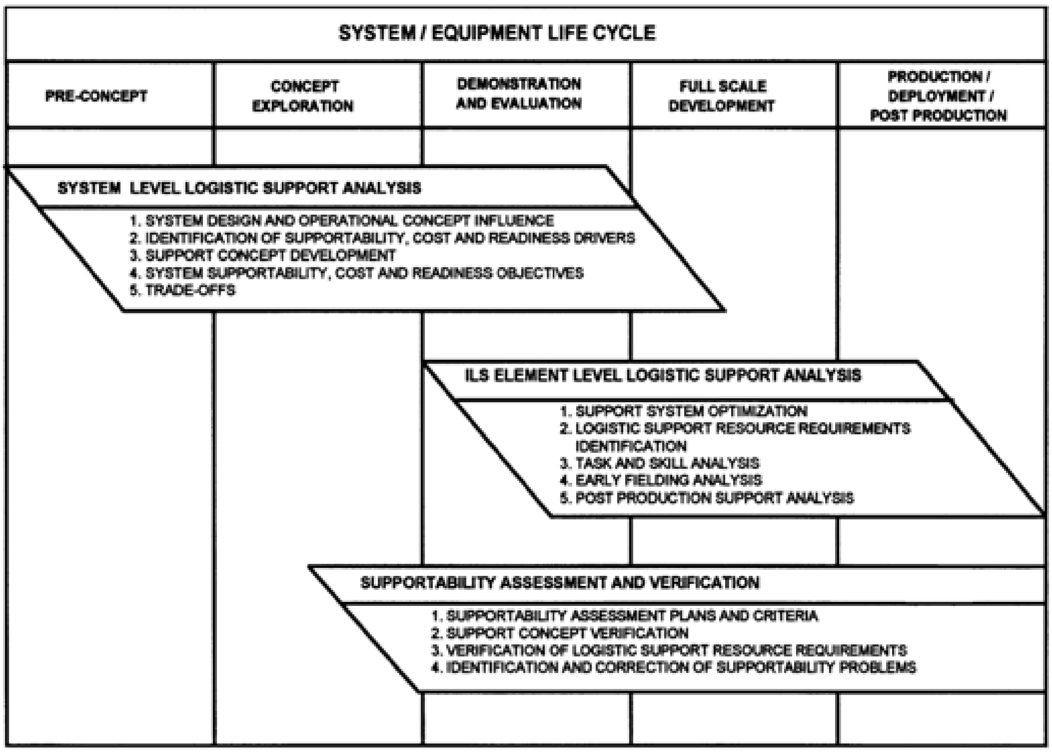

Figure A.1: System Equipment Life Cycle

Appendix B

O- and I-level support concept design flow diagram

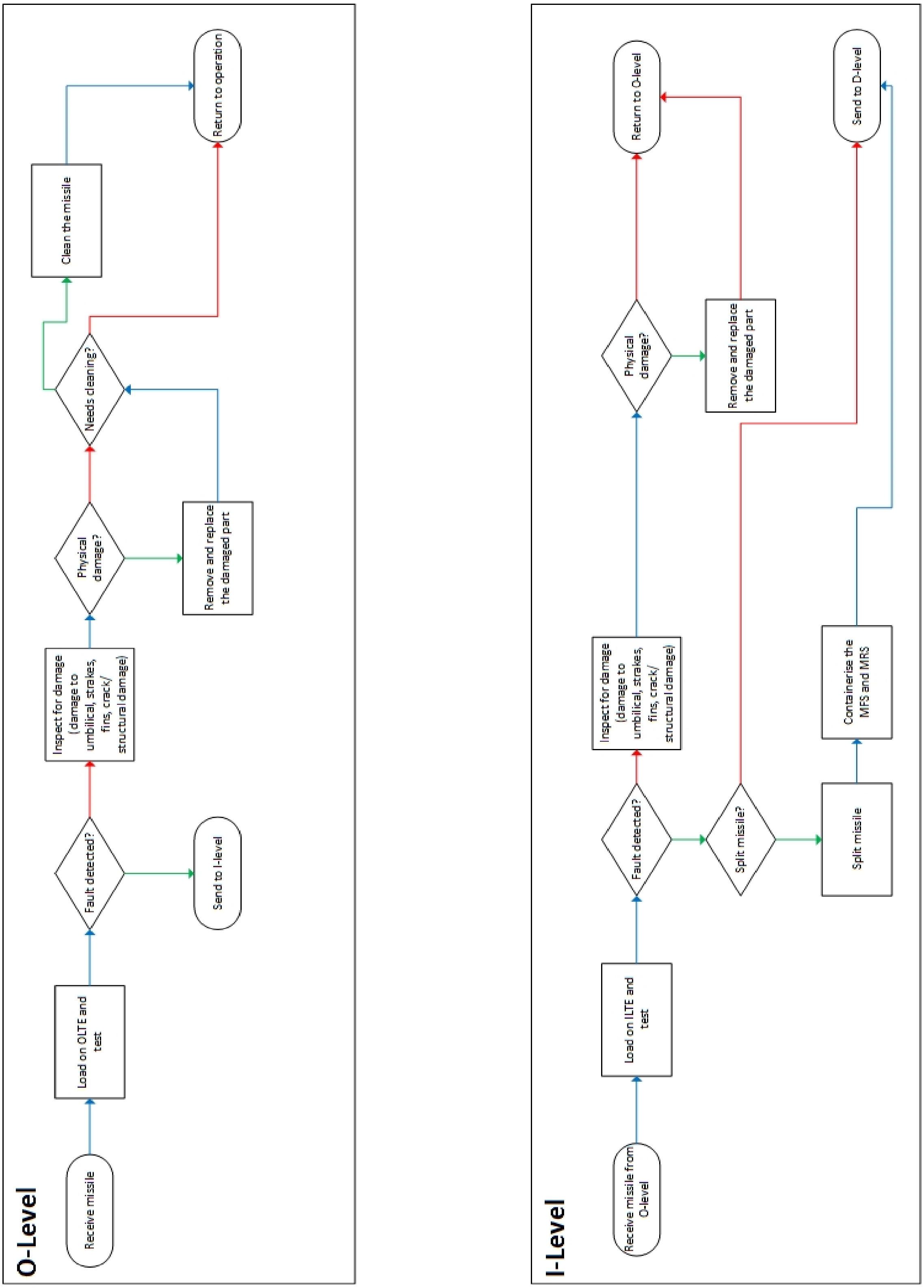

Figure B.1: O-level and I-level Support Flow Diagrams

Appendix C

D-level support concept design flow diagram

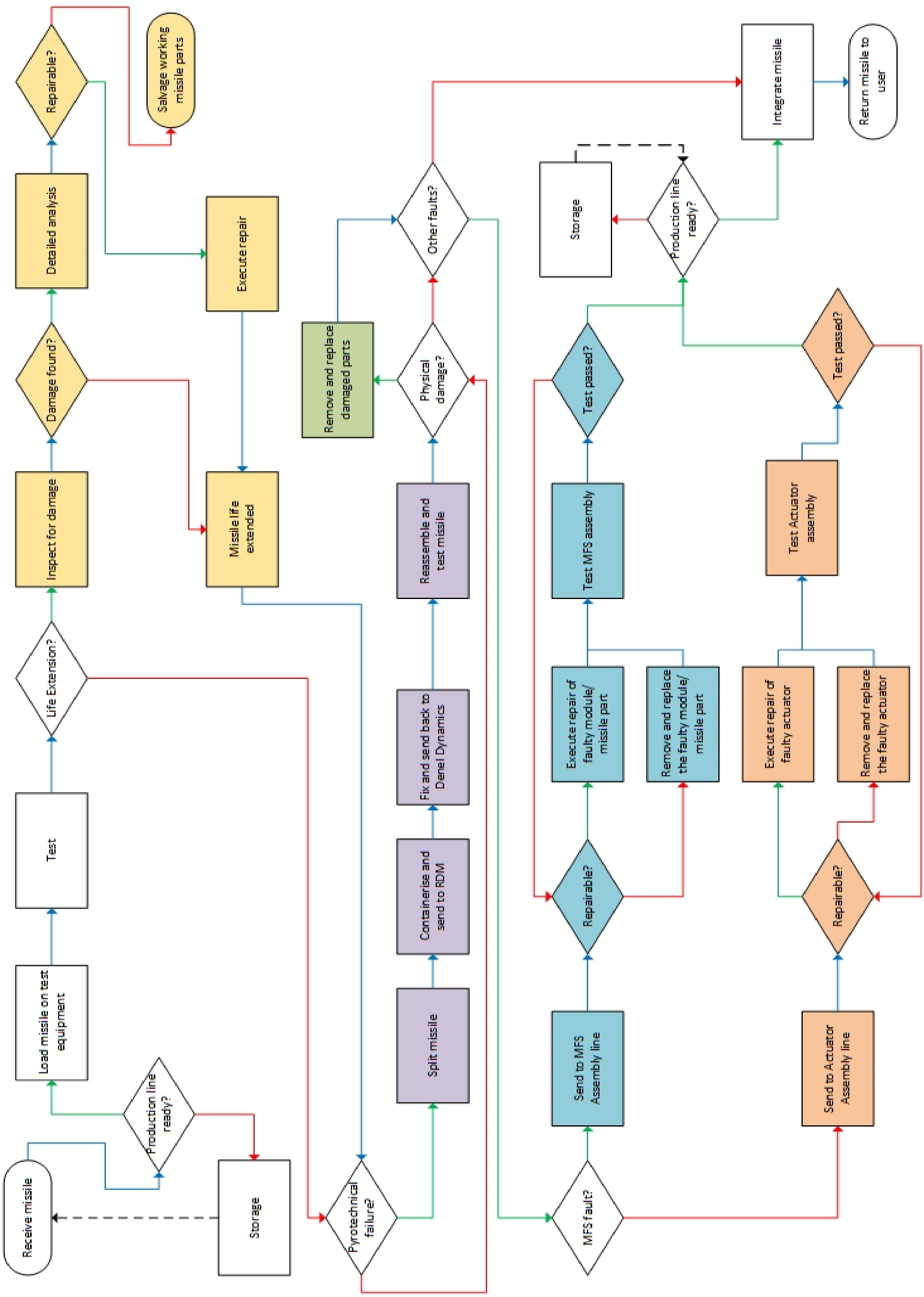

Figure C.1: D-level Support Flow Diagrams

Appendix D

Legend for design flow diagrams

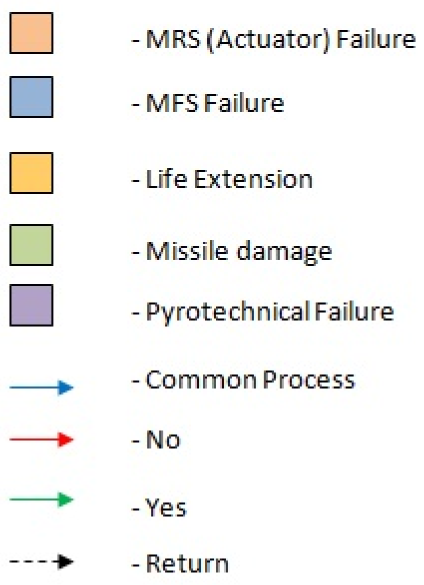

Figure D.1: Legend for Design Flow Diagrams

Appendix E

Simulation model

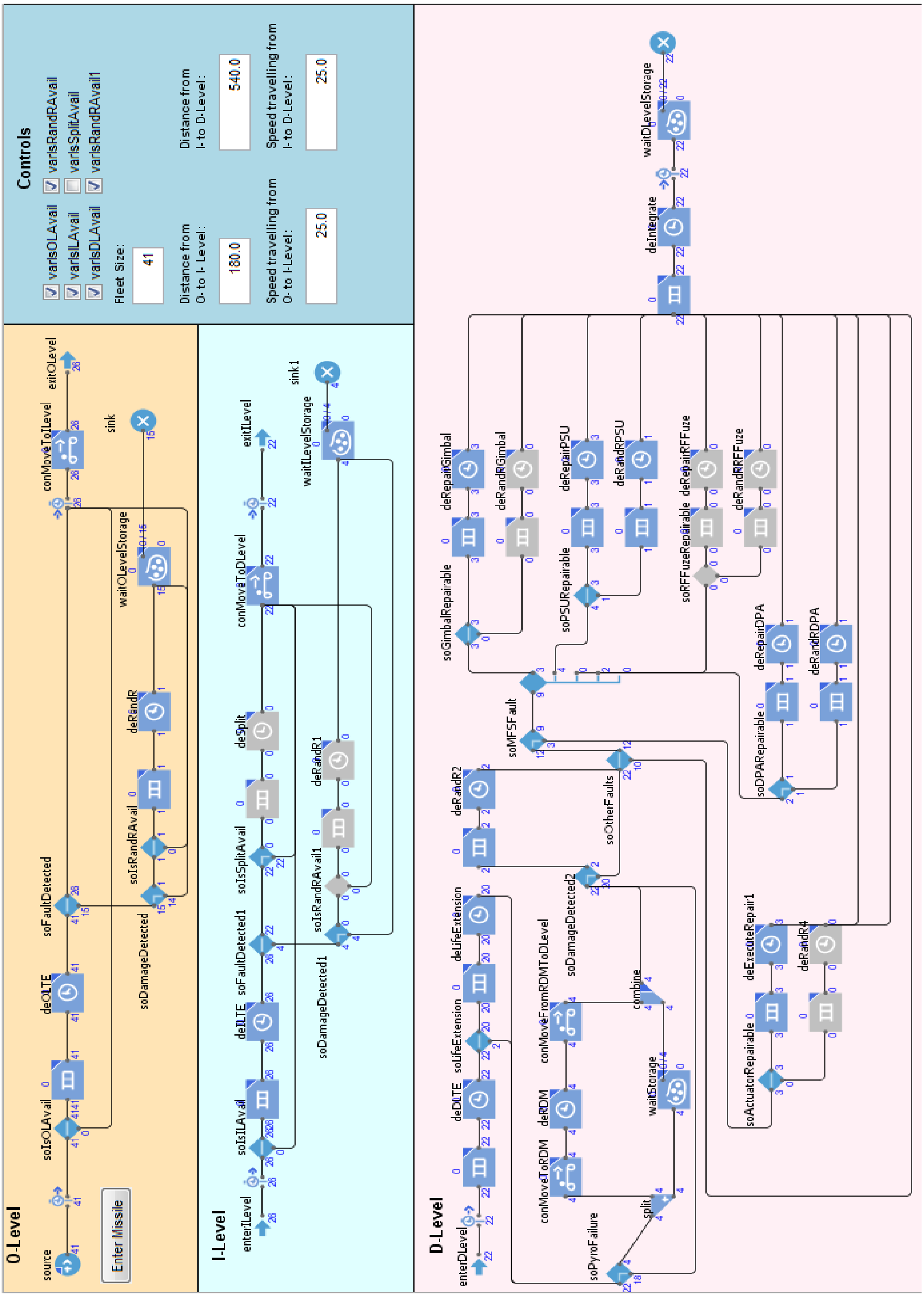

Figure E.1: Simulation model

Appendix F

Animation of simulation

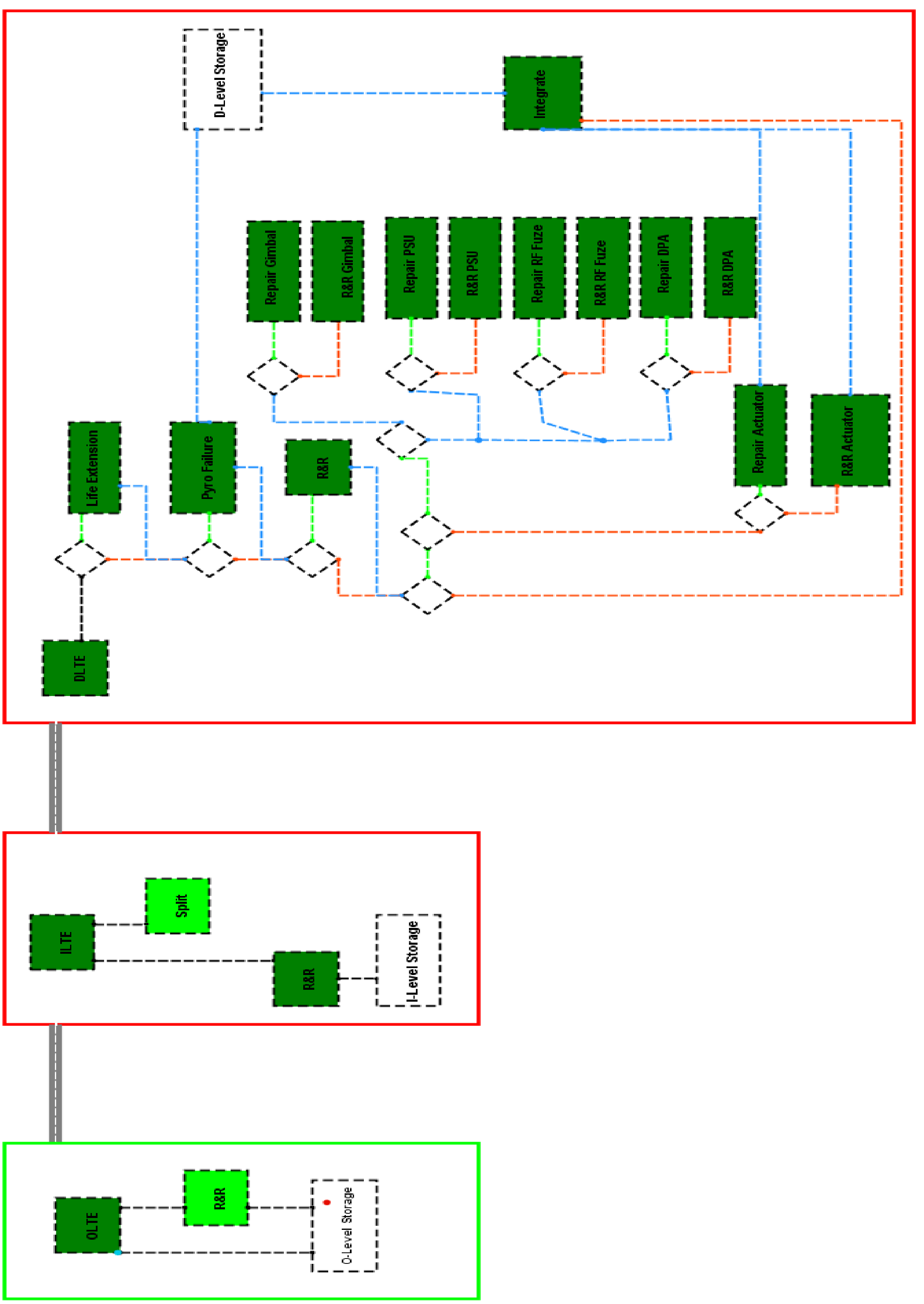

Figure F.1: Animation of simulation

Appendix G

Simulation base case results for time taken at each level

G.1 Run 1

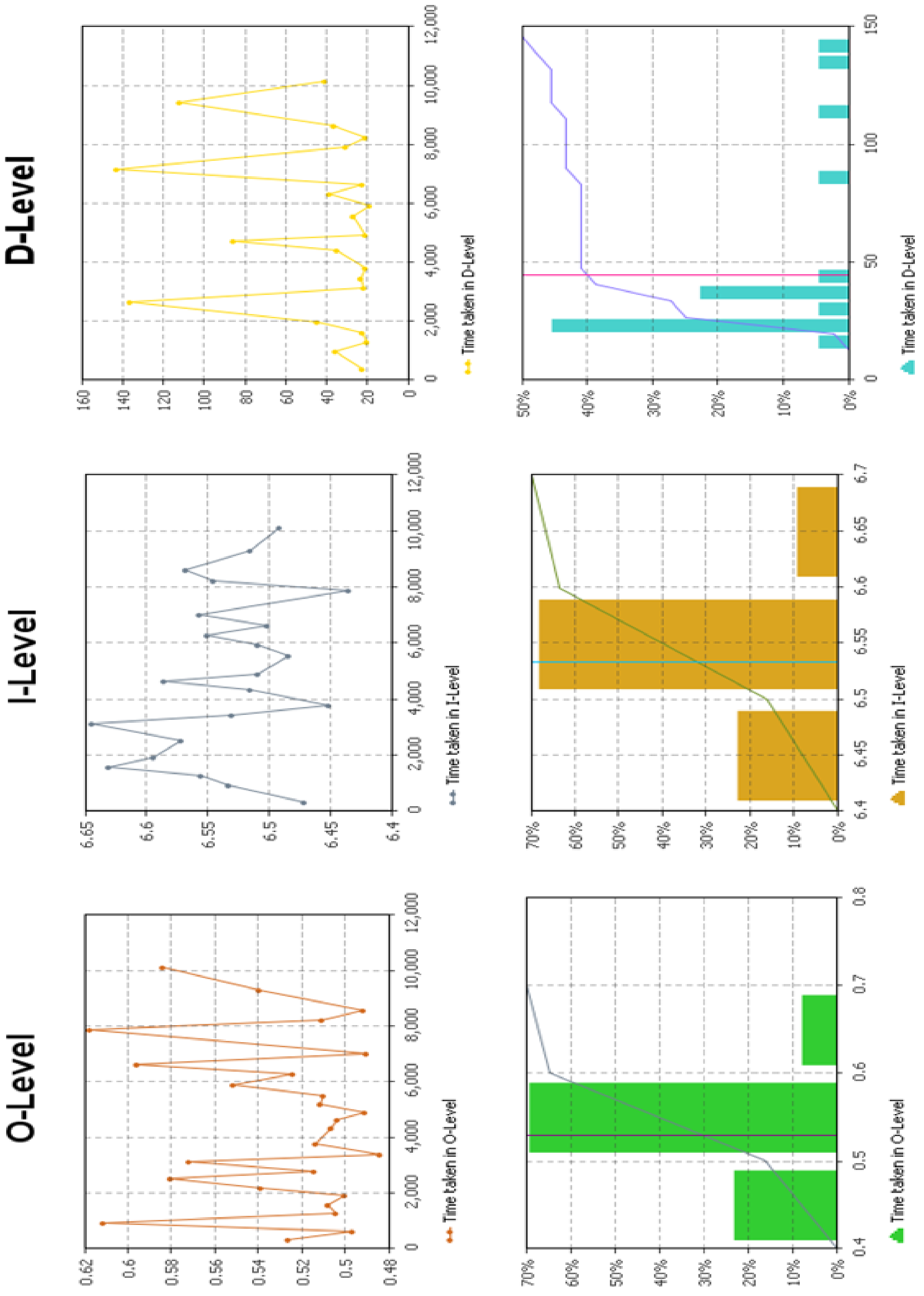

Figure G.1: Graphs for Run 1

G.2 Run 2

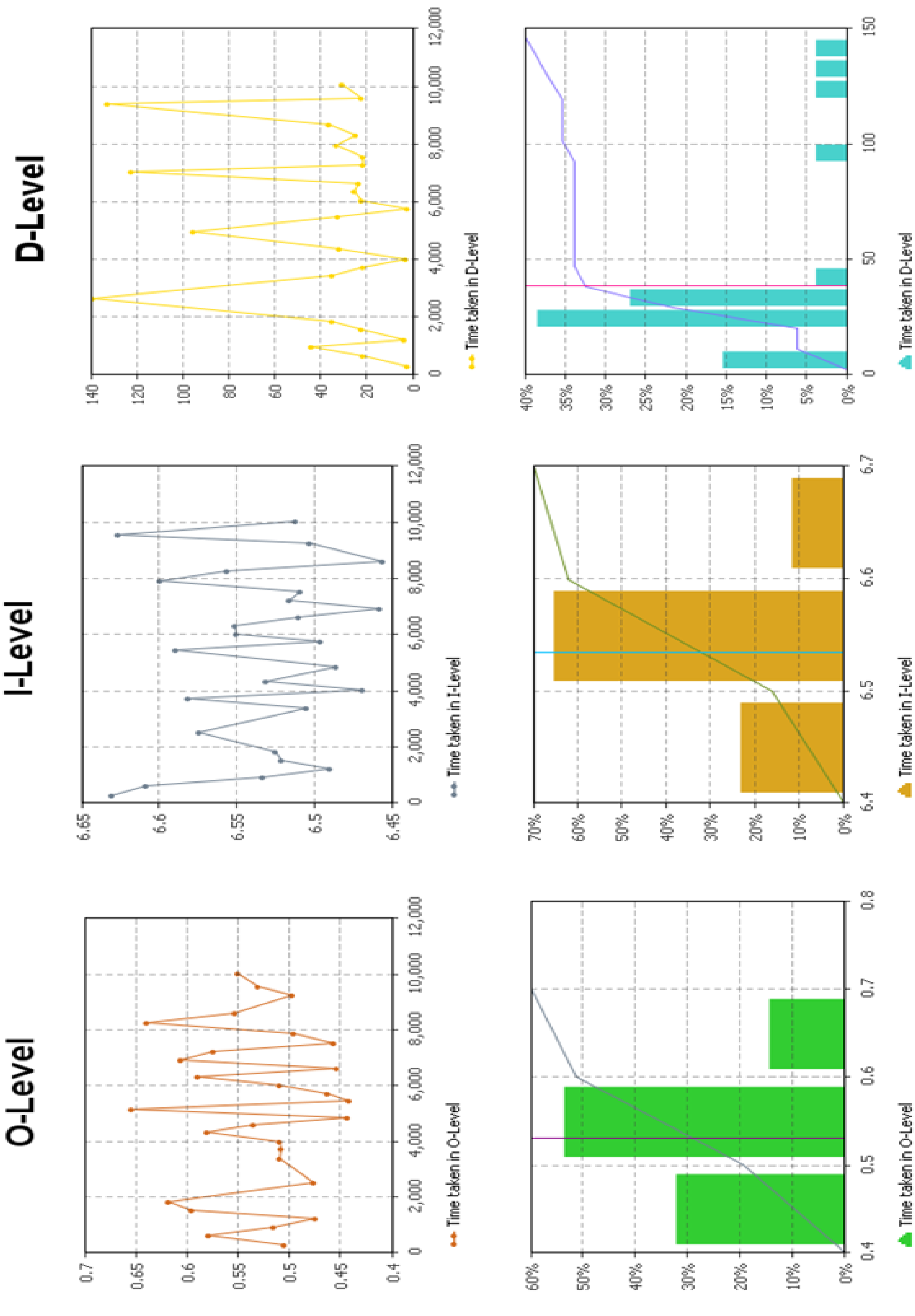

Figure G.2: Graphs for Run 2

G.3 Run 3

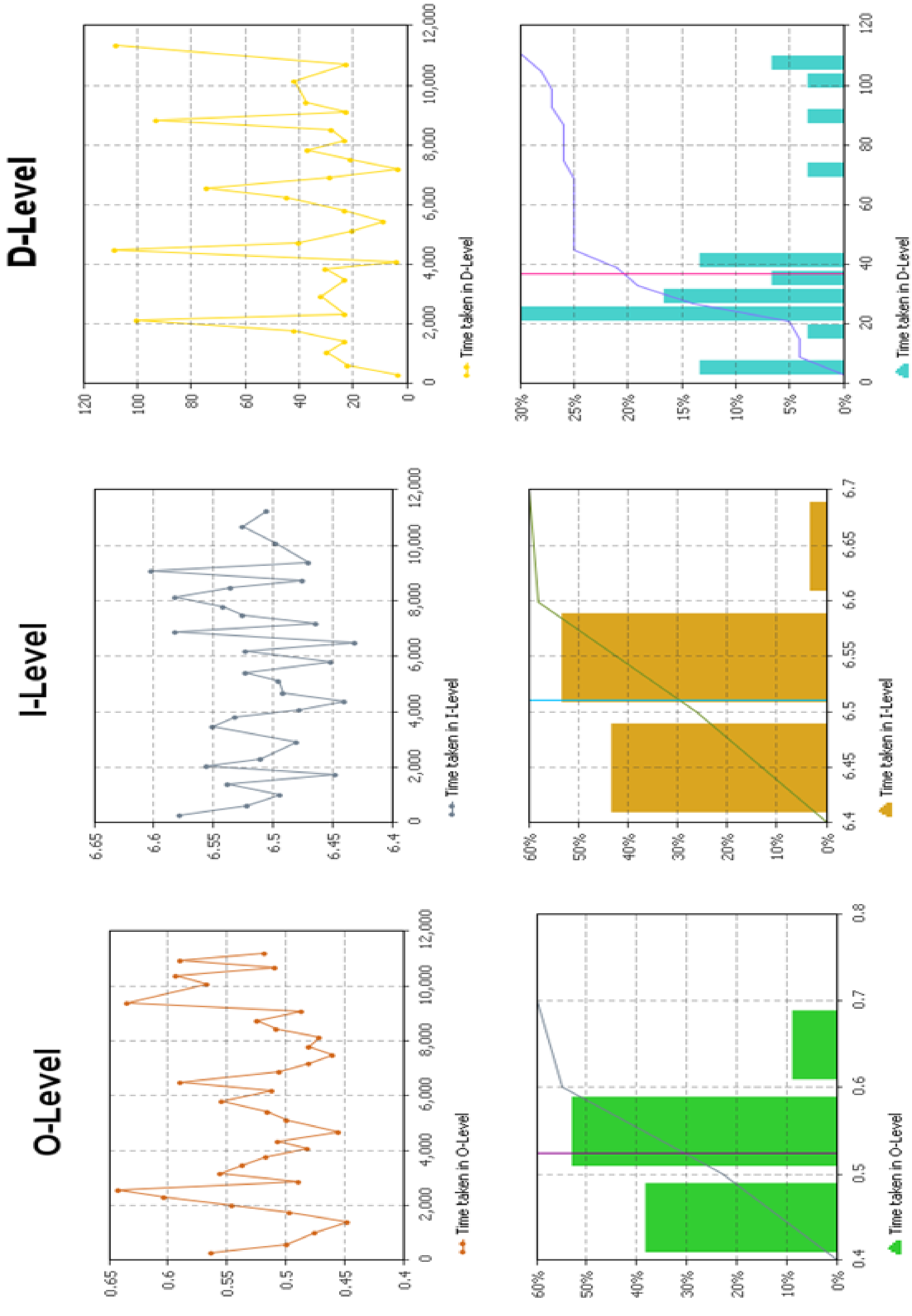

Figure G.3: Graphs for Run 3

G.4 Run 4

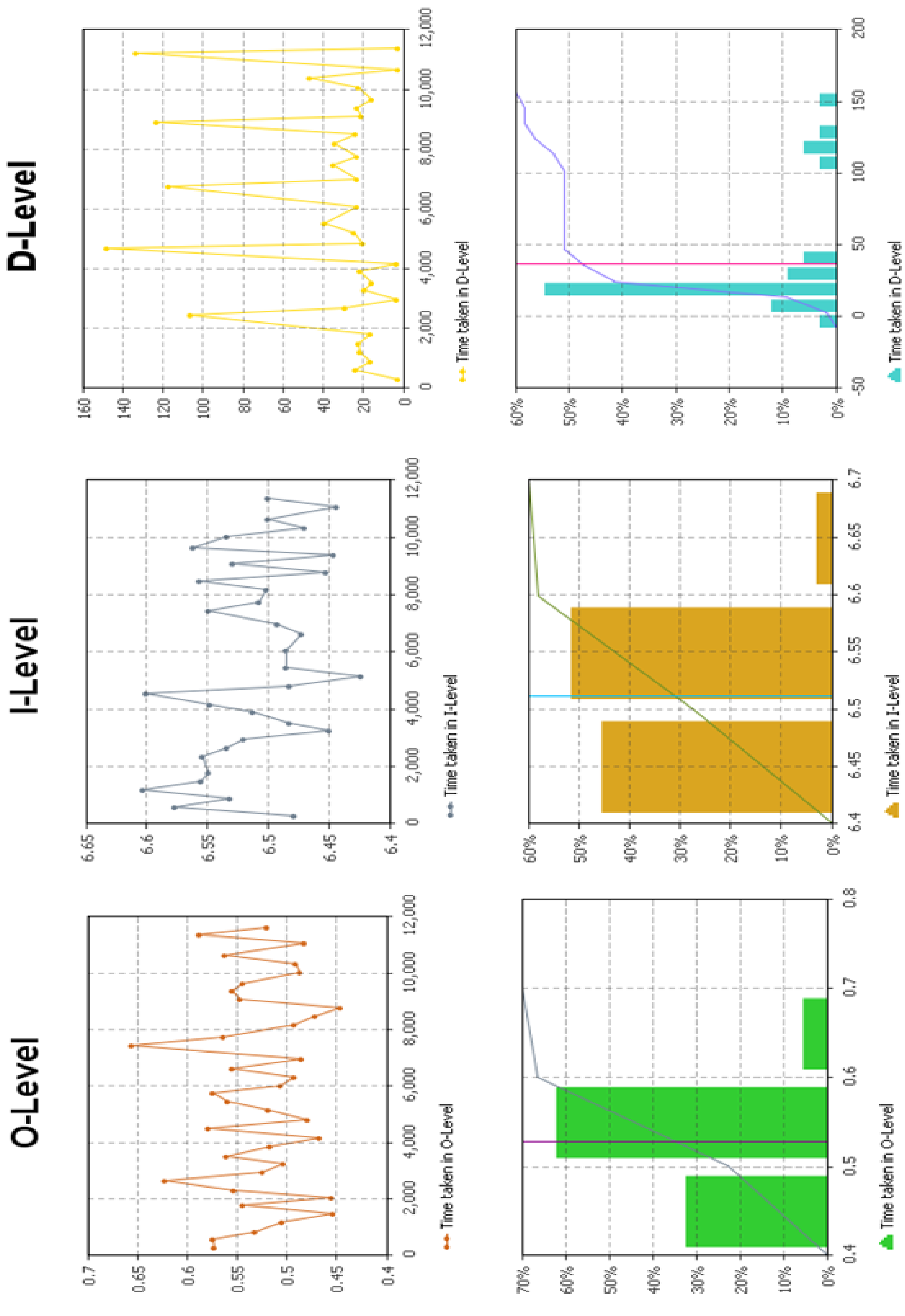

Figure G.4: Graphs for Run 4

G.5 Run 5

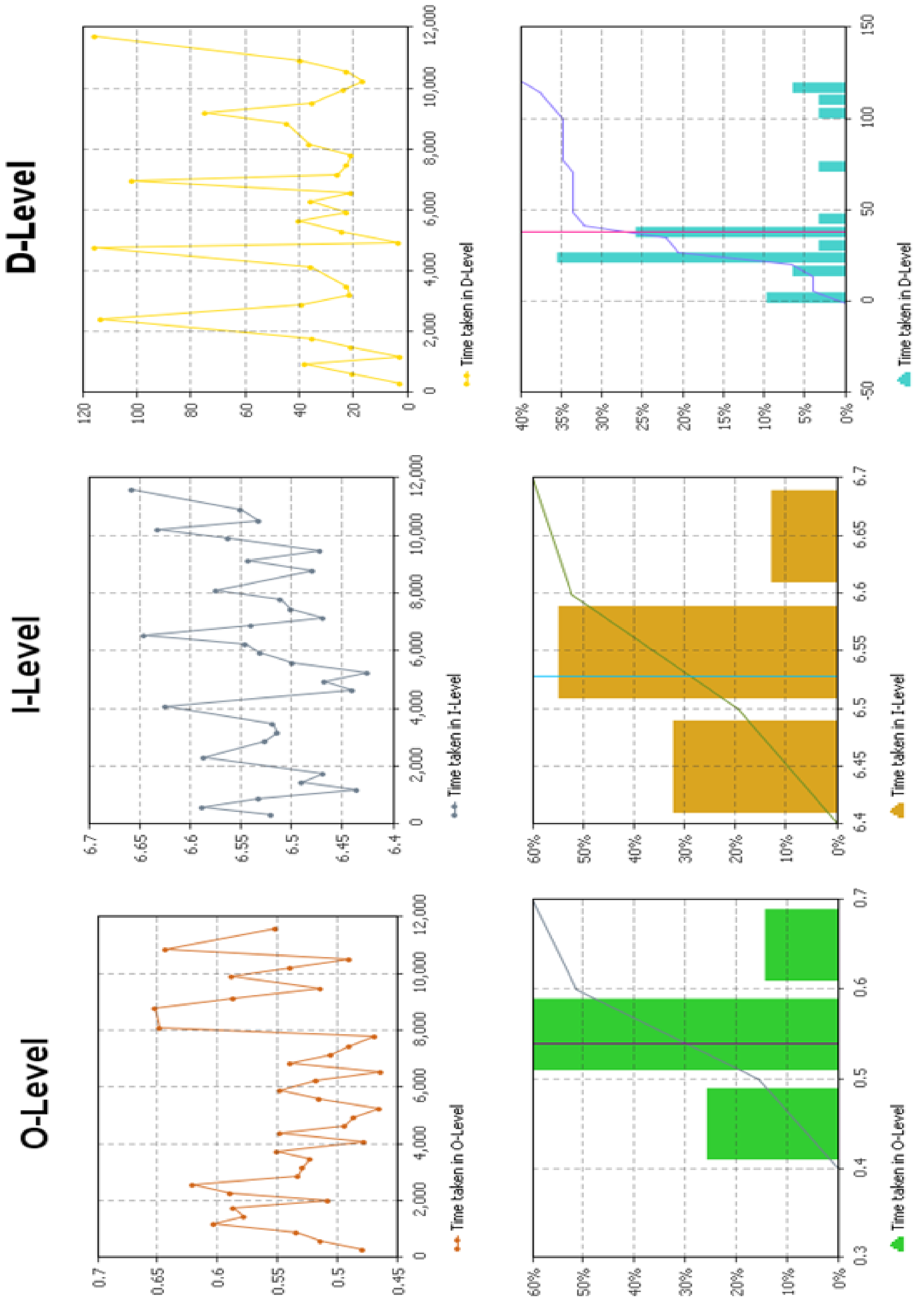

Figure G.5: Graphs for Run 5

Appendix H

Industry sponsorship form

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

Final Year Projects may be published by the University of Pretoria on *UPSpace* and may thus be freely available on the Internet. These publications portray the quality of education at the University, but they have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide guidance to the student throughout the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	DENEL ~~DATA~~ DYNAMICS
Project Description:	Creating a model that assists in Support Concept evaluating and decision making
Student Name:	AVANZA RAVINATH
Student number:	13081218
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