Title

Systems Framework for the Decommissioning/Disposal process of the Electrical Components for the Transnet Trans-Africa Locomotive

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A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering

Johannesburg 2019

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CANDIDATE'S DECLARATION

I declare that this Research Report is my own unaided work. It is being submitted to the Degree of Masters of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

Retief

……………………………………………………….

Gideon Daniël Retief

11th ….. day of September ……………..., 2020 ……………

ABSTRACT

This research focused on compiling a Systems Framework that can be used for the Decommissioning/Disposal process of electrical components used on the Transnet Trans-Africa Locomotive.

A first draft of the authors framework, based on MODAF framework from Caruso [1] and Cloete-Hopkins [2], was compiled by doing a thorough literature study. A systems approach was followed by studying systems engineering, electrical systems found on diesel locomotives, regulations, standard and legislation and industry used frameworks.

The first draft of the framework was then evaluated by gathering data from archival research, case study, survey and open questions. The final framework consisted 31 viewpoints that can be used to guide the decommissioning/disposal process for the Transnet Trans-Africa Locomotive.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor Mr. Nicolas Cloete-Hopkins for the support, guidance, leadership, patience and knowledge he contributed to this research report, without this I would have never been able to complete this report.

Additionally, I would like to thank the personnel working at the Transnet Centre of Systems Engineering at the University of the Witwatersrand for their support and guidance during presentation and report reviews.

I would also like to thank my colleagues at Transnet Engineering for their assistance in gathering the required data and assisting with the survey and open questions to complete the research report. I would also like to thank them for the immense insight and guidance in the railway environment.

Lastly, I would like to thank my family and especially my fiancée, Cherine, for her support, love and motivation through this journey.

1. INTRODUCTION

1.1. Purpose of the Study

The purpose of this study is to develop a systems framework for the decommissioning or disposal of electrical components for locomotives. The term systems framework combines the different integrated frameworks, standards and disposal/decommissioning techniques in one. A framework is a set of concepts, assumptions, values and practices combined to capture a realistic view of a project or a solution [3]. The developed framework can then be adapted for the decommissioning and disposal process for the electrical components on the Transnet Trans-Africa Locomotive (TAL).

1.2. Research Background/Context

The TAL was developed by Transnet Engineering (TE), a sub-division of Transnet SOC Ltd (from hereon in known as Transnet), that forms part of the Transnet strategy to become an Original Equipment Manufacturer (OEM) of locomotives [4]. The first TAL was completed in 2017 and is expected to be used on Transnet's branch lines and in shunting yards [5].

During the lifecycle of the locomotive it will undergo electrical component failures, replacements and overhauls that require decommissioning and disposal of assets [6,7]. These electrical components need to be decommissioned or disposed of without leaving a footprint behind on Earth [8]. One of Transnet's Sustainability Developmental Outcomes (SDOs) is the improvement of environmental stewardship by initiating initiatives and strategies to minimise environmental impact and pollution [9]. This research will be focused on the Post Project Phase of the Systems Lifecycle, highlighted in Figure 1 below:

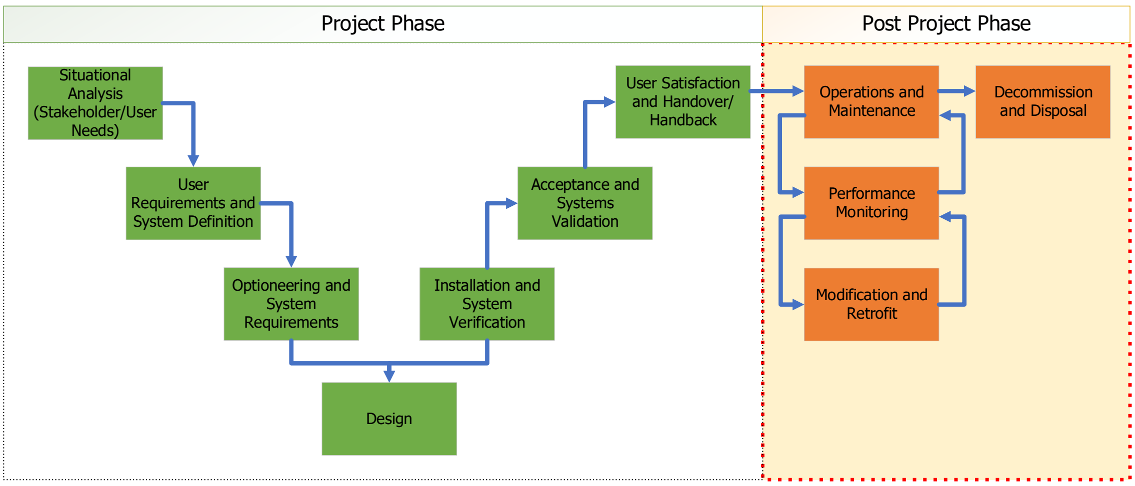


Figure 1: Systems Lifecycle.

Source: TCSE [10] adapted from BS EN 61508 [6]

This study will have a Holistic Lifecycle view which can be defined by including all the systems lifecycle stages, from the need to the disposal stage [11,12]. The context of this research will deal with the electrical systems and/or sub-systems found on a diesel locomotive [13]. The Poached Egg Diagram, developed by Hitchins [14], was used to illustrate the System-of-Interest for the study including its sub-systems and sibling systems within the broader context – see Figure 2. The area outlined in red is the defined area of this research, but all the other systems interacting with Electrical Systems will have to be taken into consideration [14].

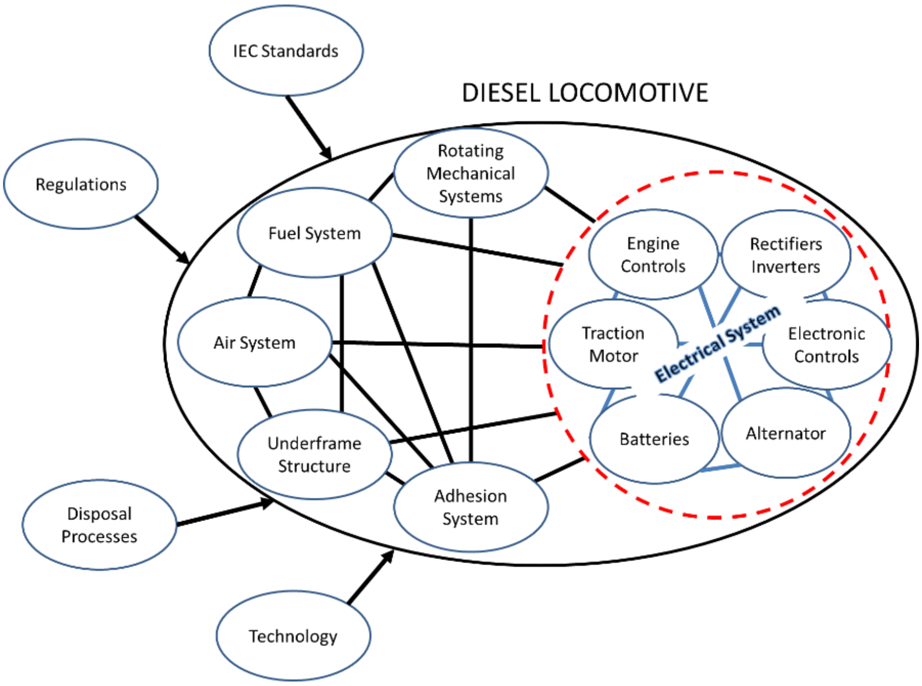


Figure 2: Poached Egg Diagram of a Diesel Locomotive.
Source: Author adapted from Hitchins [14] with information from Liudvinavičius et al. [13]

1.3. Problem Statement / Motivation

Transnet strives to be a corporate leader in being a steward of the planet's natural resources for future generations by addressing issues like carbon emissions, water management, waste management, energy use and energy efficiency [15]. Incorrect, or an absence of, decommissioning and disposal of TAL electrical waste can contribute to the contamination of the earth, which is contrary with Transnet's vision as part of "Managing our environmental impact" [15].

It is envisaged that the locomotives will be sold to railway operators in other countries that have different legislation, regulations and/or standards associated with decommissioning and disposal of electrical assets. To have a viable product all aspects of the systems life cycle should be investigated. This research will focus on providing a system framework that can be used on TAL, or identify any steps that were overlooked, when considering decommissioning or disposal of the electrical systems for the locomotive [8].

In 2011 a report from the Department of Environmental Affairs indicated that a total of 11% Waste of Electrical and Electronic Equipment (WEEE) is recycled in South Africa [16]. Furthermore, WEEE is regarded as hazardous and further identifies waste containing organic or inorganic elements that can have detrimental impact on the environment and animal / human health [16].

In South Africa there is currently limited legislation regarding the monitoring, decommissioning, disposing, recycling and handling of WEEE [17]. This poses a significant risk, whereby the systems developed in South Africa might not have taken any legislation, regulations and/or standards into consideration during the design process, confining Transnet’s locomotive OEM strategy to within the borders of South Africa. In 2003, the European Parliament and the Council of the European Union established a WEEE Directive [18]. This directive is used to set constraints on the European manufacturers by guiding the material content used on new electronic equipment [18].

Transnet is a State Owned Entity but operates as an independent corporate entry within South Africa [19]. All government institutions are responsible for the management of the entire waste cycle from the ‘cradle to grave’ including the final disposal of waste [20].

1.4. Research Questions

The Critical Research Question (CRQ) is the following:

1.4.1. How can the developed systems framework guide the decommissioning and disposal process for Transnet’s TAL’s electrical components?

The sub questions complementing the CRQ are the following:

1.4.2. How is the environment affected if decommissioning and disposal legislation, regulations and/or standards (i.e. governance) are not applied?

1.4.3. What are the proposed benefits for Transnet if this proposed systems framework is adopted?

1.5. Research Objectives

The objectives of this research are to:

a. Evaluate the current risks and opportunities associated with decommissioning and disposal of TAL's WEEE.
b. Evaluate how other OEM's manage decommissioning and disposal in line with the WEEE regulations.
c. Develop a systems framework that can guide the decommissioning and disposal of electrical systems waste for Transnet's TAL locomotive.

Evaluate the proposed systems framework including benefits that can be gained from the process by Transnet.

2. CRITICAL LITERATURE REVIEW

The main objectives of this critical literature review can be seen in the IDEF0 diagram illustrated in Figure 3.

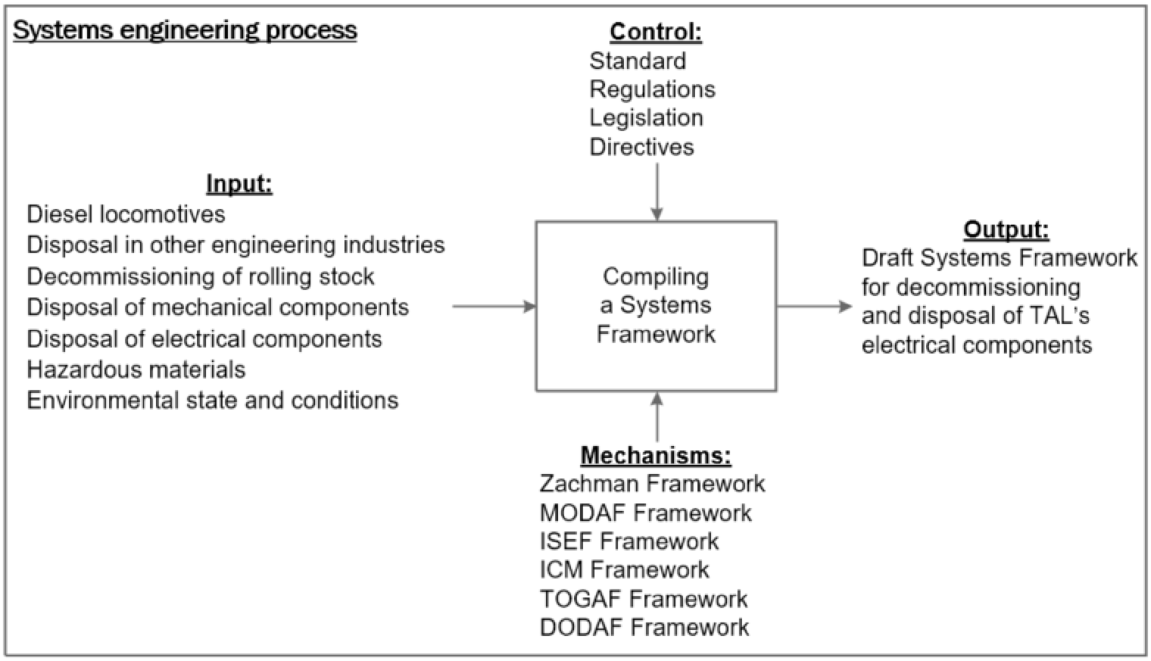


Figure 3: The IDEF0 diagram to various research elements to define a systems framework for TAL's electrical components.
Source: Author adapted from Department of Defence [21]

The critical systems literature review will be governed by a Systems Engineering Process. Various Systems Engineering models and techniques will be used to obtain a better understanding of the research. An in-depth understanding needs to be obtained regarding the Systems Engineering Process that will be the basis of this critical literature review.

This critical literature review will include studying diesel locomotives to get an in-depth understanding of the various mechanical and electrical systems found on locomotives. Different decommissioning and disposal techniques will then be investigated in the engineering industries and methods being applied to dispose of locomotive components. This will also assist with the identification of hazardous materials and effect these materials and the disposal/decommissioning process might have on the environment.

The "CATWOE" analysis makes use of six elements to define the different viewpoints looking at the same system. The six elements are described below:

Customer – This is all the people affected by the product or system.
Actor – The people responsible for the main activities of the product or system.
Transformation – The processing of the inputs to define the desired output.
World View – The bigger picture view of the product or system.
Owner – The person controlling and authorising the system or product.
Environment – The environment where the system or product should function.

A "CATWOE" analysis, developed by Checkland et al. [22], was used to supplement the viewpoints of this research report to define the different viewpoints when investigating disposal and decommissioning of electrical components – see Figure 4.

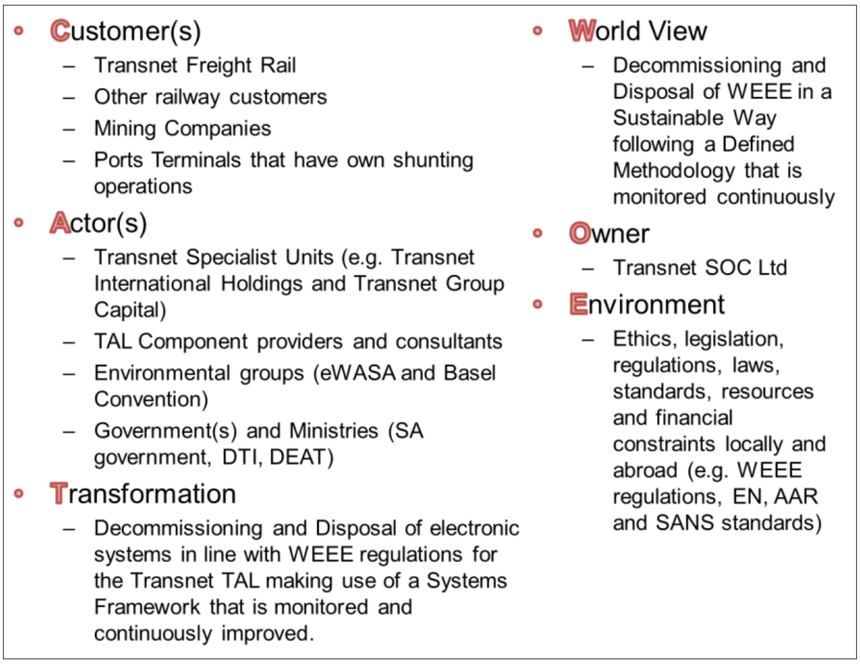


Figure 4: The different viewpoints using CATWOE.
Source: Author's adaption of the CATWOE diagram used by TCSE [10]

The Brown Cow Model makes use of four quadrants and can be used for brainstorming sessions to view the same problem from different viewpoints [23]. The y-axes of the model focus on the "what" and "how", while the x-axes focus on the "now" and the "future". This model was applied to the decommissioning and disposal processes and the outcome can be seen in Figure 5.

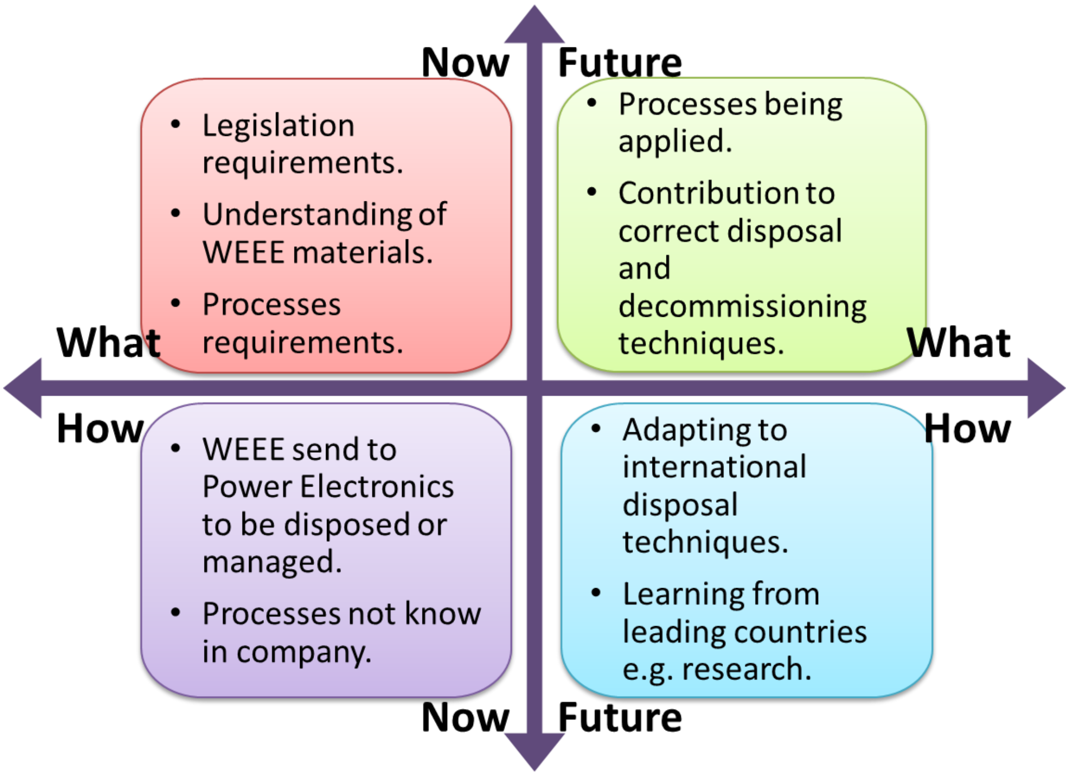


Figure 5: The Brown Cow Model.
Source: Author's adaption of the Brown Cow Model used by TCSE [10]

The Brown Cow Model gives insight to the research to be conducted in order to produce a framework that can be applied to the decommissioning and disposal process of electrical components used on the TAL locomotive.

The different standards, regulations, legislation and directives regarding disposal and decommissioning of electrical components will also be analysed. The various existing frameworks used in industries will also be compared, shortlisted and used in collaboration with all the literature to design a systems framework for the electrical components of TAL.

2.1. Systems Engineering

The Department of Defence of Fort Belvoir summarises Systems Engineering (SE) as a management process that creates and verifies a lifecycle balanced system solution that will meet the customers’ requirements [21]. The International Council for System Engineering (INCOSE) handbook defines the term SE to be the following:

> *“SE is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.”* [24]

From the definition obtained from INCOSE and the summary from Department of Defence, SE is a process that deals with the whole lifecycle of a system or solution. INCOSE developed a framework to define the Systems Engineering Competencies a practicing SE should have, this were then further divided into five different levels [25].

The five levels include Awareness, Supervised Practitioner, Practitioner, Lead Practitioner and Expert [25]. The different categories of SE Competencies are expressed in Figure 6. In order to be a competent SE the competencies in the list should be mastered. The Core Competencies includes Systems Thinking, Lifecycles and Critical Thinking which are critical for this research.

System Engineering Competencies				
Core Competencies	**Professional Competencies**	**Technical Competencies**	**Management Competencies**	**Integrating Competencies**
Systems Thinking	Communication	Requirements Definition	Planning	Project Management
Lifecycles	Technical Leadership	Systems Architecting	Monitoring and Control	Finance
Capability Engineering	Negotiation	Design for…	Decision Management	Logistics
General Engineering	Team Dynamics	Integration	Concurrent Engineering	Quality
Critical Thinking	Facilitation	Interfaces	Acquisition and Supply	
Systems Modelling	Emotional Intelligence	Verification	Information Management	
	Ethics and professionalism	Validation	Business and Enterprise Integration	
	Coaching and Mentoring	Transition	Risk and Opportunity Management	
		Operation and Support		

Figure 6: Systems Engineering competencies as defined by INCOSE.
Source: Author adapted from INCOSE [25]

To reiterate, SE is a process that deals with the whole lifecycle of a system or solution. The different functions and phases of the System Lifecycle Process can be seen in Figure 7 and list all the different phases a product will undergo. It includes the Project Phase as well as the Post Project Phase of a product.

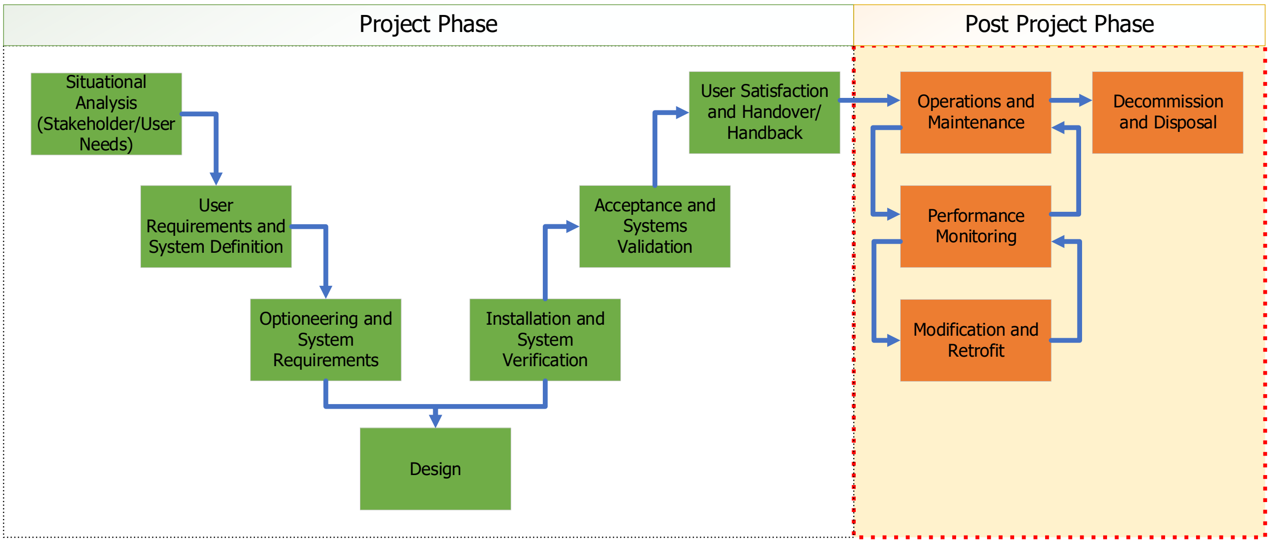


Figure 7: Systems Lifecycle with focus on Post Project Phase.
Source: TCSE [10] adapted from BS EN 61508 [6]

Each of the different phases of the lifecycle model will include activities such as system design, development, risk management, engineering analysis and modelling [26]. From Figure 7 it can be clearly seen that the focus area of this research should be on the Post Project Phase of the systems lifecycle, as highlighted, which include the following elements:

- Operations and Maintenance
- Performance Monitoring
- Modification and Retrofit
- Decommission and Disposal

The final stage of the Systems Lifecycle is 'Disposal' and a suitable plan should be constructed from the early lifecycle stages of a project [21]. From additional literature it states that the planning for the disposal stages should already be considered and planned for during the concept stages of a project [3]. It also states that care should be taken to plan and dispose of any materials generated or used during the production of the product as well [21]. Further reading states that the de-manufacturing, i.e. the decommissioning and disposal, process include the disassembly, remanufacturing, recycling and recovery processes of components [27]. The biggest contribution to unsuccessful automated disassembly lines is the lack of EOL design principles [28,29]. It is critical that the full lifecycle should be taken into consideration during systems design of products.

Systems Thinking is a method used by SE by studying the bigger surrounding systems instead of just the System of Interest (SOI), followed by objectively looking at the SOI to determine the desired characteristics and lastly looking at SOI as set of interacting objects [30]. Systems Thinking should be applied to the disposal and decommissioning of electrical components to ensure that the components are handled with the necessary care and correct processes.

Using Systems Thinking and the literature studied the focus shifts from the Post Project Phase in Figure 7 to the whole lifecycle, including as highlighted in Figure 8 below.

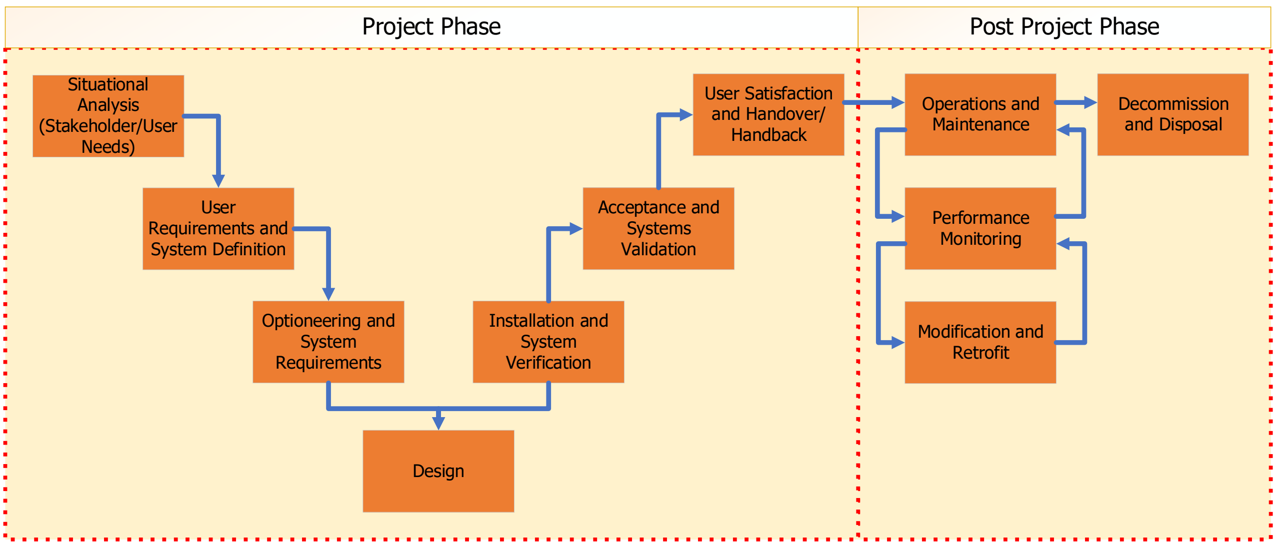


Figure 8: Systems Lifecycle with focus on all the stages.
Source: TCSE [10] adapted from BS EN 61508 [6]

The technical processes and outcomes of the System Lifecycle Process as per South African National Standard (SANS) 15288 are summarised in Table 1. The focus of this research will be on the Post Project Phase. The last column highlights the different elements regarding decommissioning and disposal (Post Project Phase) that should be defined in each lifecycle stage. The elements identified by the researcher is highlighted in the green blocks in Table 1.

Table 1: The different technical process phases of the Systems Lifecycle. Source: Author adapted from SANS 15288 [31]

Technical Processes			Decommissioning and Disposal Elements
Phase	**Purpose**	**Outcomes**	
Stakeholder Requirement Definition Process	• Used to identify stakeholders. • Define the wants/needs for the system.	• Constraints of the project defined. • Traceability of stakeholder wants/needs. • Validation of stakeholder requirements defined.	• Maintenance wants/needs. • Disposal wants/needs. • Decommissioning want/needs.
Requirements Analysis Process	• Transform the stakeholder requirements into product requirements. • Does not imply a specific solution.	• All the different type of requirements e.g. functional and performance. • Non-functional requirements, the “alities”, including Reliability, Availability, Maintainability, Dependability (RAMD) and Life Cycle Cost (LCC). • Constraints that will affect the architectural design. • Traceability of all requirements to the stakeholder requirements.	• Maintenance requirements. • Disposal requirements. • Decommissioning requirements. • Failure Modes, Effect and Criticality analysis (FMECA).
Architectural Design Process	• Synthesize a solution that meets the requirements. • Identify possible implementation strategies.	• Set of elements that can be implemented to satisfy the stakeholder requirements. • Interface requirements are integrated in the designs. • Traceability to the stakeholder requirements.	• Type of components used in the solution. • Planning for end-of-life of components. • Service life of components.
Implementation Process	• Generates a specific system element that satisfies the design requirements through verification.	• Strategy defined. • System element is generated, accepted, packaged and stored.	• Storage requirements of components, special storage requirements for batteries etc. • Shelf-life considerations
Integration Process	• Assemble the system by combining the different system elements.	• Integration strategy defined. • Assembly of a system specified through the architectural design process.	• By-products. • Materials required to assist with integration.
Verification Process	• Is the system built right and is it fit for purpose?	• Verification strategy with constraints. • Evidence supporting that the designed system meets the system requirements.	• Systems testing for immediate failures of components. • Durability testing.

Technical Processes			Decommissioning and Disposal Elements
Phase	**Purpose**	**Outcomes**	
Transition Process	• Installation of the verified and enabling systems.	• System installed in operation. • System transition strategy is defined.	• By-products. • Environmental effects influencing the product.
Validation Process	• Provide evidence that the system is functioning in its intended environment.	• Validation data as proof. • Generation of a validation strategy.	• Monitoring the performance and feeding information back to the system.
Operation Process	• Using the designed system to perform and deliver services.	• Generation of an operational strategy. • Service provided by the system that meet the requirements of the stakeholder.	• By-products during operation. • Monitoring on performance of installed components.
Maintenance Process	• Sustaining or maintaining the developed system to be able to provide services.	• Maintenance strategy. • Replacing some of the system elements. • Refurbish and recycle some elements • Plan for corrective designs and using the maintenance and failure requirements as inputs to a new system. • Data recorded of failure events during the lifetime of the system.	• Preventative maintenance strategies. • Decommissioning and disposal techniques of replaced components. • Dedicated location for replaced and failed components.
Disposal Process	• Dismantle and remove the system entity from existence.	• Generating a disposal strategy. • Environment is returned to its original state by destroying, reclaiming or recycling. • Disposal constraints are fed into input requirements. • Records are produced of disposed system.	• Handing of hazardous materials identified by Stockholm Convention and WEEE. • Special tools, techniques, equipment and facilities may be required.

Dorsey concluded from academic literature that between 50 % to 80 % of large projects fail [32]. There are certain independent factors relating to the success of a project, unfortunately it is impossible to have best of all the factors [32]. It is impossible or highly unlikely to have a cheap, high quality product, without risk of failure and manufactured in record time. The four independent factors are illustrated in Figure 9.

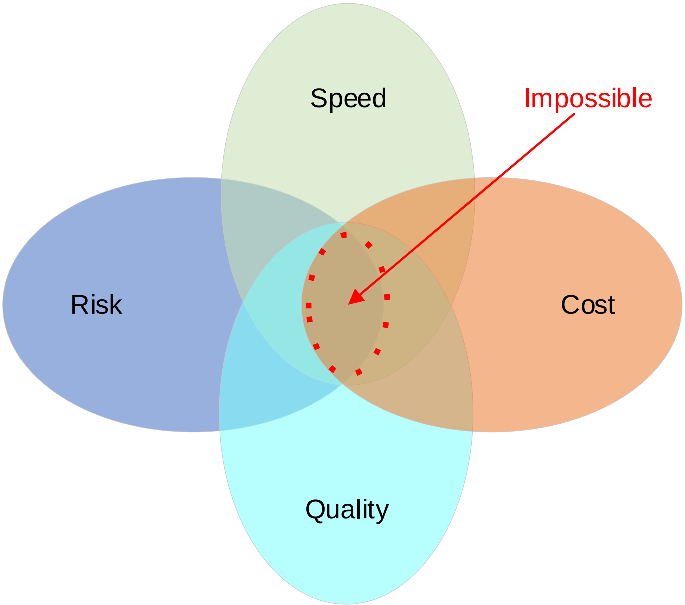


Figure 9: Independent factors for project success.

Source: Author adapted from Dorsey [32]

The seven critical repeated failures identified from different literature sources, Dorsey [32], Stanley et al. [33] Ahonen et al. [34] and Pandremmenou et al. [35] are listed below:

1) Lack of correct requirement elicitation techniques and tracking requirements to the stakeholder needs.
2) The absence of senior management, technical experience and a lack of senior management involvement and understanding.
3) Inefficient communication channels between the project team, management, stakeholders and customers.
4) Lack of planning and holistic thinking in terms of the whole systems lifecycle.
5) No methodology implemented to assist with the execution of projects.
6) Lack of implementing project management and incorrect risk identification processes e.g. compiling a project plan by working backwards from the completion dates.
7) The project scope is not clearly defined and understood by the team, leading to scope creep, thus introducing additional cost and extending the timelines.

According to Elm et al. the performance of projects can highly benefit from applying SE processes, see Figure 10, and according to this study the percentage of projects with high performance can be increased by 41 % by applying higher SE capability [36].

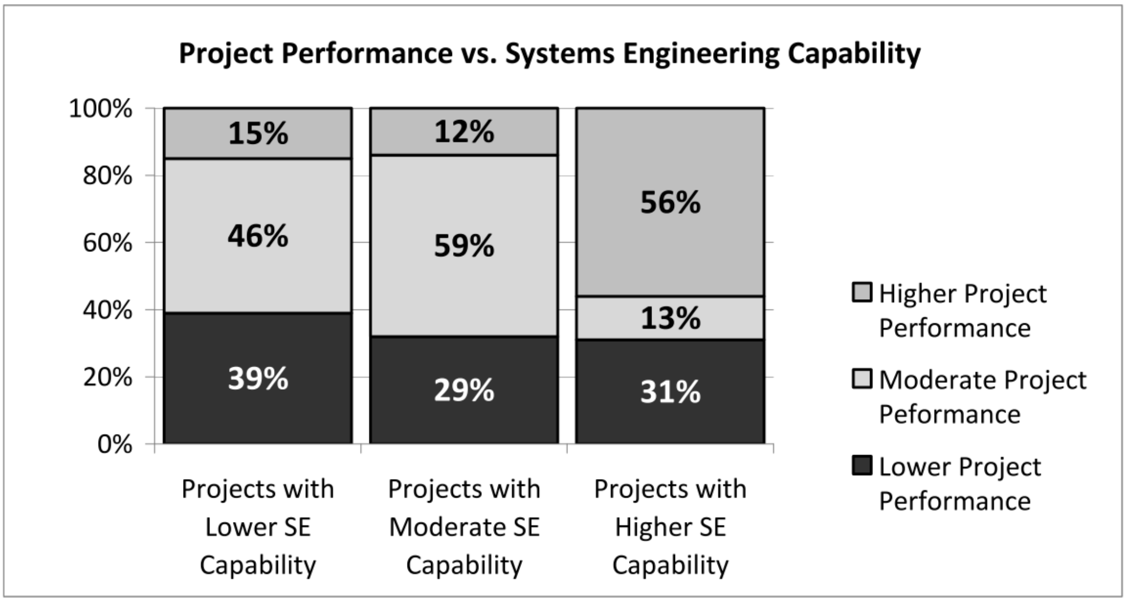


Figure 10: Comparison of Project Performance and the Systems Engineering Capability.
Source: Elm et al. [36]

The ‘Design for X’ (DFX) SE techniques are used to identify the lifecycle cost drivers of a project and enabling the designer to implement these sources of information in his design processes [37]. The implementation of the DFX techniques will lead to more optimal designs for the full lifecycle of a product ending at the decommissioning and disposal stages [38]. The ‘X’ in DFX can be substituted by any element, in the case of this study the focus will be the ‘Design for Environment’ (DFE).

The most common used DFE practices used in the industries, as obtained from Fiksel et al. [39] are the following:

- *Material substitution* – Substituting materials to increase recyclability.
- *Waste resource reduction* – Reducing the mass to reduce the waste.
- *Substance use reduction* – Limiting the use of undesirable and harmful substance in the manufacturing process,
- *Energy use reduction* – Reducing the amount of energy required to maintain, recycle and to use the product.
- *Life extension* – Extension of the useful life of the product.
- *Design for disassembly* – Reducing the labour required to disassemble the product, thus easing the recyclability.
- *Design for re-usability* – Allowing items to be reused in future products.

- *Design for remanufacture* – Using the waste recovered from post-industrial or post-customer products to manufacture new products.
- *Design for energy recovery* – Using the waste of the recycled materials to generate energy by means of burning the waste.

From the research conducted it clearly shows the benefits of using Systems Engineering for the complete lifecycle of a project. The biggest question that can be asked is whether Systems Engineering principles and techniques were applied to the TAL locomotive. If these techniques were applied, can it also be applicable to other projects?

2.2. Electrical Systems of Diesel Locomotives

2.2.1. Locomotives

Rolling stock is a precious source of heterogeneous materials and the End-of-Life (EOL) waste can be recycled and can be a source of additional income [40]. Rolling stock is built from a variety of components that include elastomers, glass, fluids, polymers, electronic components, modified organic materials and ferrous and non-ferrous materials [40]. A typical passenger railcar can contribute the same amount of waste, in weight, as 36-42 passenger vehicles [40]. Freight trains are easier to dispose compared with passenger trains, reason being that it consist of about 80 % steel and cast iron [41].

The issue with the decommissioning and disposal of railway vehicles is associated with the economic life of the vehicles versus that of its components. A summary of the different cost, see Table 2, shows that 70 % (ratio of 0.7 : 1) of the initial purchase cost is spend during maintenance, repairs and overhauls [42].

Table 2: Diesel locomotive lifecycle statistics.
Source: Author adapted from Baumgartner et al. [42]

Diesel Locomotive Statistics	
Locomotive Cost	R 30 319 254
Lifecycle	20 years (up to 30 years)
Availability coefficient	90%
Operating Hours	70 000 hours
Maintenance cost	R 303/hour
Maintenance cost	R 21 226 800
Maintenance : Locomotive Cost Ratio	0.7 : 1

As mentioned earlier the TAL is the first prototype locomotive built and developed by Transnet. The Poached Egg Diagram in Figure 11 illustrates the electrical systems found on a diesel-electric locomotive. The Poach Egg Diagram, or also called a systems hierarchy, helps to identify the system of interest where the focus should lie by defining all the other systems interacting with this system in an environment. In the case of the Poached Egg Diagram below the electrical systems are interacting with the various other mechanical systems found on a diesel locomotive in a rail environment.

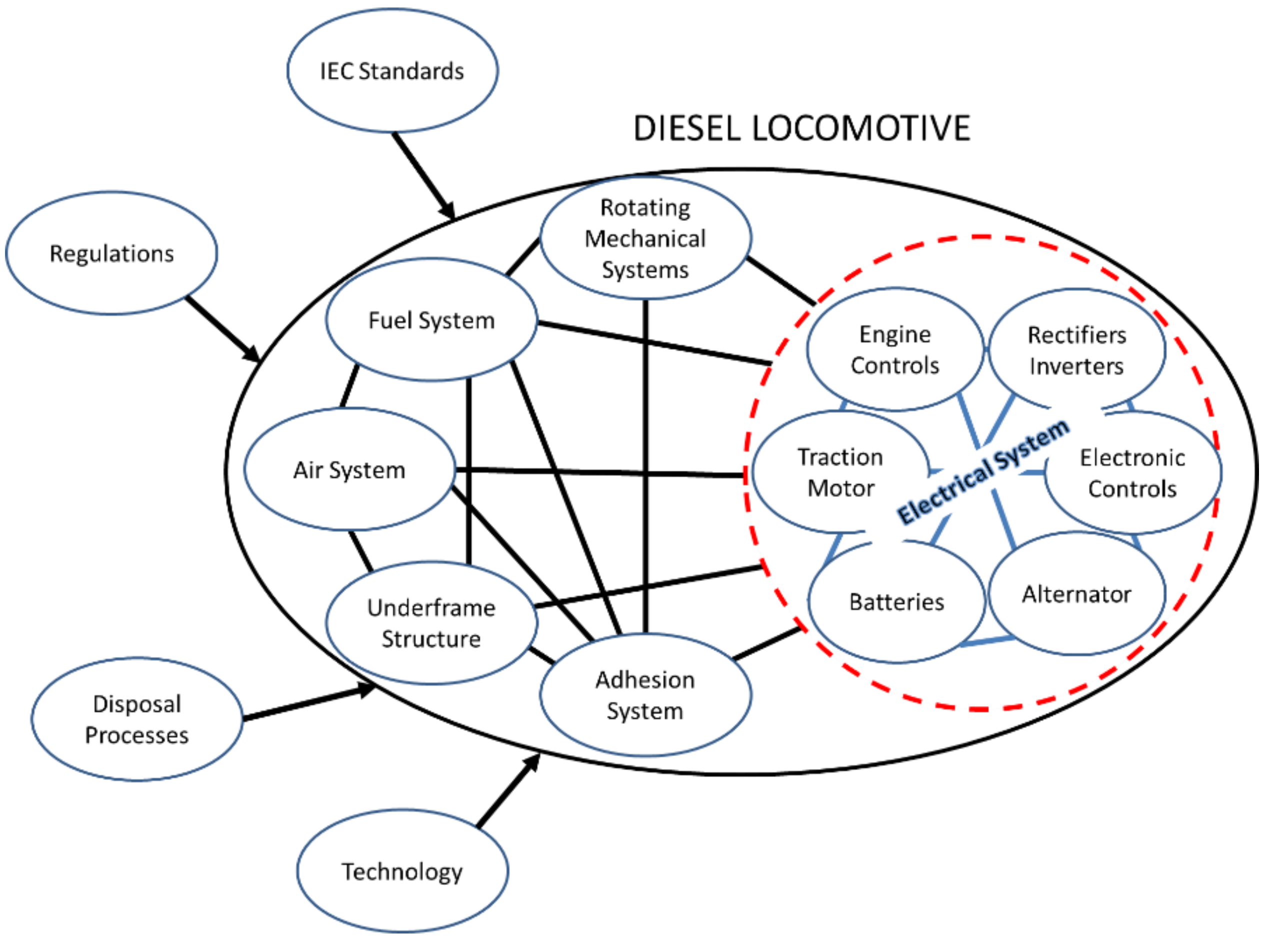
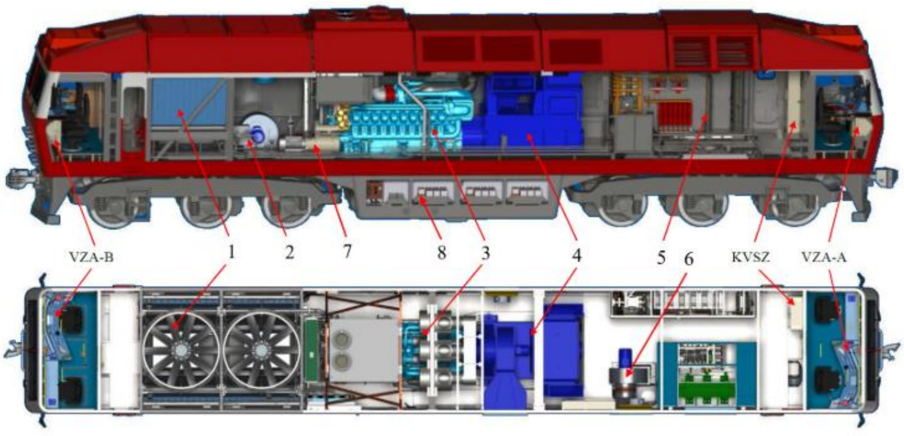


Figure 11: Poached Egg Diagram of a Diesel Locomotive.

Source: Author adapted from Hitchins [14] with information from Liudvinavičius et al. [13]

A modern diesel-electric locomotive electrical components, see Figure 12, consist of batteries, an engine, cooling fans, compressor, 3-phase rectifiers, Alternating Current (AC) excitation generator, control panels etc. [13].



No.	Description
VZA-B	Control Panels
1	Radiator
2	Cooling fan for traction motors
3	Engine
4	AC traction generator
5	Heating equipment
6	Cooling fan for traction motors
7	Comprssor
8	Batteries
VZA-A	Control Panels

Figure 12: Layout diagram of a modern diesel-electric locomotive.
Source: Author added description table, figure from Liudvinavičius et al. [13]

The basic operation of the electrical components used on a modern diesel-electric locomotive is summarised below from Spiryagin et al. [43]:

> *The basic operation of a modern diesel-electric locomotive can be seen in Figure 13. The main power source on the locomotive is the engine, turning an alternator to generate AC electricity. Therefore, mechanical energy is converter into electrical energy. The AC electricity is then rectified into Direct Current (DC) electricity. The locomotive computer is responsible for the control of the engine output power. The DC electricity is then converted by the traction inverter, controlled by the traction controller, into AC electricity and used to power the traction motors, in effect turning the wheels or axles of the locomotive. The traction controller is also controlled by the locomotive computer.*
>
> *A locomotive consists of two bogies that can either house six (named C0-C0 configuration) traction motors and six axles or four traction motors (named B0-B0 configuration) and four axles. During this generation process, motion thermal energy from combusting diesel in the engine is converted to electrical energy through the alternator, then transferred to electrical energy to the traction motors and lastly converted into mechanical energy to the wheels or axles of the locomotive. The main difference between an electrical and a diesel locomotive is the source of energy, whereby an electrical locomotive obtains its electricity through a pantograph on the locomotive roof connected to a high voltage overhead transmission line.*

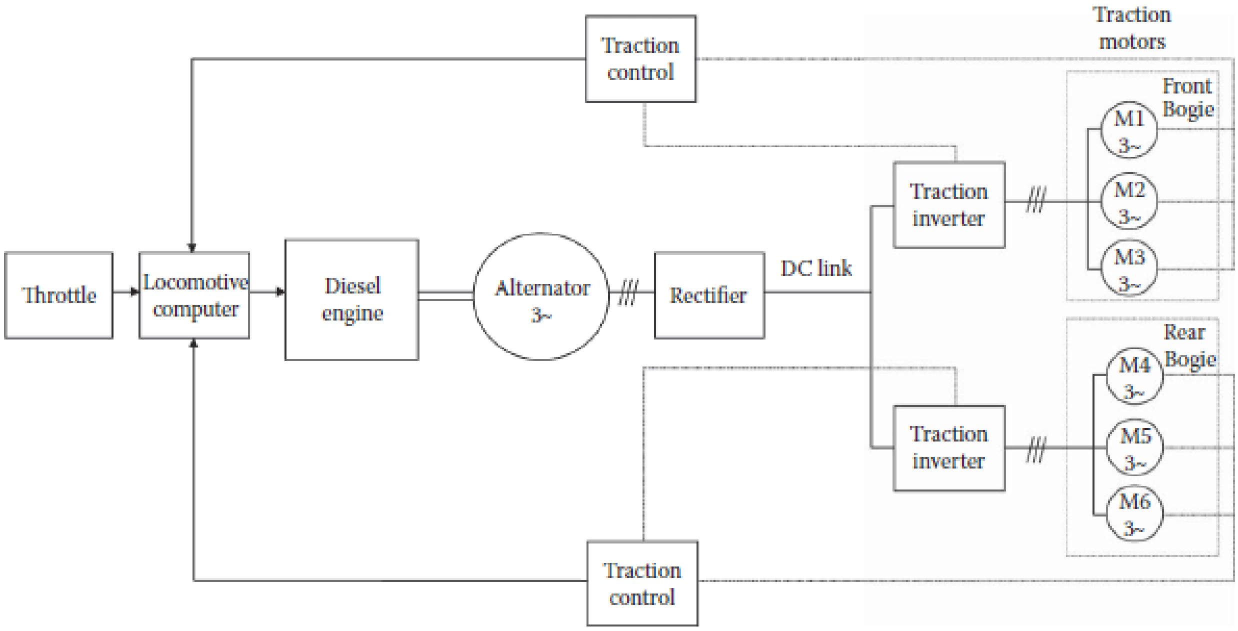


Figure 13: Example of the operation of a modern diesel-electric locomotive. Source: Spiryagin et al. [43]

2.2.2. Electrical components found on locomotives

The general maintenance schedules used on newer type and older type locomotives differs slightly, where the newer type locomotives generally require less maintenance interventions due to the newer electrical component technologies used [44]. Transnet generally defines four types of maintenance interventions that will be applied throughout the lifecycle of the locomotive. The interventions are named A Shed, B Shed, C Shed and D Shed. The maintenance intervention intervals can be seen in Table 3 below:

Table 3: Maintenance intervals of newer and older generation locomotives. Source: Author adapted from University of Pretoria [44]

Shed Type	Older generation locomotives	Newer generation locomotives	General Interventions
A Shed	38 to 45 days	90 days	Inspecting, lubricating and cleaning of components.
B Shed	Once every year	Once every year	Measurements of voltages, earth faults, inspecting, changing brushes of DC motors, lubricating and cleaning of components.
C Shed	Once every year	Once every year	Cleaning, replacement of earthing bars, magnet values.

Shed Type	Older generation locomotives	Newer generation locomotives	General Interventions
D Shed	Once every four years	Once every three to four years	Replacement of antennas, braking resistors and motors, high powered circuit breakers, earthing bus bar connections, magnet valves.
Major Overhaul	Once every six years	Once every 12 years, dependent on the locomotive type	Change of major components including batteries, switch gear (if necessary), contactors and speed probes.

From this it means that a newer type locomotive, in the first year of operation, will have to undergo the following maintenance interventions (refer to Figure 14):

- 4x A Shed interventions
- 1x B Shed intervention
- 1x C Shed intervention

In the fourth year the locomotive will also receive the same amount of interventions including a D Shed. During the operational life of the locomotive various electrical components will fail and will have to be repaired or replaced. It all depends on the maintenance philosophy adopted by the railway operator. A major overhaul will commence every twelve years on newer type locomotives whereby major components will be refurbished or replaced by new components. Major overhauls can include replacement of switch gear, emergency switches, control units, resettable fuses, circuit breakers and motors [44].

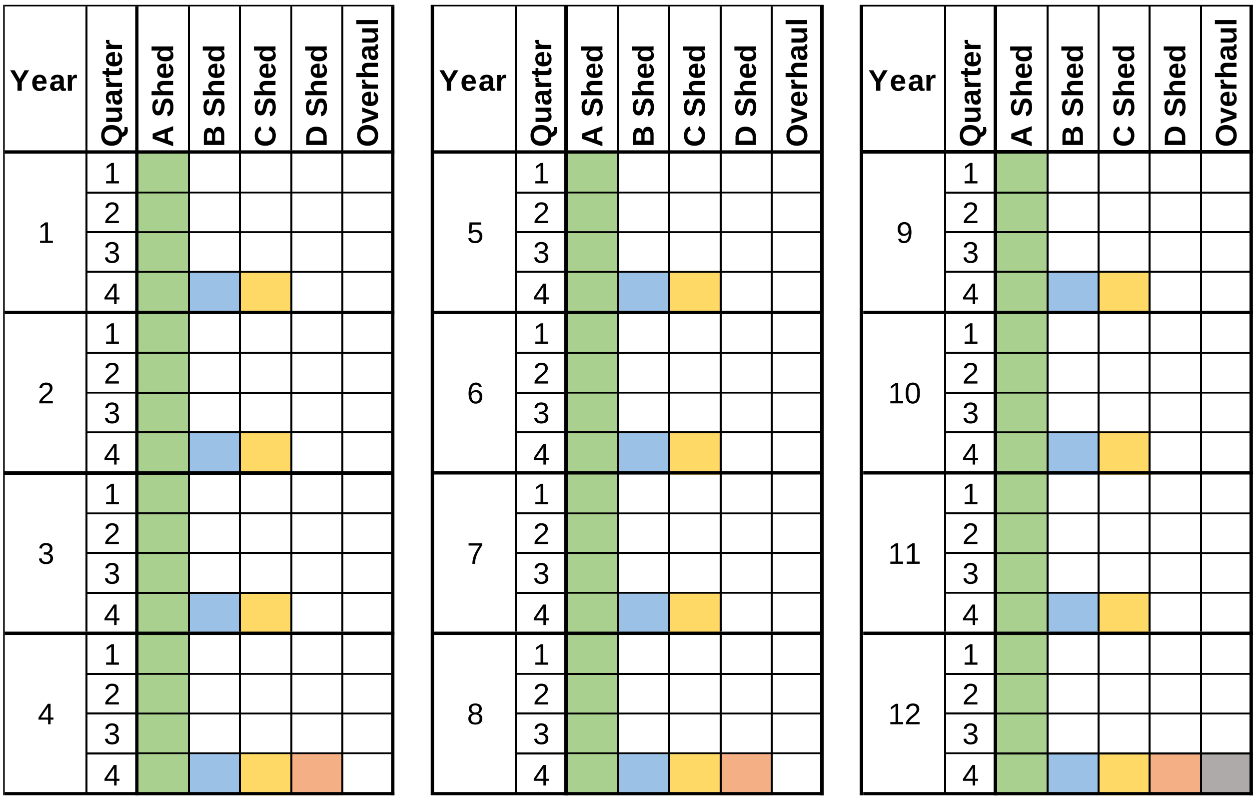


Figure 14: Maintenance cycles of a newer type locomotive.

Source: Author adapted from University of Pretoria [44]

The identified electrical components that will require repairs or maintenance are rectifiers, train control electronic modules, traction motors, traction converters, motor blowers, compressor, exhauster, batteries, circuit breakers, alternators, battery charger, transformers and inductors [13,43].

Replacement or maintenance of components are based on pre-determined criteria that can either be time based or worked based [44]. Therefore, each component, including the electrical components will be maintained based on the kilometres travelled, hours operated, or the power produced over time [44]. The decommissioning and disposal techniques are further defined in the next section of this report.

2.2.3. Decommissioning and Disposal Processes

Guanghan et al. did a study to see whether the non-metallic compounds found in Waste Printed Circuit Boards (WPCBs), used in electrical components, can be deposed in the correct manner [45]. This study showed that the right way of disposing WPCBs were not found, but WPCBs can be reused in building and paving materials [45]. From a study conducted in 2013 it shows that 40 % of WPCBs are landfilled, adding strain on the environment [27].

Rajagopal et al. found that WPCBs can be added to Waste Automotive Plastics (WAPs) used in composite panels to increase mechanical properties, increase the density and increasing the energy absorption rate of panels [46]. This highlights the endless possibilities for the reuse or recycling of electrical waste.

A lot of research went into increasing the recyclability of rolling stock and a standard method was developed to calculate the recyclability percentage of rolling stock. The recyclability rate of a locomotive can be determined by adding the mass of components that can be re-used and materials that can be recycled divided by the mass of the rolling stock as illustrated by Figure 15. The specification used on road vehicles is ISO 22628:2008 and the one being developed for railway vehicles is ISO TC269/WG:2015 [41].

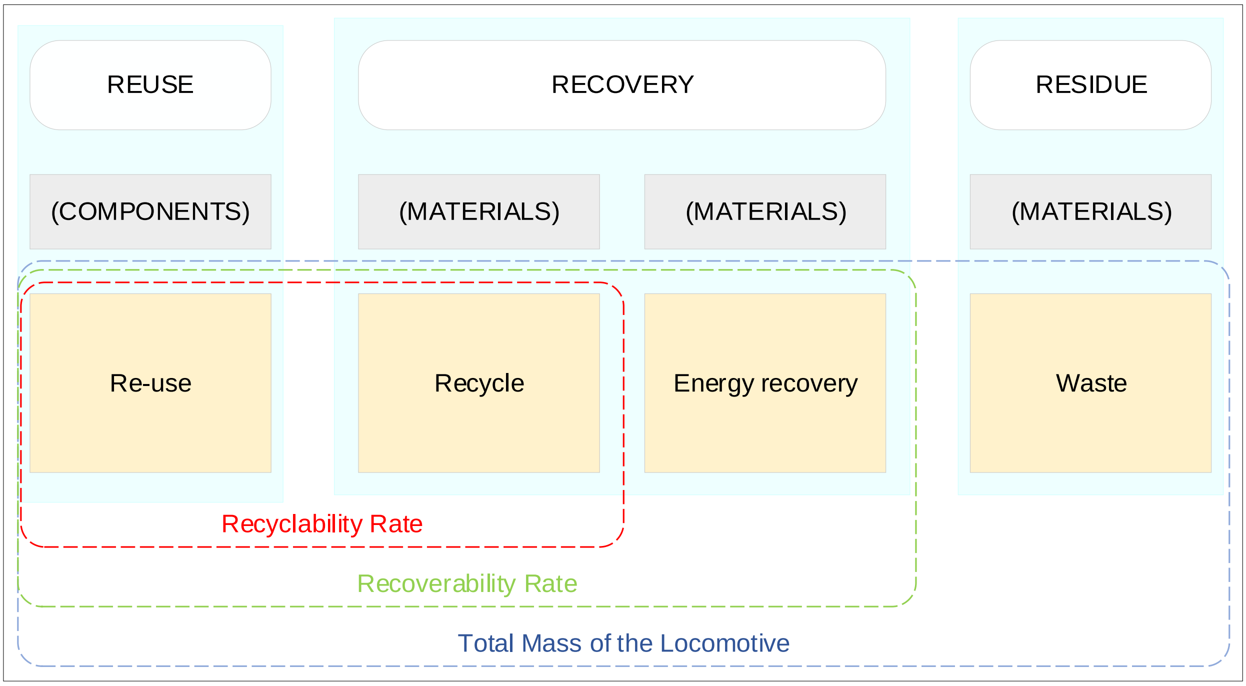


Figure 15: Recyclability and recoverability rate of a locomotive.
Source: Author adapted from Kaewunruen et al. [41]

General WEEE recycling normally includes a sorting stage to separate hazardous and non-hazardous components followed by shredding and separation stages [8,41,47]. In Europe, the recycling process for rolling stock includes the following stages: a pre-treatment stage; a dismantling stage; separation of metals stage; and the treatment of non-metallic residues

[40]. These stages are used at the EOL of rolling stock and not only for the electrical but also the mechanical components. The different stages for electrical component recycling can be seen in Figure 16 and are described below:

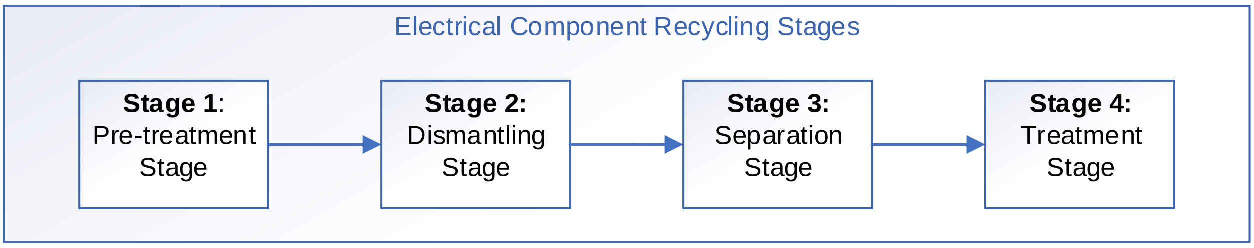


Figure 16: The electrical component recycling stages.

Source: Author

a. Pre-treatment Stage

This first stage includes the draining, removing and handling of hazardous and toxic waste found on the vehicle/locomotive in a safe manner [40,48,49]. This includes draining the operating fluid and disassembly of the parts and components that can be reused as spares [40,48]. Critical items e.g. batteries, capacitors and coolant must be removed and send to specialised recycling facilities [48,50]. These various components will be safely tested for hazardous substances at recycling facilities.

b. Dismantling Stage

The second stage includes the separating of useful materials that can be reused on other applications, this includes items like cables, power supplies and components that can be reused on electronic boards [41,46]. Informal and incorrect dismantling techniques include the separation and selling of heterogeneous materials from components by using hammers and screwdrivers, followed by open burning to recover copper, steel and aluminium [51]. It is critical that the dismantling process be completed in a designed safe environment to prevent contamination of soil or water supplies and the safety precautions required by personnel responsible for the dismantling tasks. Asante et al. found higher levels of deadly Polychlorinated Biphenyls (PCBs) in breast milk due to the informal dismantling and recovery techniques used [52]. PCBs have been proven to be carcinogens to animals and possibly in humans as well [53].

c. Separation Stage

The third stage includes the separation, preparation and shredding of metals in the different categories to group and to reduce the volume of materials [40,49]. This include grinding and milling the materials in smaller particles that are separated by eddy current separators into Shredder Heavy Fractions (SHF) and Shredder Light Fractions (SLF) [40,49]. Additional metal removal techniques included permanent magnets, magnetic head rollers, inductive metal removal methods and vibrating tables [51]. SHF include the ferrous and non-ferrous materials and SLF are a mixture of plastics, glass, fibre and residue [40]. New technological methods are also being developed to recover specialised metals, e.g. Indium found in small quantities in electrical applications [51].

d. Treatment Stage

The elements that were dismantled from the vehicle/locomotive should then be treated by the different technologies applied to the different systems [48]. Dedicated recycling techniques should be applied to components like the batteries, recovered electrical components, shredded components, oils, coolants and elements containing hazardous substances [48]. In the railway environment PCBs were used in large and small transformers, voltage regulators and circuit breakers [54]. This applies to the ferrous and non-ferrous materials as well, which will undergo specialized treatment processes [48]. Failure to apply the correct techniques might lead to unexpected environmental results [48].

Simple tests that can be completed to determine the presence of PCBs are density tests and chlorine presence tests [54]. The density test compares the density of transformer oils and water, transformer oil should float, while PCBs are heavier than water and should sink[54]. Chlorine presence tests are completed by observing the colour of a flame after burning the substance on a copper wire, a green flame will be evident of chlorine being present, which is found in PCBs [54].

PCB containing materials can be destroyed by high temperature incineration (> 1 100 °C) [54]. Other methods that can destroy PCB materials are hydrogenation, gasification, evapo-inceration, chemical dichlorination, plasma arc heating and electrochemical processing [55].

2.2.4. *Determining the maturity of decommissioning/disposal processes*

The CMMI framework, developed by Paulk et. al, can also be used to determine the maturity level of the decommissioning and disposal process used at Transnet [56]. The CMMI consists of five maturity levels determined by the achievement of goals in a predefined set of key process areas, the higher the level the higher the process maturity in the company, this can be seen in Figure 17 [57].

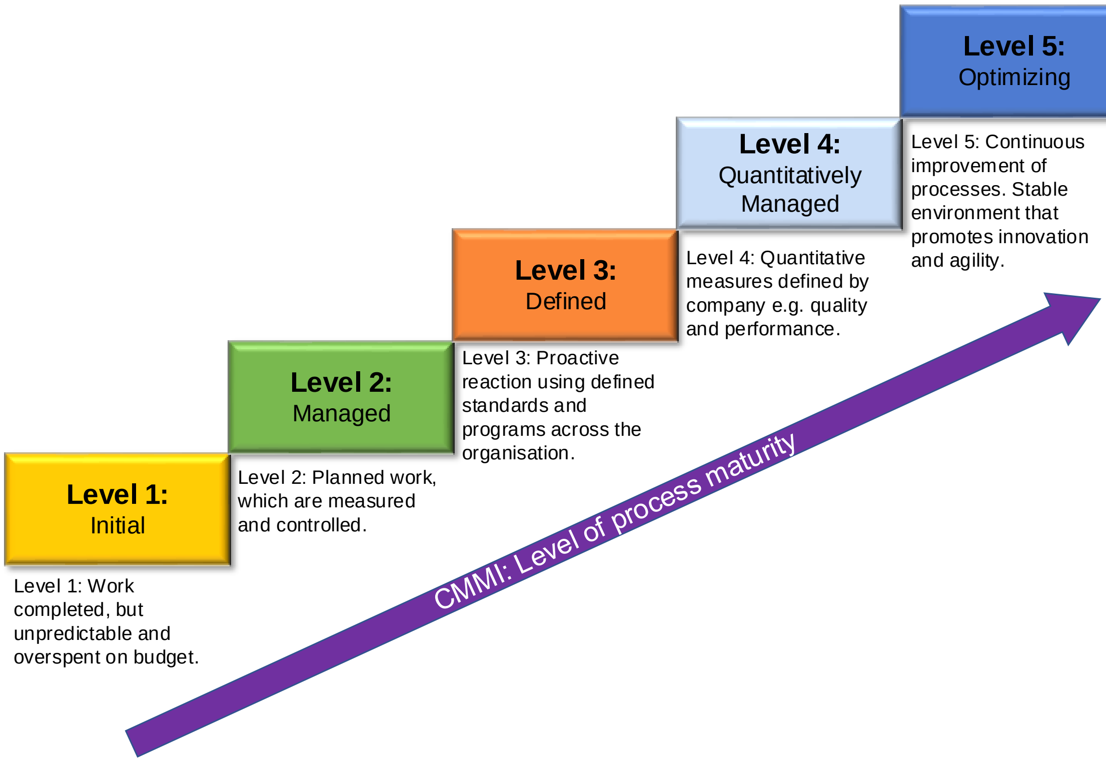


Figure 17: The five levels of the CMMI framework.

Source: Author's adaption of Mahmood [57] and CMMI Institute [58]

2.2.5. *Hazardous Materials*

The Stockholm Convention, responsible for the protection of human health and the environment, has identified 12 different types of Persistent Organic Pollutants (POPs) that can cause harm to the environment [7]. The 12 different types of POPs can be seen in Table 4. Most of the substances identified are used as pesticides and are dangerous for humans and animals. One of the identified elements is called PCBs which were normally used in electric capacitors and transformers, additives found in paint, some plastics and carbonless copy paper [7,54,59]. PCBs have been proven to be carcinogens to animals and possibly in humans as well [53]. It is critical to confirm that the materials being recycled do not contain any POPs, if so, the correct treatment processes should be followed.

Table 4: The 12 different POPs identified by the Stockholm Convention.

Source: Author adapted from the Stockholm Convention [7]

POPs	Uses / Effects
Aldrin	Pesticide used in soil to kill termites, corn rootworms and other insect pests, but can also kill humans, fish and birds.
Chlordane	Used to control termites, but Chlordane can stay in the soil for a year and can kill fish and bird species.
DDT	Was used to control malaria, typhus and other insect spread diseases in World War II.
Dieldrin	Dieldrin was used to control termites and textile pets and has a half-life of five years.
Endrin	This substance was used to control mice and rodents when sprayed on the leaves of crops. It is highly toxic to fish and has a half-life of 12 years.
Heptachlor	Used to kill soil insects and termites. Heptachlor is also classified as a carcinogenic substance.
Hexachlorobenzene (HCB)	HCB kills fungi that infects food crops. By-product during the manufacturing of industrial chemicals.
Mirex	This substance was used to control ants. A laboratory study showed that Mirex can also be carcinogenic.
Toxaphene	Used to control insects on cotton, grains and fruit. It is exposed to humans through the consumption of food. Toxaphene has a half-life of 12 years.
Polychlorinated biphenyls (PCB)	Compound used in electrical transformers. 209 different PCBs were identified.
Polychlorinated dibenzo-p-dioxins (PCDD)	This chemical is unintentionally produced by burning of hospital, municipal and hazardous waste. PCDD can also be a carcinogenic substance.
Polychlorinated dibenzofurans (PCDF)	This substance is also unintentionally produced by burning the same material as PCDD and during the production of PCBs.

The POPs in bold text in the table above are industrial chemicals or a by-product of various processes or mixture of chemicals. Care should be taken to prevent creation of these dangerous items during the de-manufacturing process. Hazardous materials and substances found in WEEE that requires special care are listed in the table below. All these items listed in the table below needs specialised recycling techniques to limit any effects it can have on humans.

Table 5: Hazardous materials and substances found in WEEE.

Source: Author adapted from Schluep [60] and Kaya [8]

Materials or Substance	Found in the following materials	Medical effects
Lead (Pb)	Printed circuit boards, Cathode-ray tube (CRT) screens and batteries.	Medical conditions e.g. vomiting, constipation, abdominal pain and headaches.
Mercury (Hg)	Batteries, relays, Liquid Crystal Displays (LCDs) switches and fluorescent lamps.	Liver and brain damage.
Chromium (CR6)	Data tapes.	Irritation to the eyes.
Barium (Ba)	Getters in CRT.	Damage to heart, brain swelling and muscle weakness.
Cadmium (Cd)	Nickel Cadmium batteries, fluorescent layers.	Lung cancer and kidney damage.
Arsenic (As)	Gallium arsenide in Light Emitting Diodes.	Skin diseases and a decrease in nerve conduction.
Americium (Am)	Smoke detectors.	Radioactive element.
Antimony (Sb)	Flame retardants in plastics and solder used on printed circuit boards.	Carcinogenic effect.
Chlorofluoro Carbon (CFC)	Cooling units, insulation foams.	Breakdown of ozone layer, skin cancer and genetic damage.
Polybrominated Diphenyl Ethers (PBDE) and Polybrominated Biphenyls (PBBs)	Flame retardants in plastics.	Hormonal effects and possible formation of dioxins and furans under thermal treatment.

Some of the current materials used in production of rail vehicles can be banned in a few years and this will make those material unrecyclable [50]. An example of this is that currently the use of the asbestos is forbidden, but it was allowed to be used in the past [50]. Asbestos was used in pipes, roofs, insulating materials and woven materials [61]. People working in the vicinity of locomotive steam engine repair shops had potentially been exposed to asbestos fibres in the air [61].

2.2.6. Environmental Impact

Transnet generates waste and greenhouse gasses which contributes to global warming [4]. Cheng et al. did a comparison about different climate models predicting the increased Ocean Heat Content (OHC), if emissions are not limited it could lead to an exponential rise in the ocean level by the end of the 21st century and increasing the ocean temperature by 0.8 degrees [62]. In effect, increasing the ocean level by 30 cm, which increases the need to stop climate change or prepare for the expected outcomes [62].

According to a report released in 2018 from the Intergovernmental Panel on Climate Change (IPCC), 1.0 degree Celsius of global warming was caused by human activities and is likely to reach 1.5 degrees Celsius between 2030 and 2052 [63]. This will have impacts on the biodiversity and ecosystems on earth and will lead to loss and extinction of species that includes plants, insects and vertebrates [63].

2.3. Regulations, Standards and Legislation

The IDEF0 technique was used to graphically represent the tasks that should be completed to produce a systems framework that can be applied to Transnet's TAL. The IDEF0 diagram, Figure 18, can be used to define the controls, inputs and mechanisms that should be taken into consideration during the decommissioning to obtain the systems framework [21]. The control portion deals with the Standards, Regulations and Legislation in South Africa and around the world. The IDEF0 diagram was used as a baseline for the research regarding regulations and legislations specifically referring to the decommissioning of electrical components and WEEE.

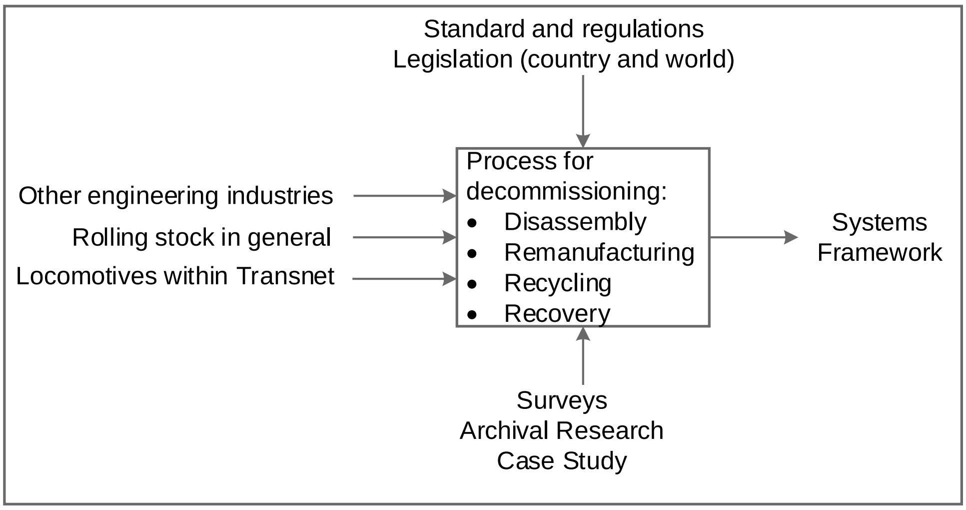


Figure 18: The IDEF0 diagram to identify requirements for a systems framework. Source: Author adapted from Department of Defence [21]

The legislation timeline relating to WEEE identified during this study can be seen in Figure 19 and shows the implementation dates of the various directives and legislation. The legislation identified from the year 2003 to 2007 were all enforced in the European Union, where South Africa adopted some of the directives. South African legislation started identifying WEEE in 2009 and identified WEEE as hazardous substance in 2014.

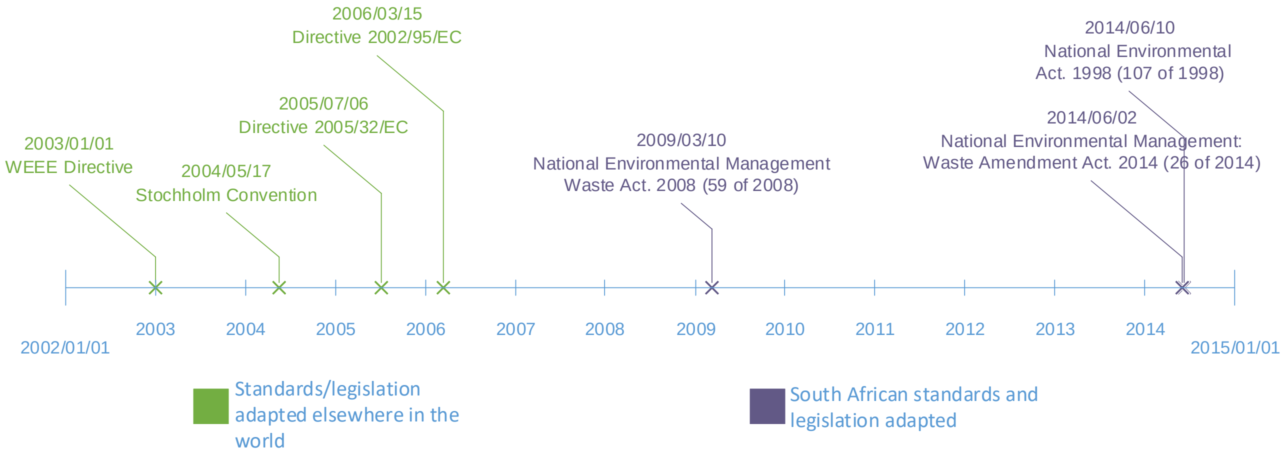


Figure 19: Timeline of disposal and WEEE legislation.

Source: Author from legislative and regulation information to follow

The three main identified legislations and regulations governing WEEE in South Africa are listed and explained below:

2.3.1. National Environmental Management Waste Act. 2008 (59 of 2008) [64]

The re-use, recycling or recovery of waste may only be applied if it uses fewer natural resources than disposal of the waste and if it is less harmful to the environment in comparison to disposal thereof. No waste management activity may commence without a valid waste management licence. This act deals on how to apply, retain, transfer the waste licence and how to prepare and asses a Waste Management Plan (WMP). The act also includes all the penalties that should be enforced if offences are committed, ranging from a R10 million fine or 10 years in prison to a minor fine not exceeding a thousand Rand.

2.3.2. National Environmental Management: Waste Amendment Act. 2014 (26 of 2014)

This act, introduced on 2 June 2014, defines that WEEE is seen as hazardous waste in Category A, as well as waste from end-of-life vehicles for means of transport and waste generated from dismantling and maintaining of vehicles [65]. This act is an amendment of Act 59 of 2008.

2.3.3. National Environmental Management Act. 1998 (107 of 1998) [66]

This regulation was introduced 10 July 2014 and addresses the phase-out and use of PCB materials and PCB contaminated materials. Contaminated material refers to material with a PCB concentration between 51 mg/kg but less than 500 mg/kg. PCB materials refer to material that has higher concentration than 500 mg/kg. This regulation also restricts the use, sale, manufacturing, importation, exportation of PCB materials in South Africa. The use of PCB materials or contaminated materials are prohibited after the year 2023 and by 2026 no person may be in possession of PCB materials or contaminated materials. Any person who fails to comply to this regulation can be fined up to R10 million or 10 years in prison.

From the three regulations listed above it can clearly be seen that WEEE were only taken serious from around 2014 where the regulations specifically address contaminated materials from WEEE. The following international regulations and legislations were identified and are explained below:

2.3.4. Basel Convention

The Basel Convention regulates the transboundary movements of hazardous wastes and the disposal thereof. South Africa is part of the Basel Convention and has implemented the ban amendment. South Africa does not restrict the export of hazardous waste that cannot be disposed of in South Africa [64,67]. However, it restricts the export of waste that can be recovered in South Africa [64,67].

2.3.5. Stockholm Convention

The Stockholm Convention was also adopted in South Africa and enforced from 17 May 2004. The list of the identified POPs is listed in Table 4 and can be seen on page 24. The Stockholm convention is responsible for the protection of human health and the environment against POPs [68].

2.3.6. European Union (EU) legislation

The three major directives in thea EU are the Restriction of Hazardous Substances (RoHS) or know as Directive 2002/95/EC, Directive 2002/06/EC or known as the WEEE-Directive and Directive 2005/32/EC or known as EcoDesign [51]. The RoHS Directive restricts the use mercury, lead, PBDE, PBB, cadmium and hexavalent chromium in electronic components and applications [51]. The WEEE Directive deals with the reuse, recycling and recovery of waste, while EcoDesigns focus on energy efficiency of products [51]. These directives are currently enforced in countries grouped within the European Union.

2.4. Industry Used Models and Frameworks

The following famous defence industry frameworks identified by Robinson [69] and Williamson [70] were investigated and studied in order to conclude a new framework for the decommissioning and disposal of the electrical components on the TAL locomotive. The famous enterprise architecture frameworks can be seen below, followed by the famous system-of-systems frameworks:

2.4.1. Enterprise Architecture Frameworks:

2.4.1.1. Zachman Framework

The Zachman Framework or also called Framework for Enterprise Architecture was founded in 1990 by John A. Zachman after working for the International Business Machines (IBM) Corporation for 26 years [71]. This framework is presented in table format consisting of six rows and six columns to assist with the simplification of descriptive representation that are significant for management, designers, developers and users [71]. In basic terms the columns are divided into ‘What’ (material), ‘How’ (process), ‘Where’ (geometry), ‘Who’ (operating instructions), ‘When’ (timing diagrams) and ‘Why’ (engineering design objectives), while the rows represent the perspectives during the design process [71]. The comprehensive Zachman Framework version 3.0, which is the latest one and the one being used in the industry, can be seen in Figure 20.

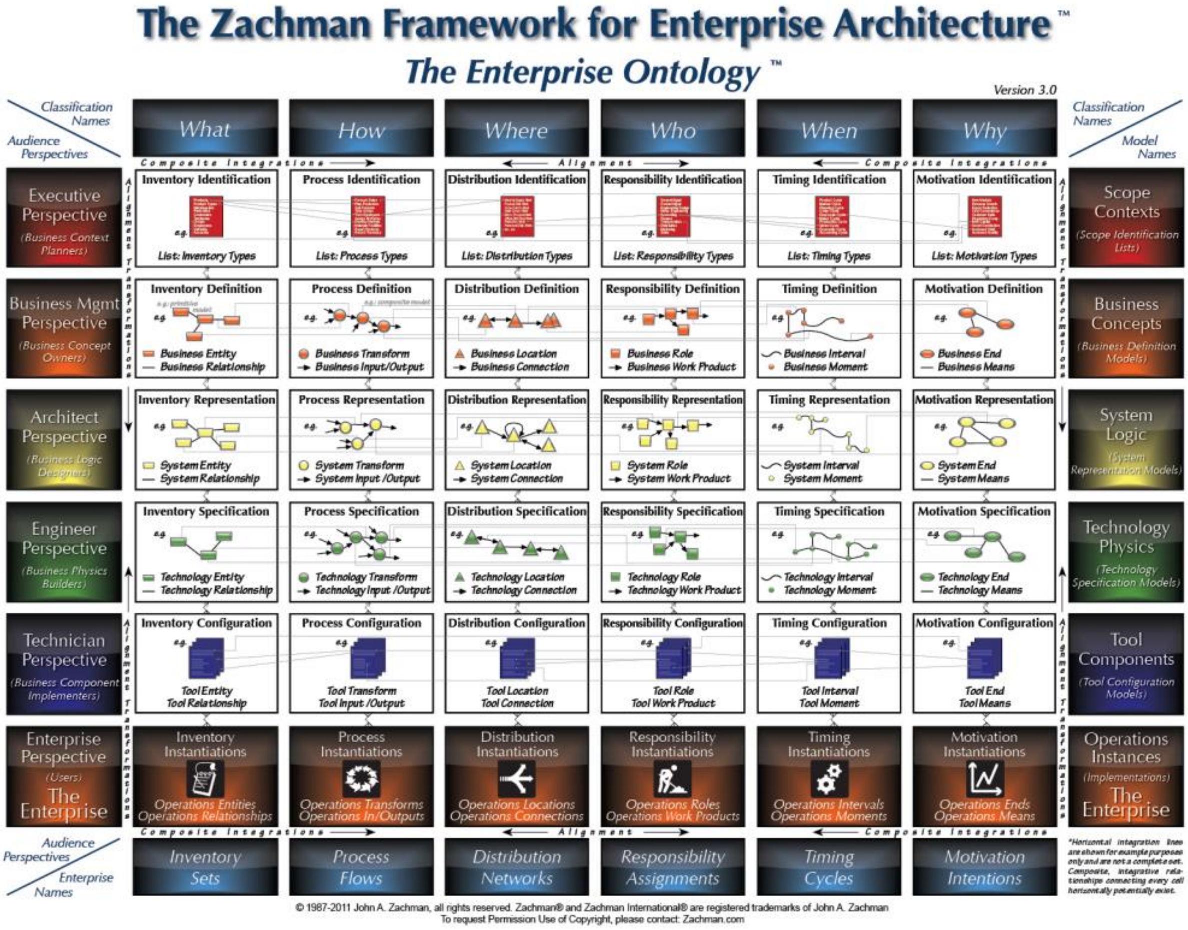


Figure 20: The completed Zachman Framework version 3.0.
Source: Zachman [71]

The Zachman Framework is an easy framework to understand in its basic form and comprehends all the different viewpoints of the various parties involved. It is a good planning and problem-solving tool that can form part of a Systems Framework.

2.4.1.2. The Open Group Architecture Framework (TOGAF)

The first version of TOGAF was developed by The Open Group in 1995 and is based on the Technical Architecture Framework for Information Management (TAFIM) developed by the US Department of Defence [72]. The TOGAF consists of various methods and tools to develop an enterprise architecture. One of the tools that was identified that could be used to assist with the framework for this research report was the Architecture Development Method (ADM), the method can be seen in Figure 21.

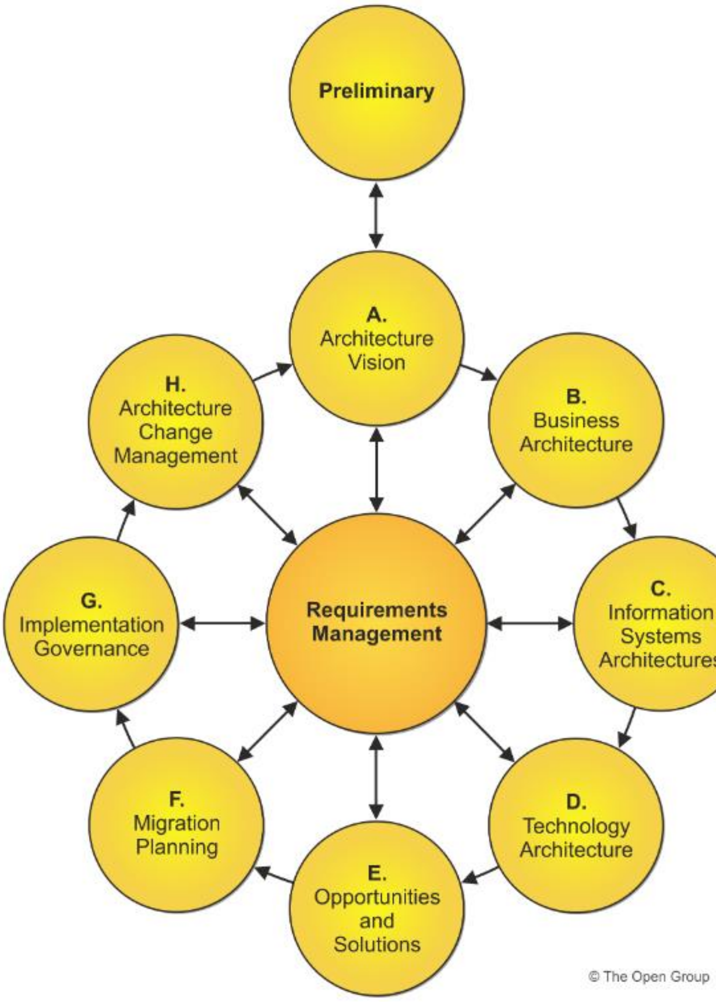


Figure 21: The Architecture Development Method (ADM) from TOGAF. Source: The Open Group [72]

2.4.2. Systems-of-systems Architecture Frameworks:

2.4.2.1. Department of Defence Architecture Framework (DODAF)

The DoDAF was introduced in August 2003 by the United States of America Department of Defence and v2.0 is latest version of the framework [73]. Figure 22 shows the interaction and information flow between the operational view, systems and services view and technical standards view. The overlapping aspects of the different views are captured by the All-View or the yellow block surrounding the three individual views.

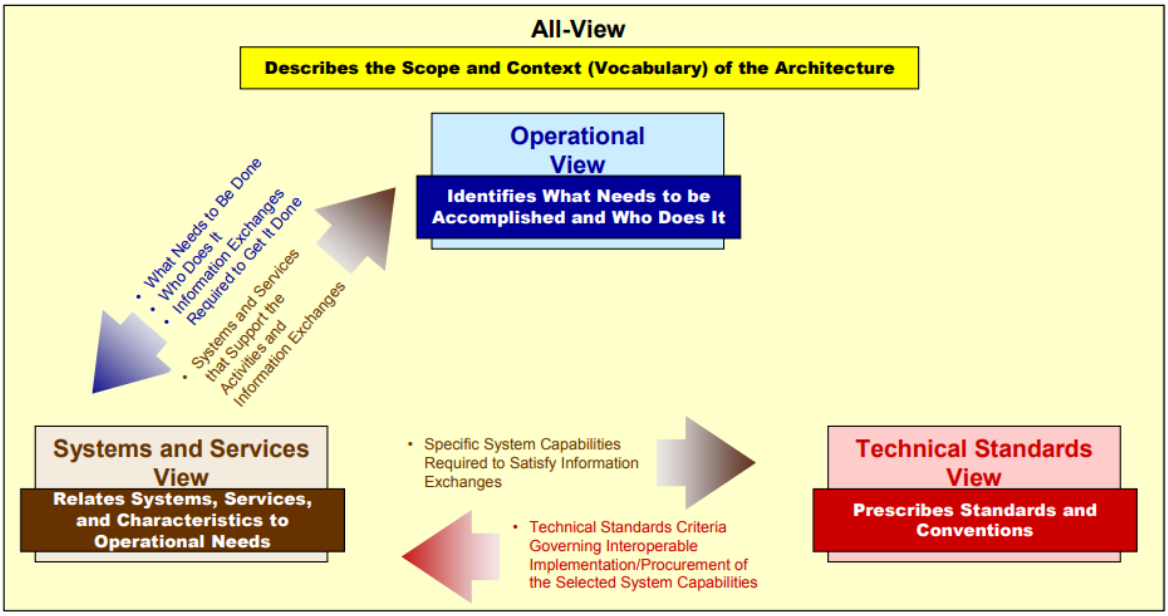


Figure 22: Viewpoint diagram of DoDAF.

Source: Unites States of America Department of Defence [73]

DoDAF is a good model to use to determine the various viewpoints that should be investigated for this research. From the research conducted it indicated that the Ministry of Defence of the United Kingdom did improvements and developed their own framework that is discussed in the next section.

2.4.2.2. Ministry of Defence Architecture Framework (MODAF)

The first version of MODAF was introduced on August 2005 by the Ministry of Defence of the United Kingdom and it is based on the DoDAF, developed by the United States Department of Defence [1]. The original MODAF framework can be seen in Figure 23.

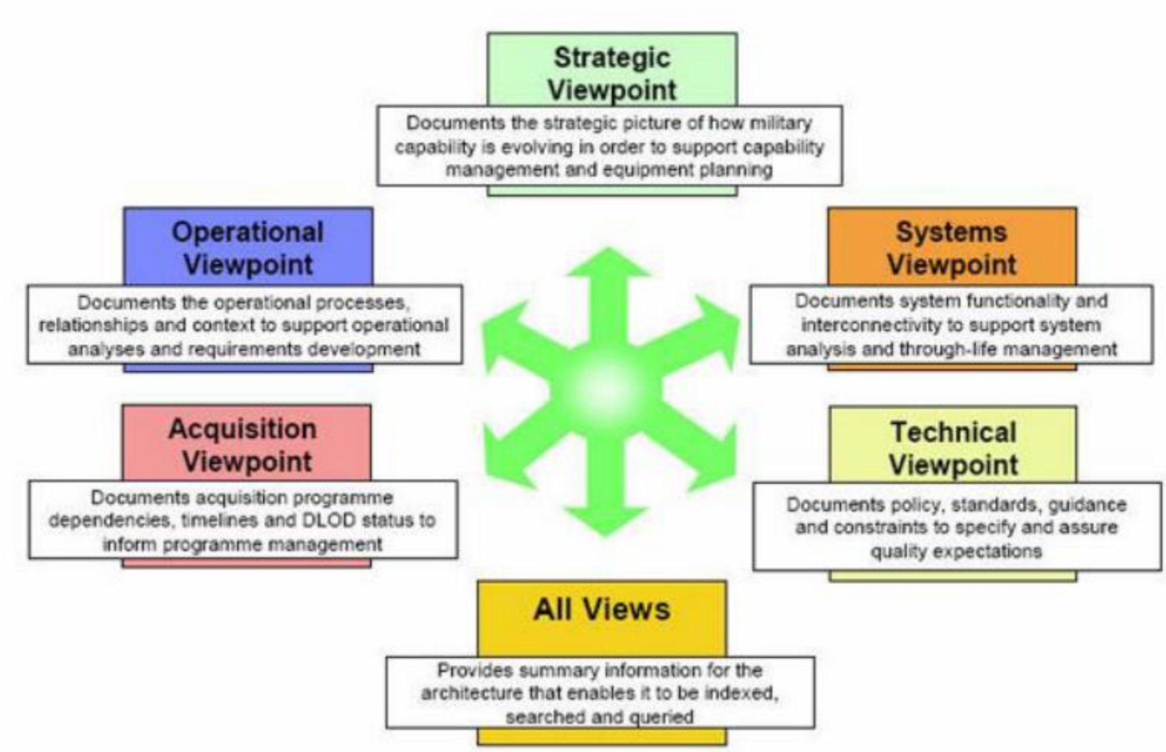


Figure 23: The original MODAF viewpoints diagram.

Source: Caruso et al. [1]

2.4.3. Comparison of Frameworks

The two different frameworks types identified were Enterprise Architecture Frameworks and System-of-System Architecture Frameworks. The Enterprise Architecture Framework focusses on the business and enterprise aspects of a big enterprise, where the Systems-of-Systems Framework addresses technical aspects of a system by using different viewpoints influencing a specific system. Therefore, for this research a Systems-of-Systems Architecture Framework will be used for the framework for the decommissioning/disposal of electrical components on Transnet Trans-Africa Locomotive.

Alghamdi [74] did an evaluation to choose between MODAF and DODAF and created a scoring methodology that was used to determine which one to use in this study. The first step was to create a ranking of the different criteria required for this framework for the decommissioning/disposal process for electrical components for the Transnet's TAL. The author created this based on his personal experience in the locomotive environment. The ranking can be seen in Figure 24 where adaptability scores the highest followed by performance. The created framework should be adaptable to be used in future projects as well.

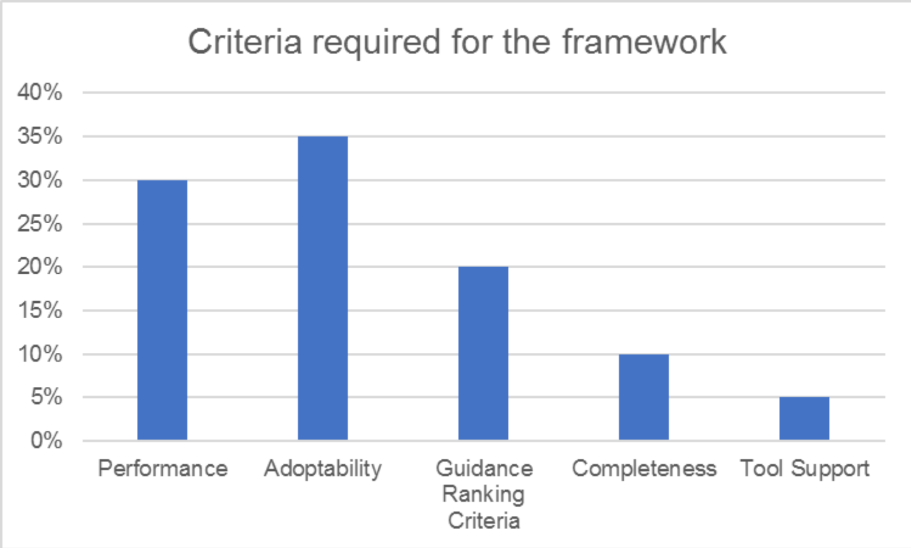


Figure 24: The ranking criteria required for the framework.

Source: Author created ranking based on Alghamdi [74]

Alghamdi [74] created a ranking between MODAF and DODAF, see Figure 25 below, based on the criteria identified in Figure 24. MODAF scores the highest in performance and adoptability, while DODAF scores the highest in tool support, completeness and guidance ranking criteria.

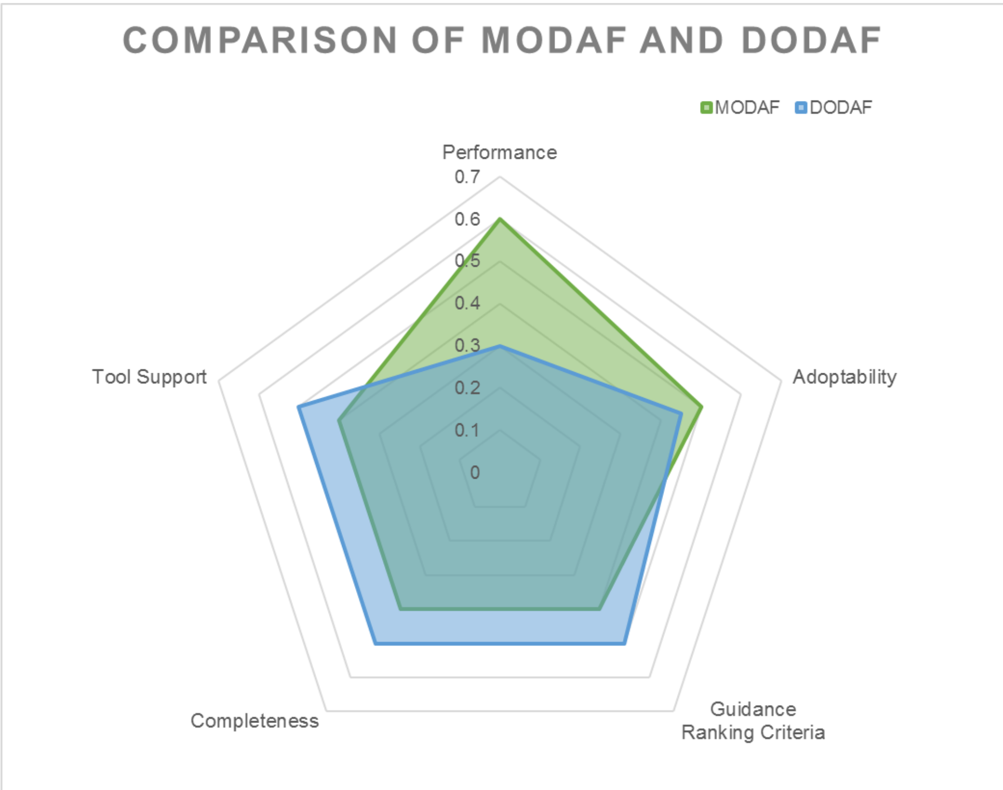


Figure 25: MODAF vs. DODAF comparison.

Source: Author adapted from Alghamdi [74]

Figure 26 is a combination of the ranking criteria created for the decommissioning/disposal framework for the locomotive (Figure 24) and the comparison between DODAF and MODAF (Figure 25). This scoring methodology from Alghamdi determines that MODAF is the preferred framework for this research and will suit the disposal framework in this report.

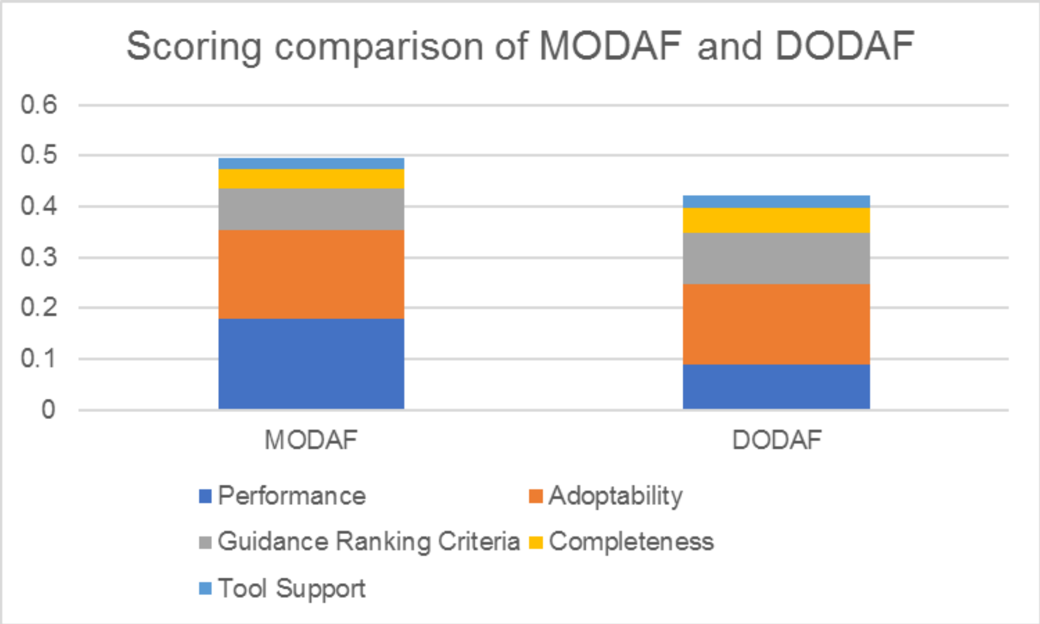


Figure 26: Combination of the ranking criteria and the MODAF vs. DODAF scoring. Source: Author adapted from Alghamdi [74]

2.5. Systems Framework for the Decommissioning/Disposal process

The following framework was constructed using inputs from the literature review, report from Cloete-Hopkins [2] and guidelines on MODAF by Caruso et al. [1]. This framework captures all the viewpoints and structures outlined and defined by Caruso et al. [1]. The first draft based on the literature study is listed in Table 6 below.

Table 6: The first draft of the systems framework for the decommissioning/disposal process for the TAL locomotive based on the literature study.
Source: Author adapted from frameworks from Caruso [1] and Cloete-Hopkins [2]

View Ref.	View Title	Purpose of the View
All Viewpoints (AV)		
AV-01	Overview and Summary	Summary of information relating to the decommissioning/disposal process. This will summarize the decommissioning/disposal process.
AV-02	Integrated Dictionary	Explanation of terms and abbreviation used in this framework.

Technical Standards Viewpoint (TV)		
TV-01	Legislation Profile	List the legislation identified in the various countries the locomotive will be sold, as well as the local legislation implemented.
TV-02	Legislation Forecast	List possible changes or evolution to existing legislation: • Short term (1 year) • Medium term (3 years) • Long term (5 years)
TV-03	Legislative Risk Register	Compile risk register capturing all risk identified in terms of legislation and regulation of the locomotive that has already been developed.
System Viewpoints (SV)		
SV-01	Lifecycle View	Investigate the complete lifecycle and identify possible • shortcomings; • phases that were not taken into consideration during the design; • and lessons learned that could be implemented during a next project similar in nature. Review the current maintenance and disposal plan and determine if the plan was constructed from the beginning of the lifecycle or only at the post project phases. Compile a lifecycle plan for the locomotive.
SV-02	Electrical System View	Create a systems-of-systems view of the different components identified on the locomotive. Note the lifecycles applicable to each of the elements in the system of systems.
SV-03	Manufacturing and Maintenance Risk Register	Compile risk register capturing all risk identified in terms of the lifecycle of the locomotive. This includes the following aspects: • Hazardous material • Waste from manufacturing • By-products produced during maintenance
SV-04	Engineering Analysis	Define the engineering analysis process that will be followed assisting the locomotive from ‘cradle to grave’.
SV-05	Resource Interaction Description	Compile a hierarchy of personnel required for the disposal and decommissioning process and assign a breakdown of tasks to each resource.
SV-06	Recyclability Analysis	Determine the recyclability rate of the locomotive according to ISO/TC 269/SC 2/WG 4 or using the road vehicle standard ISO 22628:2008.
Operational Viewpoint (OV)		
OV-01	High-level operational concept graphic	High-level description/process flow regarding the operation schedules of the locomotive.
OV-02	Procedures Profile	Identify company policies and company procedures applicable to the decommissioning and disposal process of Waste of

		Electrical and Electronic Equipment (WEEE). This will also include: • Standard Operating Procedures (SOP's) • Safe waste handling procedures If there are no policies available, it should be created.
OV-03	Maintenance Process / Logistics	Define a maintenance plan to determine the shedding cycles of the locomotive.
OV-04	Manufacturing Process / Logistics	• Identify possible by-products produced during production phases of the locomotive. • Create SOP documentation how to manage the by-products produced.
OV-05	Disposal Process / Logistics	• Create disposal process flow for each electrical component identified in the locomotive. • Create SOP documentation for the disposal of each component identified. • Combine the disposal process with the maintenance process.
Strategic Viewpoints (StV)		
StV-01	Market Analysis	Identification of where the demand for the locomotive will be. This will include a market analysis study.
StV-02	Environmental Analysis	Environmental analysis of the area considering the following elements: • By-products produced in manufacturing. • Hazardous materials introduced to the environment by incorrect handling processes. • WEEE from failures and maintenance. • Recycling processes.
StV-03	Capability Analysis	Study to determine Transnet's and local companies' capability to dispose of WEEE in a safe manner.
StV-04	Enterprise Vision	Business study to determine the possibility to generate income from disposal of WEEE.
StV-05	Energy Recovery Analysis	Identify means of recovering energy during the manufacturing, decommissioning and disposal process of locomotives.
StV-06	Life Cycle Improvement Assessment	Plan for improvements that can be made to extend the life of the locomotive.
Acquisition Viewpoint (AcV)		
AcV-01	Hazardous Materials	• Identify possible hazardous materials that must be handled with care on the locomotive. • Create safe handling procedures for the hazardous materials. • Create a plan for the replacement of the hazardous materials.
Service Orientated Viewpoints (SOV)		
SOV-01	Operation Description	• Define the operational aspects of the decommissioning and disposal of the locomotive.
SOV-02	Recycling Process	Create a recycling process that should be followed for each group of electrical components identified on the locomotive.

3. RESEARCH METHODOLOGY

3.1. Research Framework

The Research 'Onion' developed by Saunders et al. [75] was used as a framework for this research. The research onion provides a good baseline and simplifies the different steps that must be completed during this research. The Research 'Onion' breaks down the type of philosophies, approaches, strategies, methodological choices, time horizons and techniques and procedures that will be required [75]. The best way to approach the Research 'Onion' is to start from the inner layer, where the core of the data is situated, moving layer by layer until the Philosophies layer is reached [76]. The modified Research 'Onion' that was applicable to this study can be seen in *Figure 27*.

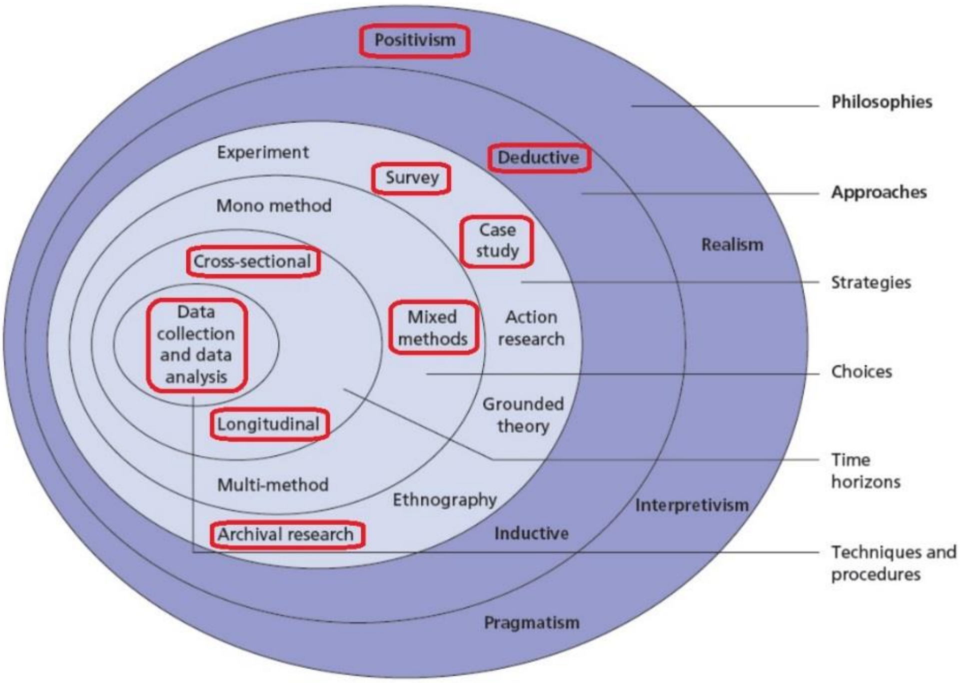


Figure 27: The Research 'Onion' applied to this study.
Source: Author adapted from Saunders et al. [75]

3.2. Research Philosophy and Approach: Positivism (Deductive)

The research philosophy adopted was Positivism. Through the adoption of the positivism philosophy, this research applied primarily a deductive approach to exploring the study area by using empirical data and logical analysis reasoning [77]. Real-world data was sought and used to find relationships between quantitative and qualitative (coded numerically for analysis) data presented. These was, in conjunction with systems principles, used to develop a suitable systems framework for the TAL.

3.3. Methodological Choice: Mixed Methods

The Mixed Methods research choice was chosen based on the Research Strategies that would be used for this research. Mixed Methods included the use of both qualitative and quantitative data. The data was generated by making use of research strategies that included surveys, case study and archival research. *Figure 28* gives a graphical description of the Mixed Methods research strategy that was adopted.

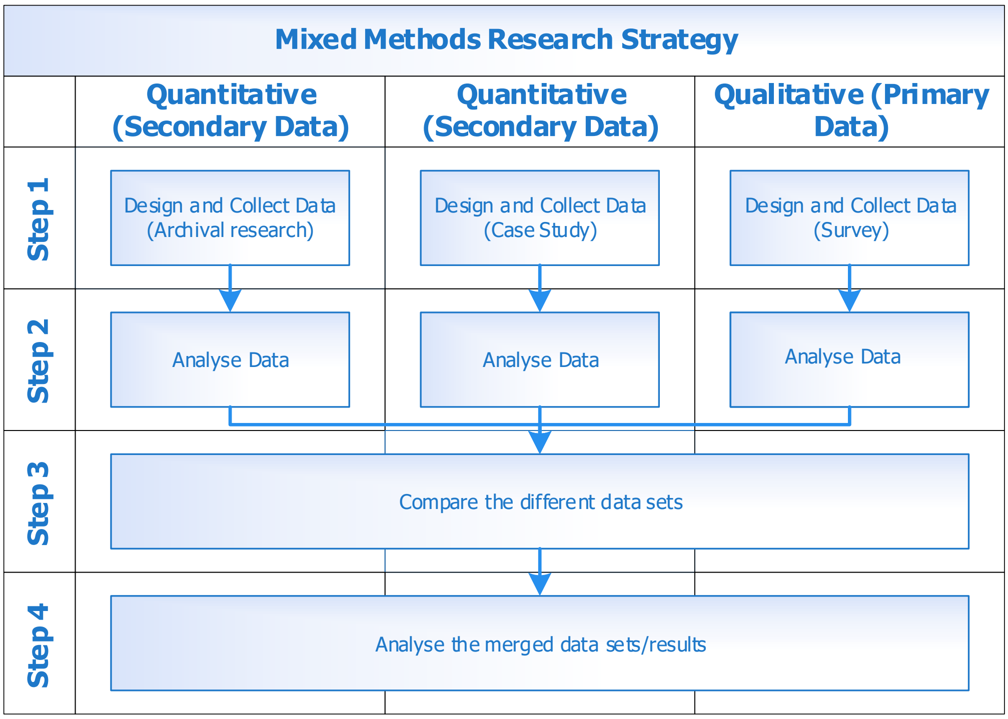


Figure 28: Description of the Mixed Methods Research that will be used.
Source: Author adapted from Bian et al. [78]

The first column of *Figure 28* shows that secondary quantitative data was captured using archival research on a longitudinal time scale. Secondary data refers to data collected from a secondary source [75]. A minimum of five years of data was analysed from a locomotive database. The data was then compared and coded. This also included studying decommissioning techniques applied to one or more classes of locomotives. This also included statistical data that would highlight typical electronic component decommissioning and disposal through the lifecycle of a locomotive. This research also drew upon other engineering technologies on how to decommission or dispose of electrical equipment. The different sources of data were then analysed for further comparison and interpretation with the other research strategies adopted. The data obtained was coded secondary quantitative data that provided insight into a framework for Transnet that could be used on TAL.

The second column of *Figure 28* shows that secondary quantitative data was captured by doing a case study on a legacy locomotive that had reached its EOL within Transnet. This included the different techniques being applied to dispose and decommission the electrical components. This gave insight into the different electrical systems used on the locomotive and it identified the hazardous materials. The data obtained was coded secondary quantitative data that provided insight into a framework for Transnet that could be used on TAL.

The third column of *Figure 28* shows that primary qualitative data was gathered during this research. Primary data refers to data sourced from the original source of data [75]. The data was gathered by using a Likert survey followed by open questions based on the responses from the Likert survey. This survey was distributed to locomotive fleet owners in Transnet, lead engineer on TAL, maintenance engineers within Transnet and an engineer working for an external railway company. The survey was distributed to 31 people, see Table 7, and the success rate was determined by receiving at least 50 % responses in each group of experts. The Likert survey was used to score the proposed first draft of the systems framework.

Table 7: The distribution list of the Likert survey.
Source: Author

Type of Participant	Send	% Minimum Participation Requirement
Fleet Owners / Maintenance Engineers	5	50%
Locomotive Experts	5	50%
Managers	5	50%
Design Engineers	6	50%
Integration and Testing Engineers	6	50%
System Engineering Practitioners	4	50%
Total:	**31**	**50%**

A total of 10 key experts were identified to answer the open questions that followed the survey questions. The same 50 % success rate was used for the open questions.

The open questions were used to answer the following questions to further expand the framework:

- With the current proposed framework, do you foresee that this can be the first stepping stone for a Systems Framework for the Decommissioning/Disposal process for the electrical components on the Trans-Africa Locomotive?
- Can you identify any shortcoming with the proposed framework? Explain.
- What additional views or concepts, if any, would you suggest adding to the framework?

The survey and open questions were sent to specialists in the locomotive industry. The results obtained during the survey and open questions were coded and analysed. The outcome of the qualitative data also provided insight whether the proposed systems framework could be applied on TAL.

Data were only collected once approval of the necessary documentation from Transnet and ethical clearance has been granted by the School of Mechanical, Industrial and Aeronautical Engineering in the Faculty of Engineering and the Built Environment.

4. RESULTS AND DISCUSSIONS

The results of this research report will be discussed in the following section. The aim of this research was to answer the following questions outlined in section 1.4 of this document:
The CRQ is the following:

- How can the developed systems framework guide the decommissioning and disposal process for Transnet's TAL's electrical components?

The sub questions complementing the CRQ are the following:

- How is the environment affected if decommissioning and disposal legislation, regulations and/or standards (i.e. governance) are not applied?
- What are the proposed benefits for Transnet if this proposed systems framework is adopted?

A mixed method approach was chosen based on the research strategies in this research report that include the use of quantitative and qualitative data. Quantitative data were gathered by archival research and a case study. Qualitative data were captured using a survey and open questions.

The steps followed in order to obtain the final framework started by creating a first draft framework, refer to Table 6 on page 35, followed by a study of real world data to improve the draft framework. The steps are shown in Figure 29. The real world data were obtained from archival research, case study, survey and open questions. Ethics clearance was obtained in order to gather the required data. The insights obtained from those data sources will result in improving the draft framework to obtain the final framework.

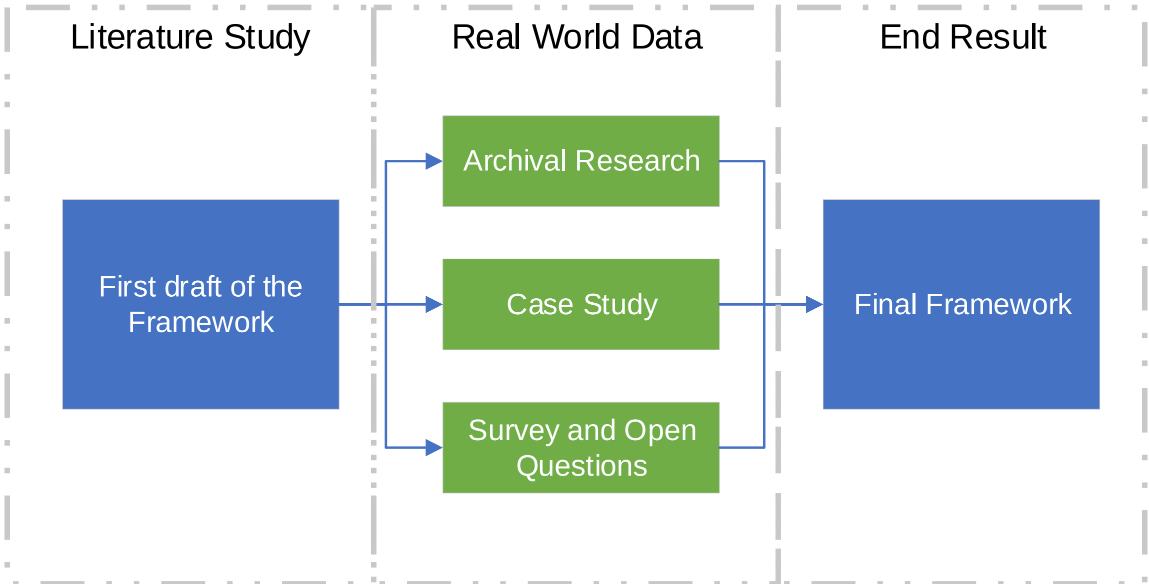


Figure 29: Steps to obtain the final framework.

Source: Author

4.1. Archival Research

Archival research was conducted to determine decommissioning techniques applied to other locomotives by using statistical data throughout the lifecycle of the locomotive, including typical electronic component decommissioning and disposal.

All data collected were generalized, therefore for this section of this report Locomotive A refers to a specific class of locomotive that was studied in order to obtain information supporting the framework for the decommissioning/disposal process for the TAL Locomotive. This class of locomotive was introduced in 2001 in the fleet of locomotives used in Transnet [79].

4.1.1. Disposal process followed by Transnet

The process that was followed when receiving components at maintenance depot responsible for the electrical components can be seen in Figure 30. It comprised of six main events e.g. receiving the components, cleaning, applying waste management, testing, documentation and storage.

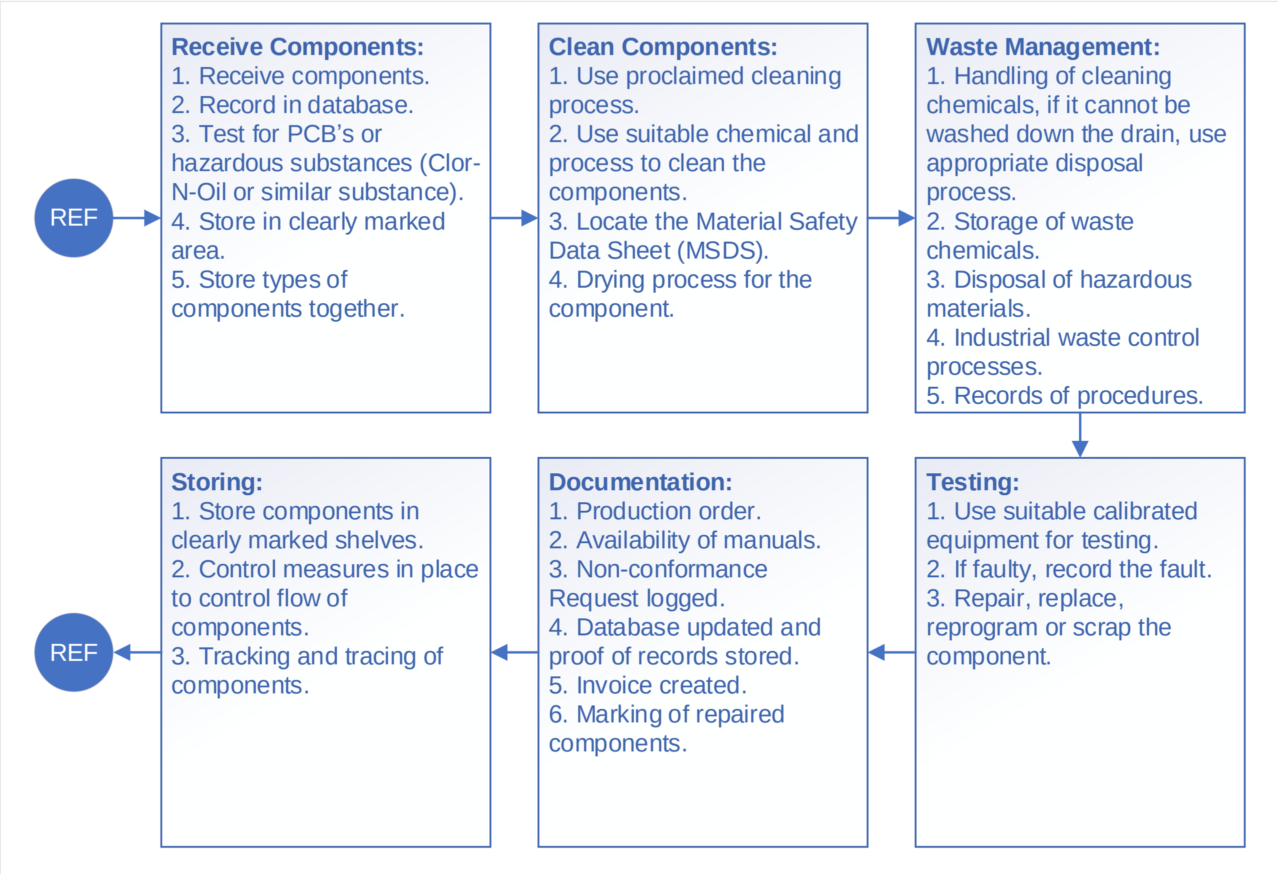


Figure 30: Process used by the maintenance depot responsible for the electrical components.

Source: Author adapted from Transnet Rail Engineering [80]

The current disposal and recycling processes were studied at Transnet Engineering to determine the level of maturity currently being applied to electrical components. After assessing the documentation and the process defined by Transnet, it can be concluded that Transnet is currently at the CMMI Level 2: Managed. See section 2.2.4 on page 23 for more information.

Processes have been put in place to dispose of obsolete electrical components, but the disposal process is only initiated once a depot sends the material to be disposed or recycled and no pro-active measures are implemented to ensure that the components are disposed of timeously and in the correct manner.

The aim should at least be to be Level 3: Defined, where the processes are applied by everyone in the company and standards and proactive programs are initiated across the company. Automated logistic systems can also be implemented to assist with the processes developed by Transnet.

4.1.2. Logistics around decommissioning/disposal of electrical components

The following data was captured by the department responsible for repairing and scrapping electrical equipment used on fleet of Locomotive A. The capturing of the data stared in 2008 and the data that was used ended in 2018, this means a total of 10 years secondary quantitative data. The data presented in Figure 31 lists the different grouping of components and equipment that were labelled as “scrap” and sold in R/kg scrap to various companies. The largest number of components that were scrapped, according to the dataset, were printed circuit boards used on the control units on Locomotive A.

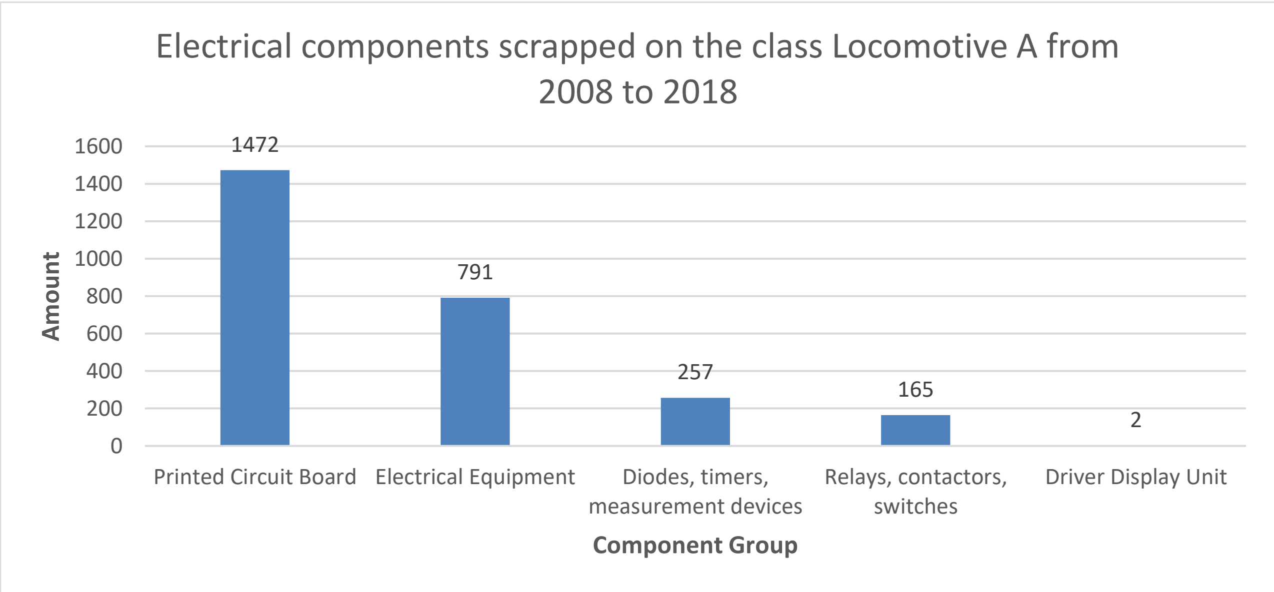


Figure 31: The total scrapped electrical components on the fleet of Locomotive A. Source: Author coded from Confidential Database [81]

The total number of grouped components like the previous section that were repaired, reprogrammed or upgraded can be seen in Figure 32. An identical timeline was used from 2008 to 2018.

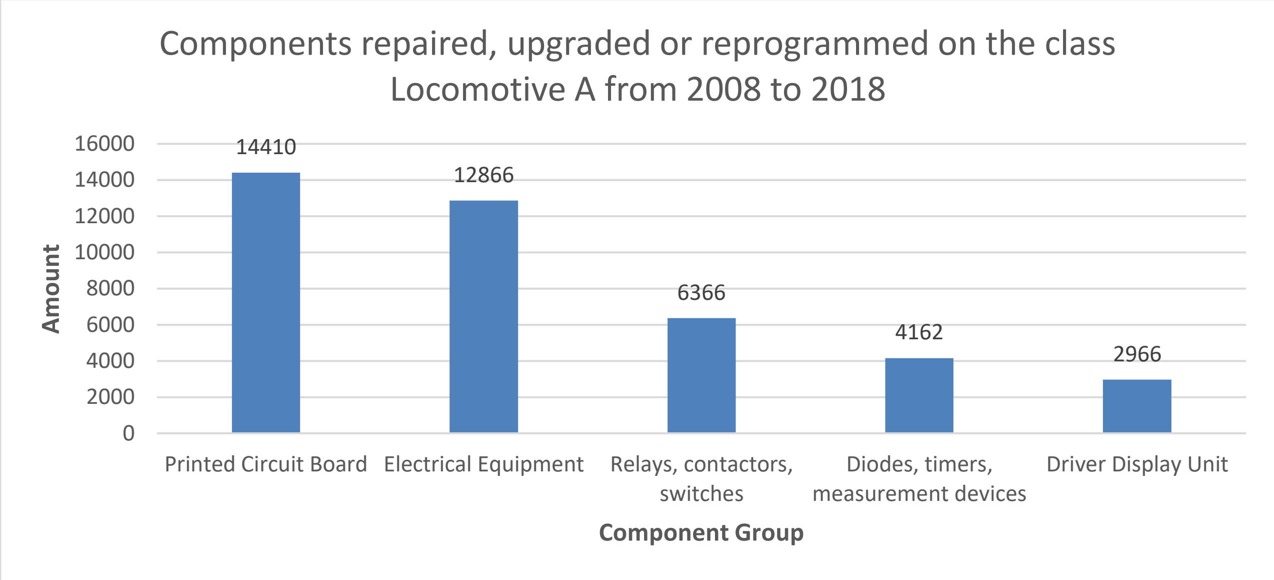


Figure 32: The total number of electrical components that was repaired, upgraded or reprogrammed on the fleet of Locomotive A.

Source: Author coded from Confidential Database [81]

By comparing the different datasets, a clear outcome can be reached that the number of electrical components that were repaired, upgraded and reprogrammed are in most cases more than tenfold that of the components that were scrapped. The comparison can be seen in Figure 33.

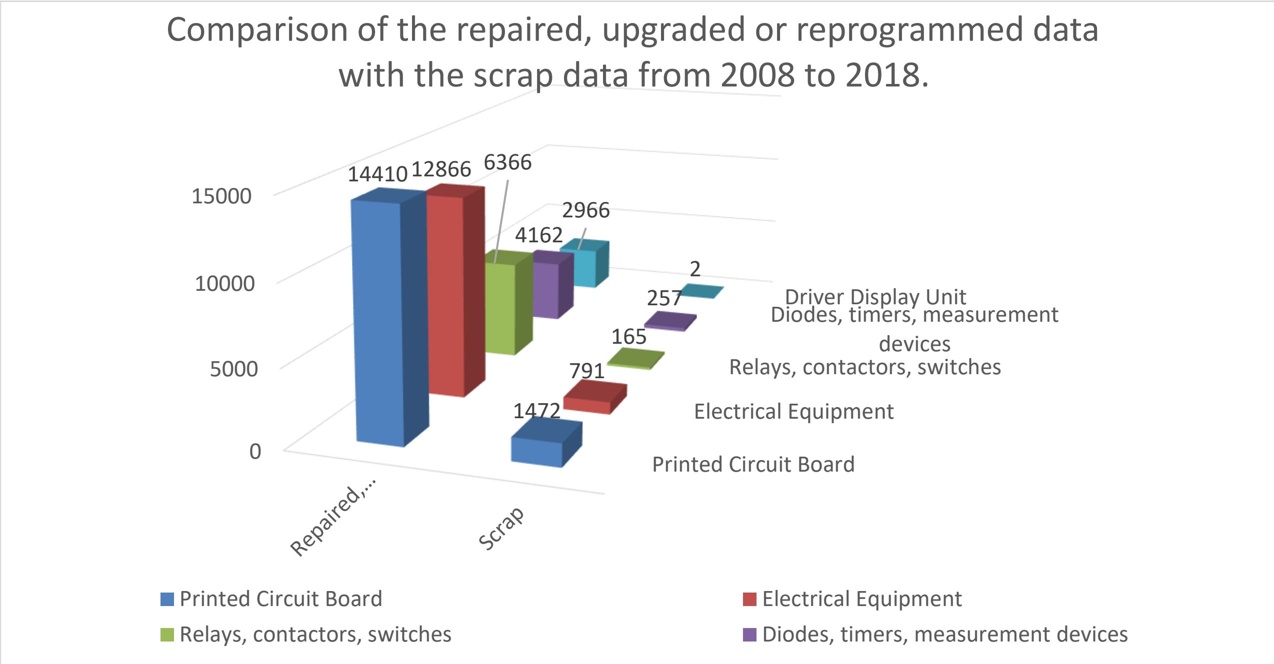


Figure 33: Comparison electrical components scrapped or repaired, replaced and reprogrammed of the class Locomotive A data.

Source: Author did a comparison using data from a Confidential Database [81]

The outcomes of the quantitative data that were collected from archival source are the following:

- The need for Material Safety Data Sheets (MSDS) for all the electrical components used on the locomotive.
- The major focus on older generation locomotives are the repair, reprogram or upgrading of electrical components and not just replacing and scrapping of components.
- The newer generation might require more replacements on electrical components due to the complexity and skills required to repair the electrical components.

4.2. Case Study

The second set of quantitative data that was captured doing a case study on a legacy locomotive that has reached its EOL. The case study was completed on a legacy locomotive, within Transnet, to identify the following:

- Identify the electrical components used on the legacy locomotive.
- Possible applications of the locomotive that has reached its end of life.
- Identify decommissioning/disposal techniques applied to this legacy locomotive
  - In terms of the electrical components.
  - Identification of hazardous materials.

This legacy locomotive was introduced in the 1970s to the Transnet fleet and has been operating for more than 40 years [82]. The diesel locomotive received a major upgrade in 2011 that consisted of upgrading the transformers, electrical circuits, traction motor and alternator overload protection, control system, resistor grids and advanced wheel slip and traction control [82].

The schematics and part list of the legacy diesel locomotive were studied and analysed. From the quantitative data collected, from a locomotive part list, this locomotive consists of more than 173 electrical components [83]. A summary of the components can be seen in Figure 34.

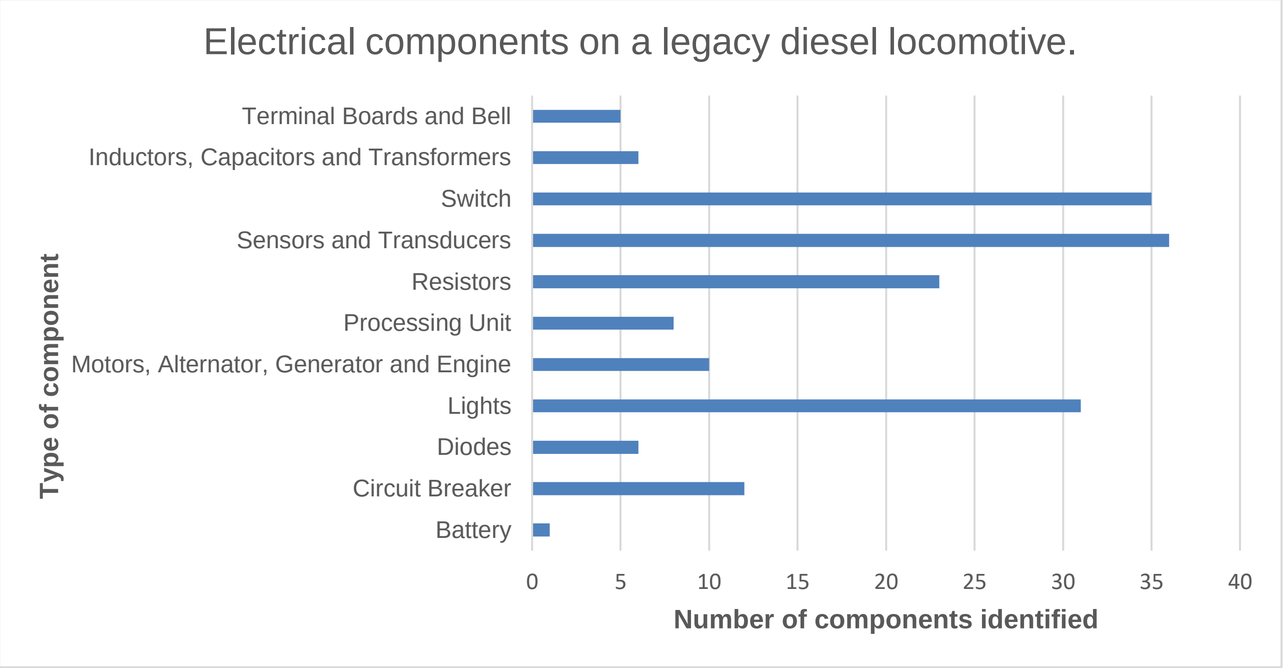


Figure 34: Legacy diesel locomotive components.

Source: Author coding information from a part list of a diesel locomotive [83]

This number of electrical components were compared to a modern diesel locomotive, whereby the modern diesel locomotive has more than 700 electrical components [84]. From the information gathered from the literature study, refer to section *2.2.5 Hazardous Materials*, in this research special care should be taken to dispose the electrical components especially the transformers, capacitors, circuit breakers and batteries. Due to the vast number of electrical components on modern diesel locomotives it just emphasises the importance of correct decommissioning and disposal processes that should be followed. Some of the locomotives in this class received a minor upgrade to extend the life of the locomotive [82]. The major reason for this was obsolescence management where some of the components could not be maintained anymore. A statement of work issued included various electrical components that should be replaced including traction motors, control system cards, contactors, circuit breakers, gauges, axle generators, engine (if underperforming), compressor, radiator fans, dynamic grid blowers, fuel pump and fuel pump motor [85].

Part of this minor upgrade included the removal and replacement of hazardous materials that were used when the locomotives were built in the 1970s [85]. Asbestos, identified in the literature study of this research, was a material that was used in many applications including the locomotive. The minor upgrade included the removal of the asbestos installed in the cab roof of the locomotive and the asbestos insulation used on the heater piping [85].

The components that were replaced during the upgrade were then send to the department responsible for managing the disposal and decommissioning of the electrical components that was identified in section *4.1 Archival Research*. The process that was followed was illustrated on Figure 30 on page 43.

As the case study further developed it became clear that the legacy locomotive can reach its EOL in various forms [85,86]:

- Locomotive was in an accident and should therefore be decommissioned or disposed.
- The locomotive was used on intensive mainline (duty cycle increased) and the underframe structure of the locomotive could not handle the in-train forces and had to be retired earlier than predicted.
- The fully functional locomotive should be decommissioned or disposed due to new locomotives being added to the existing locomotive fleet in Transnet.
- The locomotive was designed and operated for a certain timeframe and retired on the day the expiration date occurs. In layman's terms the book value of the locomotive was almost nothing.
- The locomotive is replaced by modern locomotives to reduce the running/operating and maintenance cost.

There are various options when a locomotive reaches its EOL and are summarised below [86]:

- Minor upgrade or no upgrade and then sold to neighbouring countries. This was done with a few of the older classes of locomotives, where the axle weight of the locomotive can be supported by the rail network in the neighbouring countries.
- Leasing the locomotive to neighbouring countries or mines in South Africa. Normally the servicing of the locomotives is still completed by Transnet.
- Locomotives are stripped and the components are used for spares on similar running locomotives. The underframe and mechanical structure are then auctioned to the highest bidder that recycles the material on the locomotive.
- An assessment is done to determine whether the underframe is still in a good condition, if so an upgrade of the locomotive is possible.
- Sold to private rail companies in its current state. The rail company then normally upgrades the locomotive and sells it to mines or neighbouring countries.

The outcomes of the quantitative data that were collected from case study are the following:

- Evidence obtained that there are hazardous materials used on the locomotive, but it was not certified as hazardous when the locomotive was built.
- The EOL of the locomotive is not a precise number but is influenced by various factors.
- Importance of succession planning of the legacy locomotives and the various options that exist to reuse the locomotive.
- Importance of planning for obsolescence management of components.

4.3. Survey and Open Questions

4.3.1. Survey

The third set of data that were collected included primary qualitative data collected by a Likert survey followed by open questions. The Likert survey was distributed to 31 people that comprised of mainly engineers who are locomotive experts, designers, systems engineers, maintenance engineers, fleet managers, integration and testing engineers and SE practitioners. The roles and responsibilities of the different groups that were approached are listed in Table 8.

Table 8: Roles and responsibilities of the survey participants.
Source: Author

Group Identified	Roles and Responsibilities
Fleet Owners / Maintenance Engineers	Responsible for fleets of locomotive e.g. deployment, maintenance interventions and processes. Also responsible for locomotive availability.
Locomotive Experts	In-depth understanding of the operation and logistics around diesel and electrical locomotives. These participants are experts in their field.
Managers	Managing complex engineering decisions, including decision influencing finances, timelines and vision of the company.
Design Engineers	Design of locomotive components, electrical and mechanical of nature.
Integration and Testing Engineers	On-field locomotive experience and involved in testing and commissioning of locomotives and components developed by the Design Engineers.
System Engineering Practitioners	Engineers responsible to introduce SE processes in the rail environment. These engineers apply SE in their daily work.

It is critical that responses are obtained from the Fleet Owners / Maintenance Engineers and Locomotive Experts. The Likert survey comprised of the different 25 framework viewpoints created from the literature study. The first version of framework is listed in Table 6 on page 35. The participants were then asked to rate each viewpoint according to importance. The last question of the survey then asks the participant if he/she will be willing to participate in open questions following this survey. The template of the survey can be seen in the Appendix D of this research report.

The 31 participants were given a week to complete the survey whereby 22 responses were received. This means a participation factor of 70 % was achieved. The survey was distributed to the following groups of engineers, see Table 9.

Table 9: The distribution list of the Likert survey.
Source: Author

Type of Participant	Send	Responded	% Success
Fleet Owners / Maintenance Engineers	5	4	80%
Locomotive Experts	5	4	80%
Managers	5	3	60%
Design Engineers	6	3	50%
Integration and Testing Engineers	6	6	100%
System Engineering Practitioners	4	2	50%
Total:	**31**	**22**	**70%**

The full results of the Likert survey were coded and are listed in Table 10 below. Each participant chose whether the viewpoint created from the literature was “extremely important” or “not at all important”.

Table 10: Responses of the 22 participants in the Likert survey results.
Source: Author created from the Likert survey results

View Ref.	View Title	Extremely important	Very important	Moderately important	Slightly important	Not at all important	Total
AV-01	Overview and Summary	10	11	0	1	0	22
AV-02	Integrated Dictionary	6	11	3	2	0	22
TV-01	Legislation Profile	5	14	3	0	0	22
TV-02	Legislation Forecast	3	9	4	6	0	22

View Ref.	View Title	Extremely important	Very important	Moderately important	Slightly important	Not at all important	Total
TV-03	Legislative Risk Register	5	9	7	1	0	22
SV-01	Lifecycle View	13	8	1	0	0	22
SV-02	Electrical System View	7	10	4	1	0	22
SV-03	Manufacturing and Maintenance Risk Register	9	10	3	0	0	22
SV-04	Engineering Analysis	5	8	8	0	1	22
SV-05	Resource Interaction Description	5	4	12	1	0	22
SV-06	Recyclability Analysis	4	8	9	1	0	22
OV-01	High-level operational concept graphic	2	11	5	3	1	22
OV-02	Procedures Profile	7	9	6	0	0	22
OV-03	Maintenance Process / Logistics	10	9	3	0	0	22
OV-04	Manufacturing Process / Logistics	3	12	5	2	0	22
OV-05	Disposal Process / Logistics	7	8	4	3	0	22
StV-01	Market Analysis	5	10	3	4	0	22
StV-02	Environmental Analysis	6	10	4	2	0	22
StV-03	Capability Analysis	5	12	4	1	0	22
StV-04	Enterprise Vision	3	7	11	1	0	22
StV-05	Energy Recovery Analysis	2	7	9	4	0	22
StV-06	Life Cycle Improvement Assessment	9	10	3	0	0	22
AcV-01	Hazardous Materials	14	5	3	0	0	22
SOV-01	Operation Description	3	8	9	2	0	22
SOV-02	Recycling Process	8	6	7	1	0	22

A graphical representation was then compiled and can be seen in Figure 35 on page 52. This figure compares the responses of the participants between the different viewpoints using percentages.

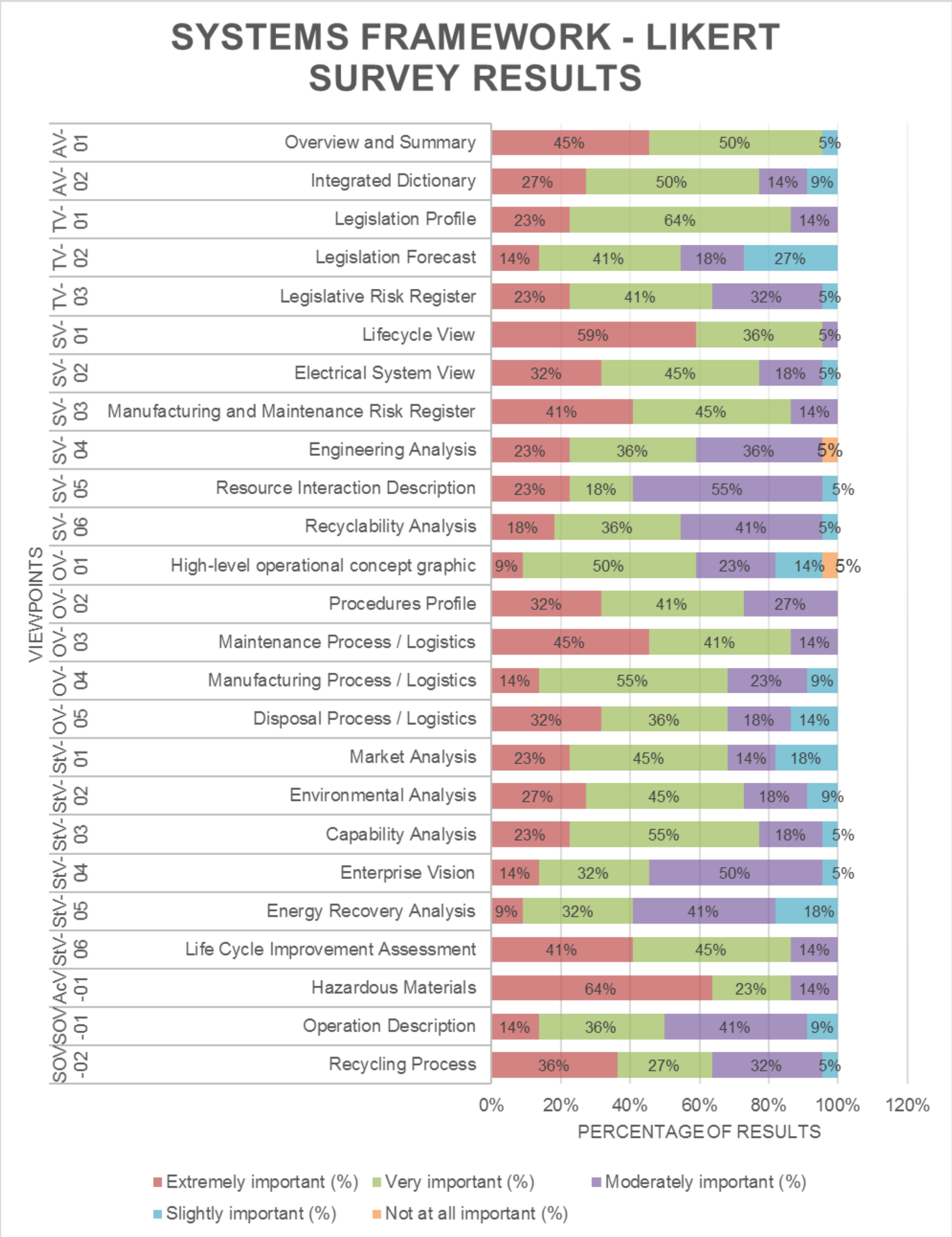


Figure 35: A graphical representation of all the Likert survey results.

Source: Author coded from the Likert survey results

A scoring technique was then added to the data to determine the relevance and importance of each viewpoint that were created [87]. The points were added to each type of responses to determine the most and least important viewpoints. The point system is tabled in Table 11 below.

Table 11: Point system allocated to the responses in the Likert Survey.
Source: Author sourced from Darbyshire et al. [87]

Response	Points Assigned
Not at all important	1
Slightly important	2
Moderately important	3
Very important	4
Extremely important	5

The points allocated to each decision of each viewpoint by all the participant were the added to arrange the viewpoint from highest to lowest level of importance, see Figure 36.

The three viewpoints that scored the highest and were regarded as the most critical viewpoints were:

- SV-01 – Lifecycle View
- AcV-01 – Hazardous Materials
- AV-01 – Overview and Summary

The three viewpoints that had the lowest score and are regarded as less critical are:

- StV-05 – Energy Recovery Analysis
- TV-02 – Legislation Forecast
- OV-01 – High-level operational concept graphic

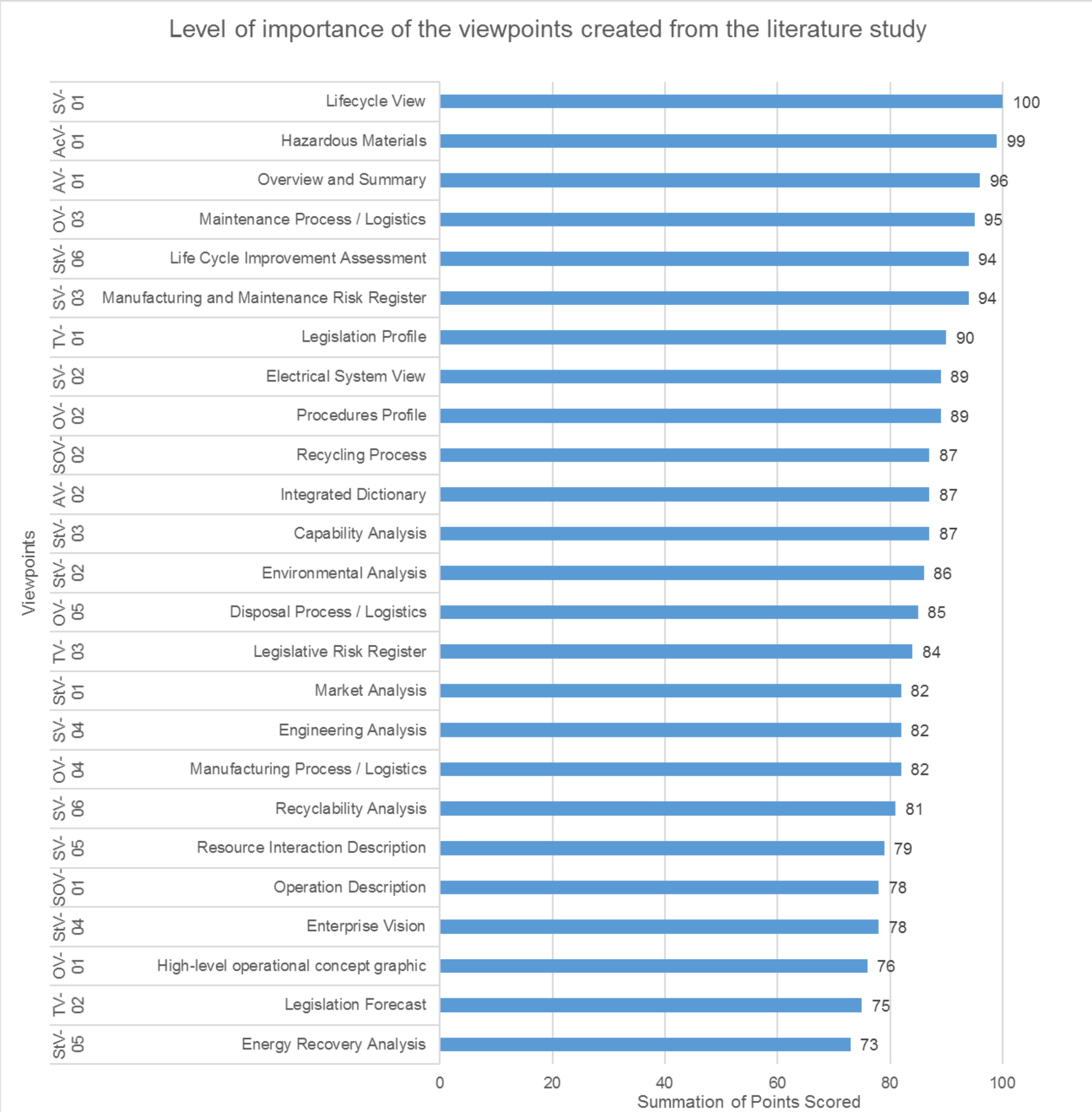


Figure 36: Graph representing the importance based on the Likert survey conducted. Source: Author coded from Likert survey results

It was critical to obtain responses from the Fleet Owners / Maintenance Engineers and Locomotive Experts as they would have the largest contribution to the proposed framework. Four participants of each group participated in this survey. A comparison of the summation of results from Fleet Owners / Maintenance Engineers and Locomotive Experts can be seen in Figure 37. Interestingly the Fleet Owners / Maintenance Engineers rated all the viewpoint with higher scores compared to the locomotive experts.

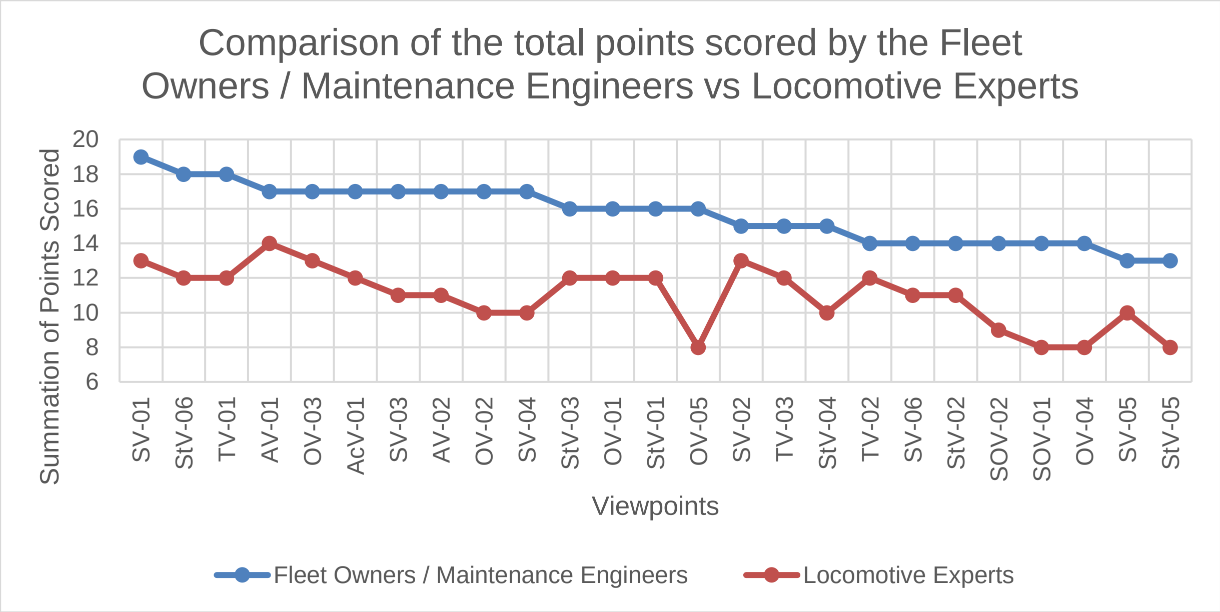


Figure 37: Comparison of the summation of points scored by the Fleet Owners / Maintenance Engineers and the Locomotive Experts.
Source: Author coded from the survey results

In conclusion, overall all the viewpoints scored high points and two viewpoints were identified as "not important at all" by only two out of the 22 participants in this survey. Thus, all viewpoints are regarded as important and none will be removed based on the survey results.

4.3.2. Open Questions

The open questions were distributed to 10 experts that participated in the survey and agreed that they would be willing to participate in the open questions. The Open Questions were distributed to the following participants, as listed in Table 12. As mentioned in the survey section, it was critical to obtain responses from the Fleet Owners / Maintenance Engineers and Locomotive Experts as they would have the largest contribution to the proposed framework. From the 10 participants 8 responses were received. A success response rate of 80 % was achieved with the Open Questions.

Table 12: The distribution list of the Open Questions.

Source: Author

Type of Participant	Send	Responded	% Success
Fleet Owners / Maintenance Engineers	4	3	75 %
Locomotive Experts	2	2	100 %
Managers	1	1	100 %
Design Engineers	1	0	0 %
Integration and Testing Engineers	1	1	100 %
System Engineering Practitioners	1	1	100 %
Total:	**10**	**8**	**80 %**

Each participant was required to answer the following questions:

- With the current proposed framework, do you foresee that this can be the first stepping stone for a Systems Framework for the Decommissioning/Disposal process for the electrical components on the Trans-Africa Locomotive?
- Can you identify any shortcoming with the proposed framework? Explain.
- What additional views or concepts, if any, would you suggest adding to the framework?

The answers from the participants were summarised and the results and comments are listed in Table 13 below. The outcomes of this table will then be used to update the final framework or can be used on future studies.

Table 13: Summary of the results from the Open Questions.

Source: Author from the information obtained from the Open Questions

Question:	Results from Open Questions
Can this framework be used for the Decommissioning/ Disposal process?	• Overall all the participants agreed that the proposed framework could be used. • It would be irresponsible for Transnet to develop a locomotive without ensuring adherence to Health, Safety and Environmental requirements of South Africa and prospective clients. • The documents and procedures should be in place timeously, thus would prevent subsequent unplanned ‘cradle to grave’ issues and cost implications that could reduce revenue made from sales. • The framework development should continue throughout the prototyping and manufacturing phases.

Question:	Results from Open Questions
	• The framework should provide all the elements for a strategy followed by a process to be developed from the framework. • The current framework is not executable, but it will result in an executable strategy and process documentation detailing how the framework can be implemented. • It is important to develop pragmatic ways to deal with recycling processes.

Identified shortcomings from the Open Questions.	• Operational experience of the locomotive can lead to possible identification of shortcomings.
	• During the fabrication of the locomotive possible Safety, Health and Environmental impacts can be identified and the manufacturing plant should plan for this. Examples of this are:
	    o Waste disposal procedure contracts to disposal of materials with hazardous chemical properties.
	    o Disposal of packaging materials.
	    o Disposal of chemically treated wooded crates and beams. If the correct processes are not followed it could eventually lead to people using this treated wood for preparing food which could result in sickness.
	• Improve and work on the decommissioning/disposal process before the final design freeze of the locomotive.
	• Cost engineering should be introduced into the lifecycle analysis, this will most definitely impact system level decisions. Included in this should be end-of-life logistics, removal and safe storage of components awaiting recycling.
	• To make this framework relevant the capability of the recycling industry should also be considered, especially compared to different countries.
	• The viewpoint SV-02 Electrical System View could be expanded in its echelon inventories, increasing the possibility to effectively manage the locomotive lifecycle.
	• The mechanical components form a major part in the locomotive and it would be critical to look into this as well. This includes the various consumables e.g. engine oils, grease and coolants.
	• The end-of-life of the locomotive will also be benefitted by doing additional studies regarding the type of coolants, grease and how to dispose these components.

Question:	Results from Open Questions
Additional views and concepts identified.	• The general socio-economic situation in Africa need an approach where WEEE need to be considered in situations where vandalism and theft play a major role. • Additional studies should include the interrogating of worldwide Safety, Health and Environmental trends, by predicting changes. • Additional studies can include studying and predicting future environmental legislation due to the existence of the locomotive can extent more than 30 years. • The proposed framework is based on a first world country, a study should be done to determine if the locomotives decommissioning/disposal processes are also applicable in a third world country. Might be wise to include additional processes to cater for this. • Missing a systems-of-systems context viewpoint describing the relationships, dependencies and interaction between the various systems and the environment. • A maintenance inventory viewpoint is missing. This will assist with the administration of recycling, obsolescence and lifecycle support.

The outcomes of the primary qualitative data that were collected from the survey and open questions that will change the framework are the following:

- The survey's outcome was that all the viewpoints listed were relevant and none of the viewpoints should be removed.
- Cost engineering should be introduced into the lifecycle analysis, this will most definitely impact system level decisions.
- Included in this should be end-of-life logistics, removal and safe storage of components awaiting recycling.
- To make this framework relevant the capability of the recycling industry should also be considered, especially compared to different countries.
- The viewpoint SV-02 Electrical System View could be expanded in its echelon inventories, increasing the possibility to effectively manage the locomotive lifecycle.
- Missing a systems-of-systems context viewpoint describing the relationships, dependencies and interaction between the various systems and the environment.

The rest of the data collected from the open questions and survey will be addressed in the conclusion of this research report.

4.4. Summary of Data Collected

The outcomes of the data collected that will influence the framework that was compiled using the literature study are the following:

- All electrical components require MSDS.
- Skill development required for the maintenance on the newer type technologies used on the newer generation locomotives.
- The importance of obsolescence management for the electrical components on the locomotive.
- The EOL of a locomotive is not only dependant on the amount of years in service, but the duty cycle and the major mechanical components.
- Based on the survey results all viewpoints are relevant.
- Cost engineering should be introduced into the lifecycle analysis.
- The end-of-life logistics, removal and safe storage of components awaiting recycling.
- Capability of the recycling industry should be considered, especially comparing different countries.
- The Electrical System View should be expanded in its echelon inventories.
- Systems-of-systems context viewpoint should be included in the framework.

4.5. Updated Framework

The updated framework for the decommissioning/disposal process for the electrical components for the TAL locomotive based on the additional information and outcomes obtained by the three different datasets are listed in Table 14 below. The changes made from the draft framework created from the literature study are emphasised in '*italic*' text.

Table 14: Final systems framework for the decommissioning/disposal process for the TAL locomotive incorporating the literature review and data collected.
Source: Author adapted from frameworks from Caruso [1] and Cloete-Hopkins [2]

View Ref.	View Title	Purpose of the View
All Viewpoints (AV)		
AV-01	Overview and Summary	Summary of information relating to the decommissioning/disposal process. This will summarize the decommissioning/disposal process.
AV-02	Integrated Dictionary	Explanation of terms and abbreviation used in this framework.

Technical Standards Viewpoint (TV)		
TV-01	Legislation Profile	List the legislation identified in the various countries the locomotive will be sold, as well as the local legislation implemented.
TV-02	Legislation Forecast	List possible changes or evolution to existing legislation: • Short term (1 year) • Medium term (3 years) • Long term (5 years)
TV-03	Legislative Risk Register	Compile risk register capturing all risk identified in terms of legislation and regulation of the locomotive that has already been developed.
System Viewpoints (SV)		
SV-01	Lifecycle View	Investigate the complete lifecycle and identify possible • shortcomings; • phases that were not taken into consideration during the design; • and lessons learned that could be implemented during a next project similar in nature. • *Detailed cost engineering planning to determine the cost of the locomotive at various lifecycle stages.* Review the current maintenance and disposal plan and determine if the plan was constructed from the beginning of the lifecycle or only at the post project phases. Compile a lifecycle plan for the locomotive. *The lifecycle plan of each locomotive will depend on the operating environment and the use of the asset.*
SV-02	Electrical System View	Create a systems-of-systems view of the different components, *based on the relevant echelons,* identified on the locomotive. Note the lifecycles applicable to each of the elements in the system of systems.
SV-03	Manufacturing and Maintenance Risk Register	Compile risk register capturing all risk identified in terms of the lifecycle of the locomotive. This includes the following aspects: • Hazardous material • Waste from manufacturing • By-products produced during maintenance
SV-04	*Engineering Process Development Plan*	*Define the engineering process that will be followed assisting the locomotive from 'cradle to grave'. This will provide insight into "how" the locomotive components will be disposed.*
SV-05	Resource Interaction Description	Compile a hierarchy of personnel required for the disposal and decommissioning process and assign a breakdown of tasks to each resource.
SV-06	Recyclability Analysis	Determine the recyclability rate of the locomotive according to ISO/TC 269/SC 2/WG 4 or using the road vehicle standard ISO 22628:2008. *Determine the relevant capabilities in the recycling industries based on where the locomotive will be sold.*

SV-07	*Obsolescence Management*	*During the lifecycle various parts of the locomotive will become obsolete. A design team should keep this in mind to design and plan for critical components that may become obsolete.*
SV-08	*Systems-of-systems Analysis*	*Analysis to determine the relationships, dependencies and interaction between the various systems and the environment. This can be done using a context diagram.*
Operational Viewpoint (OV)		
OV-01	High-level operational concept graphic	High-level description/process flow regarding the operation schedules of the locomotive.
OV-02	Procedures Profile	Identify company policies and company procedures applicable to the decommissioning and disposal process of Waste of Electrical and Electronic Equipment (WEEE). This will also include: • Standard Operating Procedures (SOP's) • Safe waste handling procedures If there are no policies available, it should be created.
OV-03	Maintenance Process / Logistics	Define a maintenance plan to determine the shedding cycles of the locomotive.
OV-04	Manufacturing Process / Logistics	• Identify possible by-products produced during production phases of the locomotive. • Create SOP documentation how to manage the by-products produced.
OV-05	Disposal Process / Logistics	• Create disposal process flow for each electrical component identified in the locomotive. • Create SOP documentation for the disposal of each component identified. • Combine the disposal process with the maintenance process.
OV-06	*Material Safety Data Sheet (MSDS)*	*Create a MSDS for each electrical component used on the locomotive.*
OV-07	*End-of-life logistics*	*Develop a strategy to be followed in terms of storage of components awaiting decommissioning or disposal.*
Strategic Viewpoints (StV)		
StV-01	Market Analysis	Identification of where the demand for the locomotive will be. This will include a market analysis study.
StV-02	Environmental Analysis	Environmental analysis of the area considering the following elements: • By-products produced in manufacturing. • Hazardous materials introduced to the environment by incorrect handling processes. • WEEE from failures and maintenance. • Recycling processes.
StV-03	Capability Analysis	Study to determine Transnet's and local companies' capability to dispose of WEEE in a safe manner.
StV-04	Enterprise Vision	Business study to determine the possibility to generate income from disposal of WEEE.

StV-05	Energy Recovery Analysis	Identify means of recovering energy during the manufacturing, decommissioning and disposal process of locomotives.
StV-06	Life Cycle Improvement Assessment	Plan for improvements that can be made to extend the life of the locomotive.
StV-07	*Skill Development Plan*	*Identification and implementation of skill development plans to assist with the repairing of more complex electrical systems used on newer generation locomotives.*
StV-08	*Succession Planning*	*Plan for the various options when the locomotive comes to the end of life that can include:* • *Leasing the locomotive.* • *Sold to neighbouring countries.* • *Major overalls/upgrades.* • *Used as spares for the locomotives still in operation.*
Acquisition Viewpoint (AcV)		
AcV-01	Hazardous Materials	• Identify possible hazardous materials that must be handled with care on the locomotive. • Create safe handling procedures for the hazardous materials. • Create a plan for the replacement of the hazardous materials.
Service Orientated Viewpoints (SOV)		
SOV-01	Operation Description	• Define the operational aspects of the decommissioning and disposal of the locomotive.
SOV-02	Recycling Process	Create a recycling process that should be followed for each group of electrical components identified on the locomotive.

5. CONCLUSION

The main contribution from this research, as outline in section 1.5 on page 4, was to develop a systems framework for the decommissioning and disposal that can be used by Transnet. The strategy to obtain this was to conduct an in-depth literature study to compile a draft framework based on theory from relevant theoretical sources.

This draft framework was then improved using a mixed method approach by using three sources of data that were collected. The three sources of data consisted of; an archival data, case study and a survey/open questions. The data collected were then used to improve the theoretical framework. The final framework listed in Table 14, can be used by Transnet to guide the Decommissioning/Disposal process of the Electrical Components for the Transnet Trans-Africa Locomotive. This proposed framework should be used as the final framework, but additional improvements and changes should be made during the progression of the lifecycle of the locomotive. This will ensure that the viewpoints identified are relevant and updated.

6. RECOMMENDATIONS

Based on the data received from the open question it was mentioned multiple times that the mechanical systems of the locomotive should also be taken into consideration and not just the electrical components. An additional comment included studying various capabilities of recycling facilities. Figure 38 shows the Viable Systems Model adapted from Umpleby [88] to shows the different systems that should be taken into consideration when developing a systems framework for the decommissioning and disposal process for the TAL locomotive. The two systems that could be studied in the future are highlighted in red block in Figure 38.

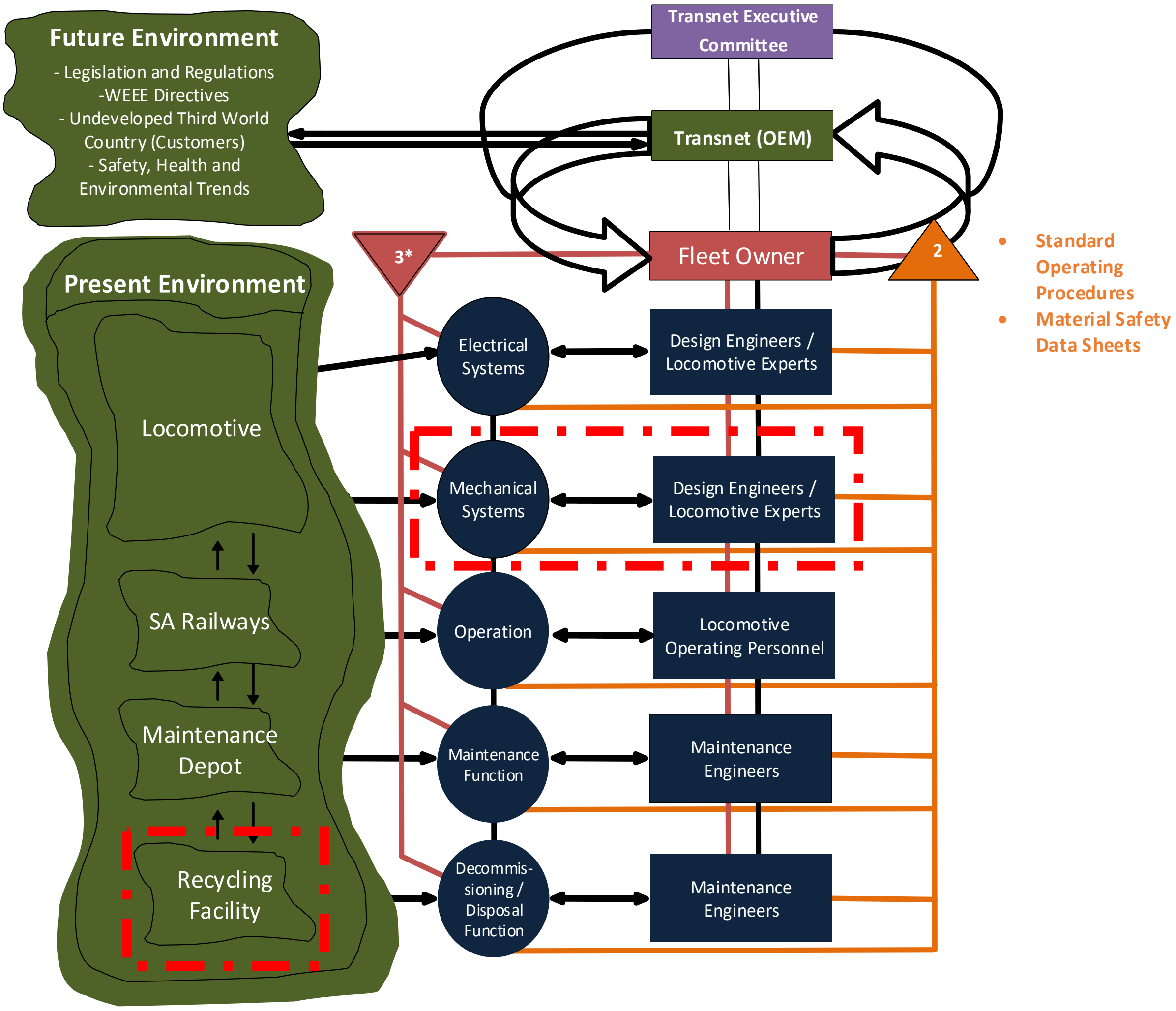


Figure 38: The Viable Systems Model identifying possible future studies.
Source: Author adapted from Umpleby [88]

The researcher further advises that this framework be used as a baseline to develop the full decommissioning and disposal processes and procedures to effectively handle waste produced from and by the TAL locomotive effectively and efficiently.

7. REFERENCES

1. Caruso J, Jakova T, Mills K, Varrone A. Ministry of Defence Architecture Framework MODAF. Policy. 2010;(Spring):66.
2. Cloete-Hopkins N. Freight Transportation and Logistics Projet. 2011.
3. Forsberg K, Mooz H, Cotterman H. Visualizing Project Management. John Wiley & Sons; 2005.
4. Transnet Group Capital. Integrated Report 2018 [Internet]. Johannesburg; 2018 [cited 2019 Apr 14]. Available from: https://www.transnet.net/InvestorRelations/AR2018/Integrated Report.pdf
5. Transnet Engineering. Engineering 2017 [Internet]. Johannesburg; 2017 [cited 2019 Apr 14]. Available from: https://www.transnet.net/InvestorRelations/AR2017/OD Reports/8335_2_Transnet 2017_Engineering HR.pdf
6. IEC 61508-1 Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements. International Electrotechnical Commission; 2010.
7. UNEP. The 12 initial POPs under the Stockholm Convention [Internet]. 2008 [cited 2019 Mar 7]. Available from: http://chm.pops.int/TheConvention/ThePOPs/The12InitialPOPs/tabid/296/Default.aspx
8. Kaya M. Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes. Waste Management. 2016;57:64–90.
9. Transnet. Sustainability Outcomes Report 2018 [Internet]. Johannesburg; 2018 [cited 2019 May 16]. Available from: https://www.transnet.net/InvestorRelations/AR2018/Transnet SOR 2018.pdf
10. Transnet Centre of Systems Engineering. The System Lifecycle. Johannesburg: s.n.; 2016.
11. Kasser J. Holistic thinking and how it can produce Innovative solutions to difficult problems. INCOSE (2010). 2010;1–17.
12. INCOSE UK Systems Engineering Competencies Working Group. Systems engineering competencies framework. 2006.
13. Liudvinavičius L, Jastremskas V. Modernization of Diesel-electric Locomotive 2M62 and TEP-70 Locomotives with Respect to Electrical Subsystem. Procedia Eng. 2017;187:272–80.
14. Hitchins D. Putting Systems To Work. New York: John Wiley & Sons; 1997.

15. Transnet Group Capital. Sustainability Report 2017 [Internet]. Johannesburg; 2017 [cited 2019 Apr 14]. Available from: https://www.transnet.net/InvestorRelations/AR2017/Transnet SR 2017.pdf
16. Department of Environmental Affairs (DEA). National Waste Information Baseline. Report. 2012;
17. Finlay, Alan Liechti D. e-Waste Assessment South Africa. 2008.
18. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance. Off J Eur Union. 2012;034(June):38–71.
19. Department of Public Enterprises - Transnet [Internet]. [cited 2019 Apr 14]. Available from: http://www.dpe.gov.za/soc/transnet/Pages/default.aspx
20. Integrated Pollution and Waste Management for South Africa. Department of Environmental Affairs and Tourism; 2000 p. 79.
21. Department of Defence. Systems Engineering Fundamentals. Virginia: Defense Acquisition Univerity Press; 2001.
22. Checkland P, Scholes J. Soft systems methodology in action : a 30-year retrospective. Wiley; 1999. 329 p.
23. Robertson S, Robertson J. Mastering the Requirements Process Getting Requirements Right [Internet]. 3rd ed. United States of America: Pearson Education; 2013. Available from: http://ptgmedia.pearsoncmg.com/images/9780321815743/samplepages/0321815742.pdf
24. INCOSE. INCOSE-TP-2003-002-03.2 International Council on Systems Engineering - Systems Engineering Handbook. 2010;(January).
25. Pickard AC, Beasley R, Nolan AJ. The Systems Engineering Competency Framework. INCOSE Int Symp [Internet]. 2018 [cited 2019 Jul 29];28(1):503–17. Available from: https://connect.incose.org/StoreProducts/ISECF-v1.pdf
26. National Aeronautics and Space Administration. NASA Systems Engineering Handbook. 1995.
27. Colledani M, Copani G, Tolio T. De-Manufacturing systems. Procedia CIRP. 2014;17:14–9.
28. Duflou JR, Seliger G, Kara S, Umeda Y, Ometto A, Willems B. Efficiency and feasibility of product disassembly: A case-based study. CIRP Ann - Manuf Technol. 2008;57(2):583–600.
29. Subramoniam R, Huisingh D, Chinnam RB. Remanufacturing for the automotive

aftermarket-strategic factors: literature review and future research needs. J Clean Prod. 2009;17(13):1163–74.

30. Halligan RJ, Cpeng FIEA, Halligan RJ, Cpeng FIEA. THE BUSINESS CASE FOR SYSTEMS ENGINEERING. 2018;(March):1–48.
31. SABS Standards Division. SANS 15288 : 2008 SOUTH AFRICAN NATIONAL STANDARD Systems and software engineering — Software life cycle processes. 2008;
32. Dorsey P. Top 10 Reasons Why Systems Projects Fail. 2005;1–9.
33. Stanley R, Uden L. Why Projects Fail, from the Perspective of Service Science. In Springer, Berlin, Heidelberg; 2013 [cited 2019 Aug 1]. p. 421–9. Available from: http://link.springer.com/10.1007/978-3-642-30867-3_38
34. Ahonen JJ, Savolainen P. Software engineering projects may fail before they are started: Post-mortem analysis of five cancelled projects. J Syst Softw [Internet]. 2010 Nov 1 [cited 2019 Aug 1];83(11):2175–87. Available from: https://0-www-sciencedirect-com.innopac.wits.ac.za/science/article/pii/S0164121210001706
35. Pandremmenou H, Sirakoulis K, Blanas N. Success Factors in the Management of Investment Projects: A Case Study in the Region of Thessaly. Procedia - Soc Behav Sci [Internet]. 2013 Mar 29 [cited 2019 Aug 1];74:438–47. Available from: https://0-www-sciencedirect-com.innopac.wits.ac.za/science/article/pii/S1877042813004618
36. Elm JP, Goldenson DR, Emam K El, Donatelli N, Neisa A, Se N, et al. A Survey of Systems Engineering Effectiveness. 2014;(January 2008).
37. Watson B, Radcliffe D, Tso BWA, Cliffe DR. Structuring Design for X Tool Use for Improved Utilization. J Eng Des [Internet]. 1998 [cited 2019 Aug 13];9(3):211–23. Available from: https://www.tandfonline.com/action/journalInformation?journalCode=cjen20
38. Kuo T-C, Huang SH, Zhang H-C. Design for manufacture and design for`X': concepts, applications, and perspectives [Internet]. [cited 2019 Aug 2]. Available from: www.elsevier.com/locate/dsw
39. Fiksel J, Wapman K. How to design for environment and minimize life cycle cost. In: Proceedings of 1994 IEEE International Symposium on Electronics and The Environment [Internet]. IEEE; [cited 2019 Aug 2]. p. 75–80. Available from: http://ieeexplore.ieee.org/document/337290/
40. Delogu M, Del Pero F, Berzi L, Pierini M, Bonaffini D. End-of-Life in the railway sector: Analysis of recyclability and recoverability for different vehicle case studies.

Waste Management. 2017;60:439–50.
41. Kaewunruen S, Rungskunroch P, Jennings D V. A through-life evaluation of end-of-life rolling stocks considering asset recycling, energy recovering, and financial benefit. J Clean Prod. 2019;212:1008–24.
42. Baumgartner JP, Polytechnique É, De F, École L, Fédérale P, Lausanne DE. Prices and Cost in the Railway Sector. 2001.
43. Spiryagin M, Wolfs P, Cole C, Spiryagin V, Sun YQ, McSweeney T. Design and Simulation of Heavy Haul Locomotives and Trains. 1st ed. CRC Press; 2016.
44. University of Pretoria. Rolling Stock Technology (RST). 2017.
45. Zhu X, Chenglong Z, Wenyi Y, Guanghan S, Wen M. Recycling and Disposal Technology for Non-mentallic Materials from Waste Printed Circuit Boards(WPCBs) in China. Procedia Environ Sci. 2016;31:935–40.
46. Rajagopal RR, Rajarao R, Cholake ST, Sahajwalla V. Sustainable composite panels from non-metallic waste printed circuit boards and automotive plastics. J Clean Prod. 2017;144:470–81.
47. Wong YC, Al-Obaidi KM, Mahyuddin N. Recycling of end-of-life vehicles (ELVs) for building products: Concept of processing framework from automotive to construction industries in Malaysia. J Clean Prod. 2018;190:285–302.
48. Merkisz-Guranowska A, Merkisz J, Jacyna M, Pyza D, Stawecka H. Rail vehicles recycling. WIT Trans Built Environ. 2014;135:425–36.
49. Recyclability and Recoverability Calculation Method Railway Rolling Stock. Brussels; 2013.
50. Merkisz-Guranowska A, Merkisz J, Jacyna M, Stawecka H, Wasiak M. Recycling Guidelines of the Rolling Stock. Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance. 2014;104.
51. Goodship V, Stevels ALN. Waste electrical and electronic equipment (WEEE) handbook. Waste Electrical and Electronic Equipment (WEEE) Handbook. 2012. 1–724 p.
52. Asante KA, Adu-Kumi S, Nakahiro K, Takahashi S, Isobe T, Sudaryanto A, et al. Human exposure to PCBs, PBDEs and HBCDs in Ghana: Temporal variation, sources of exposure and estimation of daily intakes by infants. 2011;
53. Birnbaum LS, Staskal-Wikoff DS. Polychlorinated Biphenyl (PCB) carcinogenicity with special emphasis on airborne PCBs. Environ Int. 2010;36(8):814–8.
54. UNEP Chemicals. Guidelines for the Identification of PCBs and Materials

Containing PCBs. Geneva; 1999.
55. Wiesert P, Rippen G. Uberarbeitung der PARCOM - decision zu polychlorierten biphenylen. In Oslo - Paris Konvention; 1997.
56. Paulk M, Curtis B, Beth M, Chrissis C. Capability Maturity Model for Software. Software Engineering Institute, editor. Pittsburgh: Carnegie Mellon University; 1991.
57. Mahmood S. Capability Maturity Model Integration [Internet]. 2015. Available from: https://www.researchgate.net/publication/272817266_Capability_Maturity_Model_Integration
58. CMMI Institute. How is CMMI V2.0 different from V1.3? [Internet]. [cited 2019 Oct 7]. Available from: https://cmmiinstitute.zendesk.com/hc/en-us/articles/360000175667-How-is-CMMI-V2-0-different-from-V1-3-
59. Schluep M, Manhart A, Osibanjo O, Rochat D, Isarin N, Mueller E. Where are WEee in Africa? [Internet]. 2011. Available from: https://www.basel.org.ng/index.php/where-are-weee-in-africa
60. Schluep M. What is e-waste - and why is it and issue? In [cited 2019 Sep 2]. Available from: http://slideplayer.com/slide/4776306/15/images/11/Hazardous+substances+in+EEE.jpg
61. Wagner GR, Lemen RA. International Encyclopedia of Public Health. Heggenhougen HK, editor. Vol. 106. Boston: Elsevier; 2008. 238–245 p.
62. Cheng L, Abraham J, Hausfather Z, Trenberth KE. How fast are the oceans warming? Science (80-). 2019;363(6423):128–9.
63. Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, et al. Global warming of 1.5°C [Internet]. 2018 [cited 2019 Aug 18]. Available from: https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
64. Republic of South Africa. National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008). Government Gazette No. 32000:278 South Africa; 2009.
65. Republic of South Africa. National Environmental Management: Waste Amendment Act, 2014 (Act No. 26 of 2014). Government Gazette No. 37714:449 South Africa; 2014.
66. Republic of South Africa. National Environmental Management Act 1998. 2014.
67. UNEP. Decisions to prohibit or restrict import or export of hazardous or other wastes [Internet]. [cited 2019 Sep 23]. Available from: http://www.basel.int/Countries/ImportExportRestrictions/tabid/4835/Default.aspx
68. UNEP. Stockholm Convention on Persistent Organic Pollutants (POPs) as

amended in 2009 [Internet]. Available from: http://chm.pops.int/Portals/0/Convention text/UNEP-POPS-COP-CONVTEXT-2009.En.pdf#page=28
69. Robinson K. System Design Module - Architectural Design. University College London, UCL Centre for Systems Engineering; 2008.
70. Williamson R. INCOSE MBSE Initiative [Internet]. Raytheon Corporation; 2008. Available from: http://www.updm.com/document/archive/MBSESystemOfSystems-WilliamsonFinal.pdf
71. Zachman J. The Framework for Enterprise Architecture: Background, Description and Utility [Internet]. 2016 [cited 2019 Oct 1]. Available from: https://www.zachman.com/resources/ea-articles-reference/327-the-framework-for-enterprise-architecture-background-description-and-utility-by-john-a-zachman
72. The Open Group. Architecture Framework (TOGAF) - Introduction [Internet]. 1999 [cited 2019 Oct 2]. Available from: http://www.togaf.org/togaf9/chap01.html
73. United States Department of Defence. DoD Archtecture Framework Version 1.5. 2007 [cited 2019 Oct 6];1. Available from: https://dodcio.defense.gov/Portals/0/Documents/DODAF/DoDAF_Volume_I.pdf
74. Alghamdi AS. Evaluating Defense Architecture Frameworks for C4I System Using Analytic Hierarchy Process. J Comput Sci. 2009;5(12):1075–81.
75. Saunders M, Lewis P, Thornhill A. Research Methods for busines students. 5th ed. England: Pearson Education.; 2009.
76. Sahay A. Peeling Saunder’ s Research Onion. ResearchGate. 2016;(October).
77. Leong FTL. Positivist Paradigm. In: Encyclopedia of Counseling Psychology. 2008. p. 343.
78. Bian H. Mixed Methods Research [Internet]. [cited 2019 Apr 2]. Available from: http://core.ecu.edu/StatisticsResearch
79. Transnet Engineering. Diagram and Data Manual Electric Locomotives. 2017;(September).
80. Transnet Rail Engineering. Power Electronics Procedures. Pretoria;
81. Transnet Engineering. Locomotive Failure Database. Pretoria;
82. Dulez JA. Railways of Southern Africa 150 years. Vidrail; 2012.
83. General Electric. Part List. 1974.
84. Transnet Engineering. Locomotive Part List. Pretoria; 2018.
85. Transnet Engineering. Statement of Work - Minor Upgrade. 2008.
86. Transnet Engineering. Africa Locos Summary. 2018.
87. Darbyshire P, McDonald H. Choosing Response Scale Labels and Length:

Guidance for Researchers and Clients. 2004;

88. Umpleby A. “Viable Systems Model.” In: Management 201: Management and Organization. The George Washington University; Department of Management School of Business; 2017.

8. APPENDICES

Appendix A: Acronyms List

Acronym	Description
AC	Alternating Current
ADM	Architecture Development Method
AV	All Viewpoints
CFC	Chlorofluoro Carbon
CRQ	Critical Research Question
CRT	Cathode-ray tube
DC	*Direct Current*
DFE	Design for Environment
DFX	Design for X
DODAF	Department of Defence Architecture Framework
EOL	End-of-Life
FMECA	Failure Modes, Effect and Criticality analysis
HCB	Hexachlorobenzene
IBM	International Business Machines
INCOSE	International Council for System Engineering
IPCC	Intergovernmental Panel on Climate Change
LCC	Life Cycle Cost
LCDs	Liquid Crystal Displays
MODAF	Ministry of Defence Architecture Framework
MSDS	Material Safety Data Sheet
OEM	Original Equipment Manufacturer
OHC	Ocean Heat Content
OV	Operational Viewpoint
PBBs	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ethers
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
POPs	Persistent Organic Pollutants
RAMD	Reliability, Availability, Maintainability and Dependability
SANS	South African National Standard
SDOs	Sustainability Developmental Outcomes
SE	Systems Engineering
SHF	Shredder Heavy Fractions
SLF	Shredder Light Fractions
SOI	System of Interest
SOP's	Standard Operating Procedures
SV	System Viewpoints
TAFIM	Technical Architecture Framework for Information Management
TAL	Trans-Africa Locomotive
TE	Transnet Engineering
TOGAF	The Open Group Architecture Framework
TV	Technical Standards Viewpoint
WAPs	Waste Automotive Plastics

Acronym	Description
WEEE	Waste of Electrical and Electronic Equipment
WMP	Waste Management Plan
WPCBs	Waste Printed Circuit Boards

Appendix B: Archival Data

Decommissioning/disposal techniques and statistical locomotive data

1. Gather information regarding the current decommissioning and disposal processes being applied to electrical components on locomotives.

2. Obtain 10 years of secondary qualitative data of a locomotive fleet that has been operating for at least the past 10 years containing:
    a. Repairs
    b. Failures
    c. Components
    d. Upgrades
    e. Work completed

The data will then be coded and incorporated into the research report.

Appendix C: Case Study

Legacy locomotive that reached end-of-life

1. Identify possible applications for the locomotive that reached its end of life.

2. Identify the electrical components used on the legacy locomotive.

3. Identify decommissioning/disposal techniques applied to the legacy locomotive.
    a. In terms of the electrical components.
    b. Identification of any hazardous materials.

Appendix D: Survey Template

Survey on a Proposed Systems Framework for Trans-Africa Locomotive (TAL)

Dear Participant,

This survey is conducted by Gideon Retief under the supervision of Nicolas Cloete-Hopkins, Academic Lead of the Transnet Center of Systems Engineering (TCSE) at the University of the Witwatersrand (WITS). The information obtained will be used in a Research Report that will be submitted for a Msc in Systems Engineering.

The main objective of this research is to develop a framework for the decommissioning/disposal of electrical components for the Trans-Africa Locomotive (TAL). The framework in this survey was based on the literature study that was completed. Three methodologies will be used to verify and test this framework, one being a Likert survey.

The survey comprises of the 25 different viewpoints created and asks the question whether the viewpoint is not important or extremely important. Each viewpoint is listed followed by the description/outcome/task.
The survey consists of 27 questions and should not take more than 15 minutes to complete.

The outcome of this survey will provide feedback if the framework should be adjusted or changed. All information submitted will be treated as confidential as required by policies of WITS. By participating in this survey consent is given to the researcher to use the information obtained in the Research Report.

Thank you in advance for participating in this survey.

Regards
Gideon Retief
0825198176

1. **Please supply your name and surname in the text box below.**

The following viewpoints were created, based on industry used framework called Ministry of Defence Architectural Framework (MODAF), to guide the decommissioning/disposal process for the electrical components of the Transnet Trans-Africa Locomotive (TAL).

MODAF is comprised of seven different viewpoints named:
- All Viewpoints (AV)
- System Viewpoints (SV)
- Operational Viewpoints (OV)
- Strategic Viewpoints (SV)
- Acquisition Viewpoints (AV)
- Service Orientated Viewpoints (SOV)

Complete the following Likert survey by indicating the level of importance with each viewpoint.

(more information can be found at: https://www.gov.uk/guidance/mod-architecture-framework)

All Viewpoints (AV)

2. AV-01: Overview and Summary

Summary of information relating to the decommissioning/disposal process. This will summarize the decommissioning/disposal process.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

3. AV-02: Integrated Dictionary

Explanation of terms and abbreviation used in this framework.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

Technical Standards Viewpoints (TV)

4. TV-01: Legislation Profile

List the legislation identified in the various countries the locomotive will be sold, as well as the local legislation implemented. Each country is governed by its own rules, policies and legislation.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

5. TV-02: Legislation Forecast

List possible changes or evolution to existing legislation:
- Short term (1 year)
- Medium term (3 years)
- Long term (5 years)

An example is the use of asbestos that was used regularly and due to legislative changes banned from being used.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

6. TV-03: Legislative Risk Register

Compile risk register capturing all risk identified in terms of legislation and regulation of the locomotive that has already been developed.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

System Viewpoints (SV)

7. SV-01: Lifecycle View

Investigate the complete lifecycle and identify possible
- shortcomings;
- phases that were not taken into consideration during the design;
- and lessons learned that could be implemented during a next project similar in nature.

Review the current maintenance and disposal plan and determine if the plan was constructed from the beginning of the lifecycle or only at the post project phases.

Compile a lifecycle plan for the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

8. SV-02: Electrical System View
Create a systems-of-systems view of the different components identified on the locomotive. Note the lifecycles applicable to each of the elements in the system of systems.

This provides a simplistic overview of all the electrical systems and components used within the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

9. SV-03: Manufacturing and Maintenance Risk Register
Compile risk register capturing all risk identified in terms of the lifecycle of the locomotive. This includes the following aspects:
• Hazardous material
• Waste from manufacturing
• By-products produced during maintenance

Not at all important	Slightly important	Moderately important	Very important	Extremely important

10. SV-04: Engineering Analysis
Define the engineering analysis process that will be followed assisting the locomotive from 'cradle to grave'.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

11. SV-05: Resource Interaction Description
Compile a hierarchy of personnel required for the disposal and decommissioning process and assign a breakdown of tasks to each resource.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

12. SV-06: Recyclability Analysis
Determine the recyclability rate of the locomotive according to ISO/TC 269/SC 2/WG 4 or using the road vehicle standard ISO 22628:2008.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

Operational Viewpoints (OV)

13. OV-01: High-level operational concept graphic
High-level description/process flow regarding the operation schedules of the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

14. OV-02: Procedures Profile
Identify company policies and company procedures applicable to the decommissioning and disposal process of WEEE. This will also include:
• Standard Operating Procedures (SOP's)
• Safe waste handling procedures
If there are no policies available, it should be created.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

15. OV-03: Maintenance Process / Logistics
Define a maintenance plan to determine the shedding cycles of the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

16. OV-04: Manufacturing Process / Logistics

- Identify possible by-products produced during production phases of the locomotive.
- Create SOP documentation how to manage the by-products produced.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

17. OV-05: Disposal Process / Logistics

- Create disposal process flow for each electrical component identified in the locomotive.
- Create SOP documentation for the disposal of each component identified.
- Combine the disposal process with the maintenance process.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

<u>Strategic Viewpoints (SV)</u>

18. StV-01: Market Analysis

Identification of where the demand for the locomotive will be. This will include a market analysis study.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

19. StV-02: Environmental Analysis

Environmental analysis of the area considering the following elements:

- By-products produced in manufacturing.
- Hazardous materials introduced to the environment by incorrect handling processes.
- Waste of Electrical and Electronic Equipment (WEEE) from failures and maintenance.
- Recycling processes.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

20. StV-03: Capability Analysis

Study to determine Transnet’s and local companies capability to dispose of Waste of Electrical and Electronic Equipment (WEEE) in a safe manner.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

21. StV-04: Enterprise Vision

Business study to determine the possibility to generate income from disposal of Waste of Electrical and Electronic Equipment (WEEE).

Not at all important	Slightly important	Moderately important	Very important	Extremely important

22. StV-05: Energy Recovery Analysis

Identify means of recovering energy during the manufacturing, decommissioning and disposal process of locomotives.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

23. StV-06: Life Cycle Improvement Assessment

Plan for improvements that can be made to extend the life of the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

Acquisition Viewpoint (AcV)

24. AcV-01: Hazardous Materials

• Identify possible hazardous materials that must be handled with care on the locomotive.
• Create safe handling procedures for the hazardous materials.
• Create a plan for the replacement of the hazardous materials.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

Service Orientated Viewpoints (SOV)

25. SOV-01: Operation Description

Define the operational aspects of the decommissioning and disposal of the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

26. SOV-02: Recycling Process

Create a recycling process that should be followed for each group of electrical components identified on the locomotive.

Not at all important	Slightly important	Moderately important	Very important	Extremely important

27. Would you be willing to participate in answering open questions to further expand the framework. This will include expressing your views, identifying possible shortcoming or concepts that were overlooked.

Yes	**No**

Appendix E: Open Questions

Maintenance/Locomotive Experts

1. With the current proposed framework, do you foresee that this can be the first stepping stone for a Systems Framework for the Decommissioning/Disposal process for the electrical components on the Trans-Africa Locomotive?

2. Can you identify any shortcoming with the proposed framework? Explain.

3. What additional views or concepts, if any, would you suggest adding to the framework?

Appendix F: Ethics Clearance

The ethics clearance number to gather information from Transnet was approved by the University of Witwatersrand, reference number MIAEC 002/20.