



Title

A Systems Framework for the Acquisition of Bogies Through Lifecycle for Transnet
Engineering Product Development (TE PD) Projects.

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DECLARATION



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ABSTRACT

This research was conducted to investigate factors affecting acquisition of rolling stock, specifically bogies through lifecycle of rolling stock, and developed a conceptual framework for Transnet Engineering Product Development (TE PD) to assist in the acquisition of bogies through lifecycle of rolling stock.

A review of the literature with focus on rolling stock, new product development, lifecycles, systems engineering, architecture frameworks, logistics, and project management was conducted. The first draft of the framework consisted of 37 viewpoints. It was developed by adapting Ministry of Defence Architecture Framework (MoDAF)(Caruso et al, 2010) and Department of Defence Architecture Framework (DoDAF)(DoD, 2007) architecture. The framework was developed along with a checklist matrix with 32 factors affecting the acquisition of bogies through lifecycle of rolling stock.

Research was conducted using a Likert survey and archival research to evaluate current acquisition processes and identify problematic factors affecting acquisition of rolling stock within TE PD. The survey reached a response rate of 60.0% (42 respondents). The survey was used to rank the issues affecting acquisition of rolling stock within TE PD from the perspective of former and current employees of TE PD. Then, archival research was conducted by going through two main project document templates that were used for all the projects considered for this research. The archival research found that each projects followed process as per intent, but the process could benefit greatly from introducing new templates such as a standardised acquisition lifecycle process, SEMP template, WBS template, ConOps template as well as the check list matrix. This was followed by semi-structured interviews conducted with subject matter experts to give their critique of the first draft of the conceptual framework.

A final framework updated from the input from subject matter experts is presented with a total of 41 viewpoints. Pareto Principle, which states that 80% of problems are caused by the top 20% of the issues, was used to pick the top 21.8% of the top acquisition issues according to the survey responses and interventions proposed by the framework to address these critical issues.

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I would like to thank **Transnet Centre of Systems Engineering (TCSE)** for introducing me to Systems Engineering and for being a hub of information for System Engineering. It has undoubtedly changed how I view the world and handle problems for the better.

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I'd like to dedicate this work to my late mother, **Casiwe Florence Boo**. She taught me the value of hard work and self-reliance.

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CONTENT

DECLARATION.....	ii
ABSTRACT.....	iii
ACKNOWLEDGMENTS	iv
CONTENT.....	v
LIST OF TABLES	viii
LIST OF FIGURES	x
ACRONYMS AND ABBREVIATION.....	xii
1. INTRODUCTION.....	1
1.1 Background	1
1.2 Problem Statement.....	8
1.3 The Purpose of the Study	8
1.4 Problem Analysis	9
1.4.1 Problems Contextualization	9
1.4.2 Research Gap	11
1.5 Research Question.....	11
1.5.1 Critical Research Question (CRQ).....	11
1.5.2 Research Sub-questions	12
1.6 Research Objectives.....	12
1.6.1 Main Objective	12
1.6.2 Sub-objectives.....	12
1.7 Summary of Research Methodology	12
1.8 Summary of Chapter Overviews	12
2. CRITICAL LITERATURE REVIEW.....	14
2.1 Rolling Stock and Bogies	15
2.2 Transportation Industry Projects that Failed	17
2.3 Lifecycle Processes	19
2.3.1 Acquisition Lifecycle Process	20
2.3.2 Project Lifecycles Process	23
2.3.3 System Lifecycle Process	25
2.3.4 Product Development Lifecycle	27
2.4 Acquisition Strategy/Plan.....	29
2.5 Acquisition Processes.....	30
2.5.1 Acquisition Process Outcomes	30
2.5.2 Acquisition Process Activities	31

2.6	Acquisition for Retrofit	32
2.7	Commercially Off the Shelf (COTS)	33
2.8	Principles of Acquisition Tenders and Contracts	33
2.9	Frameworks.....	36
2.9.1	Enterprise Architecture.....	37
2.9.2	Architecture Framework Models and Methodologies	37
2.9.2.1	The Zachman Framework.....	37
2.9.2.2	Ministry of Défense Architecture (MoDAF)	39
2.9.2.3	Department of Défense Architecture Framework (DoDAF)	40
2.9.2.4	The Open Group Architecture Framework (TOGAF).....	41
2.9.3	Framework Selection	42
2.9.4	Acquisition of Bogie Framework Viewpoints	43
2.10	Systems Engineering.....	44
2.10.1	Systems Engineering Capacity and Project Performance.....	44
2.10.2	Systems Engineering Process	44
2.10.4	Requirements Analysis	48
2.10.5	System Development Methodologies	52
2.10.5.1	Sequential/Waterfall Model	53
2.10.5.2	Incremental Model.....	53
2.10.5.3	Spiral Model	54
2.10.5.4	Vee Model	54
2.10.6	Requirements Functionality Synthesis (RFS) Loop.....	55
2.10.7	Project Management and Systems Engineering Process	56
2.10.7.1	Project Management Plan (PMP) and Systems Engineering Management Plan (SEMP)	57
2.11	Customer Value Proposition	59
2.12	Supply Chain Party Logistics.....	60
2.13	Systems Framework for the Acquisition of Bogies for TE PD.....	61
3.	RESEARCH PROCESS	73
3.1	Research Design	73
3.2	Research Philosophy and Approach	73
3.3	Methodological Choice	73
3.3.1	Archival Research.....	74
3.3.2	Likert Survey.....	74
3.3.3	Semi-structured Interviews.....	75
3.4	Reliability and Validity.....	76

3.5	Ethical Considerations.....	76
4.	RESEARCH RESULTS	77
4.1	Survey Results	77
4.2	Archival Research Results.....	80
4.3	Semi-structured Interview Results	81
4.4	Revised Framework	82
5.	ANALYSIS AND DISCUSSION	84
5.1	Archival Research	84
5.2	Surveys	84
5.3	Semi-structured Interviews	85
6.	CONCLUSION	86
6.1	Summary	86
6.2	Limitations.....	87
6.3	Future Research and Recommendations	88
	LIST OF REFERENCES	89
7.	APPENDIX A: Ethics Clearance.....	95
8.	APPENDIX B: LIKERT SURVEY RESPONSE RATE	96
9.	APPENDIX C: SEMI-STRUCTURED INTERVIEWS RESPONSE RATE.....	99
10.	APPENDIX D: WRITEup FOR REVISED FRAMEWORK.....	101
11.	APPENDIX E: ACQUISITION AND DESIGN FACTORS CHECK LIST	112

LIST OF TABLES

Table 1: Rail industry projects in Africa for acquisition of wagons until 2024.....	4
Table 2: Rail industry projects in Africa for acquisition of locomotives until 2024.	5
Table 3: TE PD root definition using CATWOE analysis.....	10
Table 4: NPD process critical success factors	18
Table 5: Factors contributing to challenges faced during rolling stock acquisition and aviation industry	19
Table 6: Ranking of factors that lead to project failure	19
Table 7: NASA’s elements for the development of an acquisition strategy	30
Table 8: Elements and performance criteria	32
Table 9: Principles of acquisition tenders	34
Table 10: Useful contracting techniques.....	35
Table 11: Attributes of a framework.....	37
Table 12: The seven rules of ZFEA	39
Table 13: The seven different categories that make up the views of the MoDAF.....	39
Table 14: Maintenance Organization vs OEM Organization.....	47
Table 15: Characteristics of a requirement and characteristics of a set of requirements	50
Table 16: Requirements quality ranges.....	50
Table 17: Requirements analysis task areas.....	50
Table 18: Different types of requirements	51
Table 19: Requirement specifications types	52
Table 20: Requirements acceptance.....	56
Table 21: PMP inputs.....	58
Table 22: PMP inputs.....	59
Table 23: Description of party logistics	61
Table 24: All viewpoints (AV)	63
Table 25: Lifecycle viewpoint (LCV), project lifecycle process	64
Table 26:Lifecycle viewpoint (LCV), acquisition lifecycle process continued.....	65
Table 27:Lifecycle viewpoint (LCV), system lifecycle process continued	66
Table 28: Lifecycle viewpoint (LCV), system/product development lifecycle process continued	67
Table 29: Technical standards viewpoint (TV).....	68
Table 30: Project management and systems engineering management viewpoint (PSMV).....	68
Table 31: Strategic viewpoint (StV)	69
Table 32: Systems engineering technical process viewpoint (SETPV)	70
Table 33: Systems engineering technical process viewpoint (SETPV) continued	71
Table 34: Operational viewpoint (OV)	72
Table 35: Project for cross-sectional and longitudinal horizon time zones	74
Table 36: The required sample set for the survey	75
Table 37: Sample set for the semi-structured interview.....	76
Table 38: Survey questions	79
Table 39: NPD process critical success factors	80
Table 40: Ranking of factors that lead to project failure	81
Table 41: Transnet vs TE PD vs proposed framework acquisition processes though lifecycle.....	81
Table 42: Top seven rolling stock acquisition issues in TE PD.....	87
Table 43: Survey response rate	96

Table 44: Reponses to survey open questions	98
Table 45: Semi-structured interview actual sample set.....	99
Table 46: Semi-structured interviews responses.....	100
Table 47: Revised All viewpoints (AV)	101
Table 48: Revised Lifecycle viewpoint (LCV), project lifecycle process	102
Table 49: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued	103
Table 50: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued	104
Table 51: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued	105
Table 52: Revised Technical standards viewpoint (TV).....	106
Table 53: Revised Project management and systems engineering management viewpoint (PSMV) .	106
Table 54: Revised Strategic viewpoint (StV)	107
Table 55: Revised Strategic viewpoint (StV) continued.....	108
Table 56: Final Systems engineering technical process viewpoint (SETPV).....	109
Table 57: Revised Systems engineering technical process viewpoint (SETPV) continued	110
Table 58: Revised Operational viewpoint (OV)	111

LIST OF FIGURES

Figure 1: Transnet operating divisions context.....	1
Figure 2: Poached egg diagram of Railway industry of Southern Africa	2
Figure 3: Poached egg diagram of the rest of TE.....	2
Figure 4: TE's transition to be an OEM of rolling stock and port equipment.....	3
Figure 5: Railway track gauges across continent of African.	4
Figure 6: Current and future (2030) customers of Transnet on the African continent.....	5
Figure 7: A closeup of future (2030) customers of Transnet on the African continent.	6
Figure 8: A mapping of Transnet's competitors on the African continent	6
Figure 9: Transnet's organizational structure	7
Figure 10: Hierarchy of the Sol	8
Figure 11: Current situation and future situation of TE PD.....	11
Figure 12: The IDEFO process followed to develop the first draft of the System Framework for the Acquisition of Bogies for TE PD.....	14
Figure 13: Focus areas for the development of the framework	15
Figure 14: Railway vehicle (Locomotive)	15
Figure 15. top left: locomotive bogie (Allert, 2013), Top right: trailer coach bogie (Shubhamkar, 2020), Bottom left: motorized coach bogie (CRRC, 2016), Bottom right: wagon bogie (Tatravagónka, 2016)	16
Figure 16: 3D CAD conceptual diagram of a bogie	16
Figure 17: Physical model of a coach bogie	17
Figure 18: Acquisition lifecycle process.....	20
Figure 19: Lifecycle rating rubric	21
Figure 20: Acquisition lifecycle process.....	22
Figure 21: Acquisition lifecycle processes rating	23
Figure 22: Project lifecycle processes for different organizations.....	24
Figure 23: Project lifecycle processes rating	25
Figure 24: System lifecycle processes for different organizations	26
Figure 25: System lifecycle processes rating	27
Figure 26: Product development lifecycle processes for different organizations	28
Figure 27: Product development lifecycle processes rating.....	29
Figure 28: Generic retrofit process	32
Figure 29: Contracting process stakeholders.	36
Figure 30: Contracting process	36
Figure 31: The Zachman Framework for Enterprise Architecture.....	38
Figure 32: MODAF v1.2 views	40
Figure 33: The evolution of the DoDAF.....	41
Figure 34: DoDAF version 2.02 Architecture Viewpoints	41
Figure 35: TOGAF Model	42
Figure 36: Graphical representation of the key differences between MoDAF and DoDAF.....	43
Figure 37: Viewpoints for a systems framework for the acquisition of bogies in TE PD	43
Figure 38: Systems engineering capacity vs project performance	44
Figure 39: Systems engineering and systems approach.....	45
Figure 40: System processes	45
Figure 41: Systems lifecycle process, Transnet's PLP, and research focus area	47
Figure 42: Generic requirements analysis process.....	48

Figure 43: Specification hierarchy	52
Figure 44: Waterfall system development process	53
Figure 45: Incremental Model.....	53
Figure 46: Spiral Model	54
Figure 47: Vee Model	55
Figure 48: RSF Loop	55
Figure 49: Systems Engineering and Project Management	57
Figure 50: Systems engineering and project management through lifecycle.....	57
Figure 51: Development of the PMP across project lifecycle.....	58
Figure 52: Customer value proposition canvas	59
Figure 53: X Party logistics	60
Figure 54: A Systems Framework for the acquisition through lifecycle of bogies for TE PD projects	62
Figure 55: The research onion used for the study	73
Figure 56: Mixed methods research data collection and analysis strategy	74
Figure 57: Survey response distribution in %	78
Figure 58: Revised framework.....	83
Figure 59: Process of creating final framework.....	84
Figure 60: Survey response distribution	97
Figure 61: Bogie development cost model	115

ACRONYMS AND ABBREVIATION

ABBREVIATION/ACROMYM	DESCRIPTION
AMEA	Asia, Middle East and Africa
AV	All Viewpoints
CAD	Computer Aided Design
CC	Close Corporation
CDRL	Contract Data Requirement List
CNR	China North Rail
Co	Company
ConOps	Concept of Operations
COTS	Commercial Off the Shelf
CSR	China South Rail
DLW	Diesel Locomotive Works
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
EN	European Norm
FEA	Finite Element Analysis
FFBD	Functional Flow Block Diagram
FMECA	Failure Mode, Effects, and Criticality Analysis
GE	General Electric
HC	Human Capital
IDEF	Integrated Definition for Function Modeling
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
Inc	Incorporated
INCOSE	International Council of Systems Engineering
IR	Integrated Report
ISO	International Organization for Standards
IW	International Workshop
JAXA	The Japanese Aerospace Exploration Agency
LAPSSET	Lamu Port and Lamu-Southern Sudan-Ethiopia Transport
LCV	Lifecycle Viewpoint

LTD	Limited
MCAS	Manoeuvring Characteristics Augmentation System
MDS	Market Demand Strategy
MIL-STD-961D	Military Standard 961D, on Standard Practice for Defence Specifications
MoE	Measure of Effectiveness
NASA	National Aeronautics and Space Administration
NMPP	New Multi-Product Pipeline
NPD	New Product Development
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
OV	Operational Viewpoints
PFMA	Public Funds Management Act
PL	Party Logistics
PLP	Project Lifecycle Process
PMBok	Project Management Body of Knowledge
PMO	Project Management Office
PMP	Project Management Plan
PPI	Project Performance Institute
PSMV	Project Management and Systems Engineering Viewpoints
PWC	Price Waterhouse Coopers
R&D	Research & Development
RA	Requirements Analysis
RCM	Reliability Centered Maintenance
RSA	Republic of South Africa
RVTM	Requirement Verification and Traceability Matrix
SE	Systems Engineering
SEBok	Systems Engineering Body of Knowledge
SEMP	Systems Engineering Management Plan
SETPV	System Engineering Technical Process Viewpoints
SOC	State-Owned Company
SoI	System-of-Interest
SOW	Statement of Work

StV	Strategic Viewpoints
TE	Transnet Engineering
TE PD	Transnet Engineering Product Development
TFR	Transnet Freight Rail
TNPA	Transnet National Ports Authority
TOGAF	The Open Group Architecture Framework
TPT	Transnet Port Terminal
TV	Technical Viewpoints
WBS	Work Breakdown Structure
ZFEA	Zachman Framework for Enterprise Architecture

1. INTRODUCTION

This section focuses on providing the background, context, and purpose of the research as well as defining the problem statement, analyzing the problem, summarizing the research methodology, and providing a summary of the chapters. This research focuses on the acquisition of bogies through lifecycle of rolling stock within Transnet Engineering Product Development (hereafter TE PD), which is a department within Transnet Engineering (hereafter TE). TE is an operating division within Transnet SOC LTD (hereafter Transnet) and specializes in advanced manufacturing and maintenance as well as developing specialised equipment for the rest of Transnet (Transnet-ir, 2020).

1.1 Background

TE’s headquarters are in Pretoria, South Africa, and they are the advanced manufacturing, research, engineering, and maintenance division of Transnet. TE manufactures mainly rolling stock such as wagons, locomotives, and passenger coaches (TransnetEngineering, 2021). It has workshops in Koedoespoort, Germiston, Bloemfontein, Durban, Uitenhage, and Salt River (Transnet-ir, 2020). Figure 1 below shows the engineering division (TE) of Transnet in context to other divisions.

Transnet Freight Rail (TFR)	Transnet Engineering (TE)	Transnet National Port Authority (TNPA)	Transnet Port Terminals (TPT)	Transnet Pipeline (TP)
<ol style="list-style-type: none"> Operate 30 400 km of rail track across South Africa Transport bulk, break-bulk and containerized freight. Freight rail network and rail services provide strategic links between mines, production hubs, distribution centres and ports, and connect the cross-border railways of the region. 	<ol style="list-style-type: none"> Provides advanced manufacturing, maintenance and refurbishment of rolling stock and specialised equipment to TFR, TNPA, TPT, as well as external clients Houses Transnet’s Research and Development (R&D) unit Delivers customer centric products and services as a growing hub and systems integrator of rail in the Asia Pacific, Middle East and Africa (AMEA) region. 	<ol style="list-style-type: none"> Services eight(8) commercial sea ports in South Africa Core function include the planning, provision, maintenance and improvement of ports infrastructure Provide marine related services and navigation aids to assist navigation of vessels within ports limits and along the coast 	<ol style="list-style-type: none"> Provides cargo handling services to a wide spectrum of customers, including shipping lines, freight forwarders and cargo owner Operates 16 terminal in seven (7) ports spread along the South African coast line Operation are divided into four (4) major segments, containers, bulk, break-bulk and automotive 	<ol style="list-style-type: none"> Transnet pumps fuel and crude oil imports from the coastal refineries to the inland market Transport gas from Secunda to industrial users in Durban and Richards Bay The New Multi-Product Pipeline (NMPP) enables the increase in liquid fuels volume through put to meet forecast demand

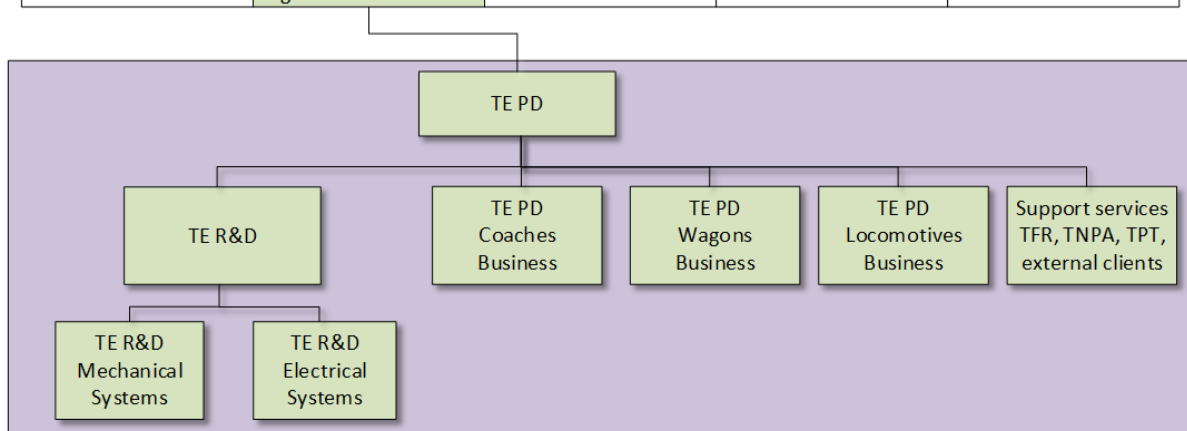


Figure 1: Transnet operating divisions context

Source: Author Adapted from (Transnet-ir, 2020; Transnet HC Portal, 2021)

To understand the context in which TE PD operates in relation to other departments within Transnet and the railway industry in Southern Africa, a Poached egg method developed by Hitchins (Hitchins, 1999) was used to illustrate its position. This method is usually used to show the context in which the System-of-Interest (SoI) is located relative to other systems. This is shown in Figure 2 below.

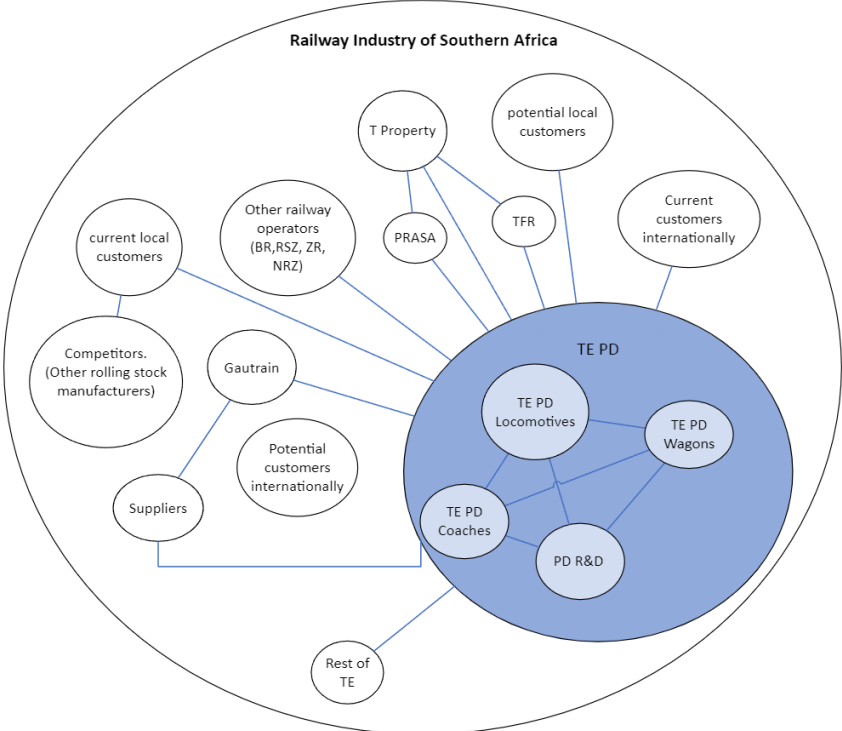


Figure 2: Poached egg diagram of Railway industry of Southern Africa

Source: Author Adapted from (Hitchins, 1999; Transnet HC Portal, 2021)

Taking a closer look at the rest of TE and all the departments within TE, we look at the illustration of Figure 3 shown below. It shows how these departments depend on each other and the interfaces.

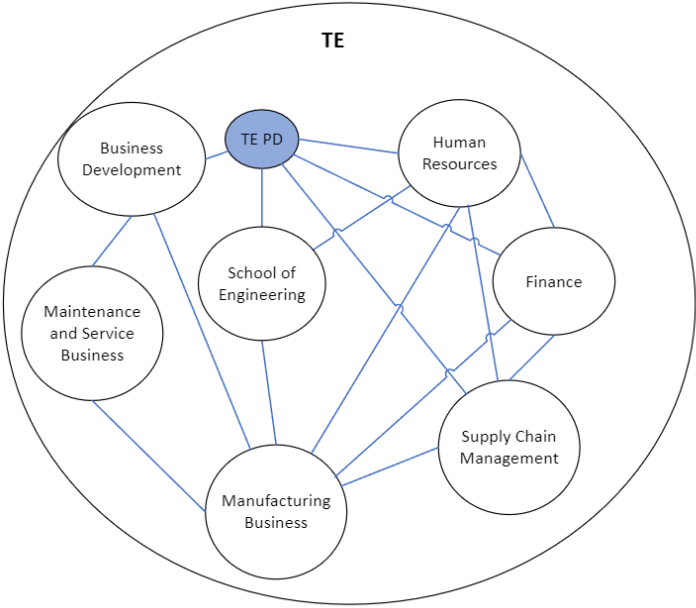


Figure 3: Poached egg diagram of the rest of TE

Source: Author adapted from (Hitchins, 1999; Transnet HC Portal, 2021)

With assistance from Price Waterhouse Coopers (PWC), TE set out a plan to transition from being reliant mainly on maintenance and refurbishment for revenue to becoming an Original Equipment Manufacturer of Rolling Stock as well as Port Equipment (Shaw *et al.*, 2014). Figure 4 below shows transition by TE to strengthening its OEM capability by 2024 (Shaw *et al.*, 2014). Additionally, the authors predicted new revenue streams in 2024 that would require capabilities in developing and producing coaches, port equipment, wagons, and locomotives. Transnet has embarked on a transition from Market Demand strategy to Transnet 4.0, which is focused on investing in the country’s freight system among others (RSA_PublicEnterprises, 2019). Transnet 4.0 aims to reposition the country’s freight system, making it competitive and digitizing it in this fast technology-driven 4th industrial revolution world. Transnet aims to grow its market share by improving its operational efficiency and reliability and become a R100 billion company (Transnet-4.0, 2017). TE’s responsibility to the group is mainly engineering services such as manufacturing, maintenance, and research and development of rolling stock (Shaw *et al.*, 2014).

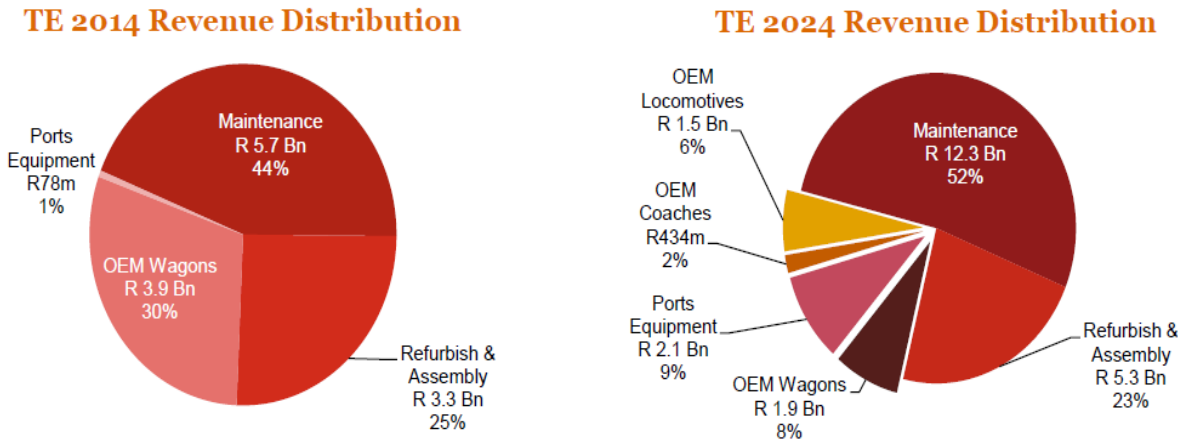


Figure 4: TE's transition to be an OEM of rolling stock and port equipment

Source: Adapted from (Shaw *et al.*, 2014)

From the extensive market research conducted for TE by (Shaw *et al.*, 2014), a summary of wagons acquisition projects for the African continent that will run until 2024 was provided. In order to take full advantage of the potential new revenue streams, TE needs to improve its acquisition processes. The projects are shown in Table 1 below with the number of wagons to be acquired for each project. In Table 1 below narrow gauge is 1067 mm and not 600 to 800 mm as in Figure 5. Different parts of the world use the terms interchangeably. A total of 30,626 narrow gauge and 19,068 standard gauge wagons will be acquired during this period. As TE shifts its focus to becoming an OEM of other rolling stock a decline in revenue of wagons from R3.9b to R1.9b by 2024 is expected while revenue as an OEM of locomotives at R1.5b and OEM of coaches at R434m is expected (Transnet Africa Strategy, 2015). Over 70% of the railway track on the African continent is cape gauge. That is 44 870 km of total of 63 337km which is shown in Figure 5 below (Morgan, 2012). Transnet has competitive advantage when it comes to cape gauge as it has over a century of experience operating on cape gauge. Of all cape gauge across the continent South Africa makes up 45% of it (Morgan, 2012). Bogies are the most challenging mechanical sub-system to design in a railway vehicle and it is more challenging to design one for cape gauge due to the dynamics involved when it comes to cape gauge compared to standard gauge. In order to take advantage of skills developed by TE engineers Transnet has decided to venture into developing all rolling stock as an OEM and not just wagons and this is expected to reflect in their projected revenue.

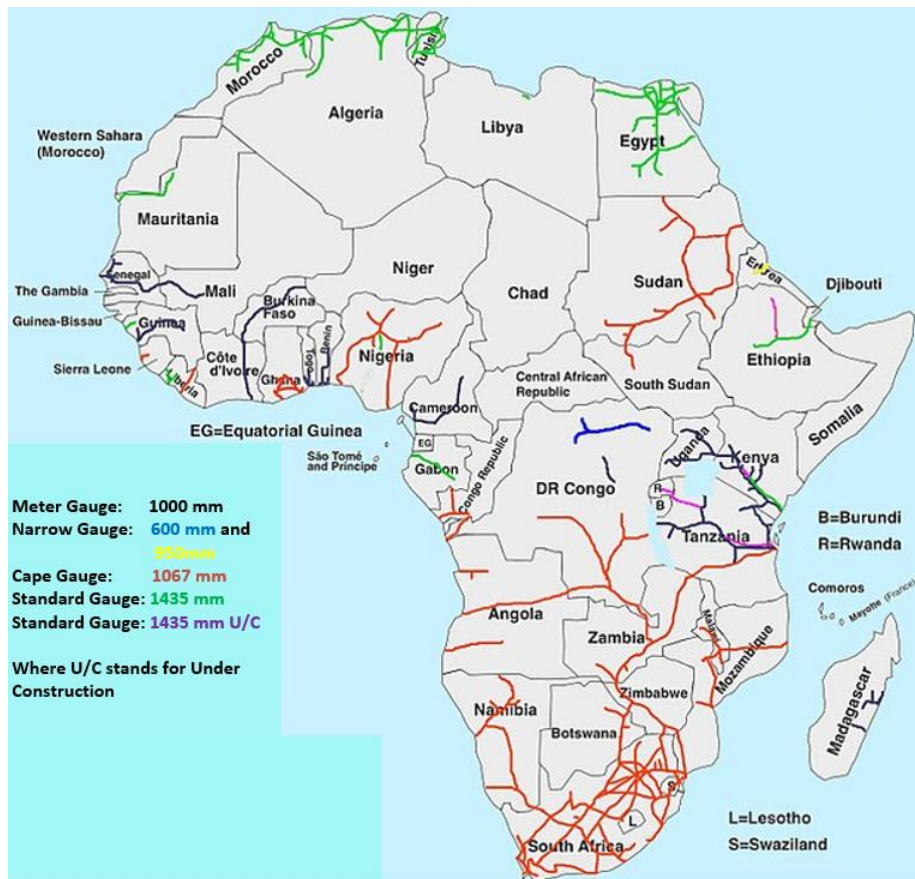


Figure 5: Railway track gauges across continent of African.

Source: Adapted from (Morgan, 2012) and (Irandu, 2020)

Table 1: Rail industry projects in Africa for acquisition of wagons until 2024.

Source: Adapted from (Shaw et al., 2014) and (Transnet Africa Strategy, 2015)

Project	Country	Gauge	Total	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Local Replacement	All Africa	Narrow	19434	1943	1943	1943	1943	1943	1943	1943	1943	1943	1943
Local Replacement	All Africa	Standard	8510	851	851	851	851	851	851	851	851	851	851
Trans-Kalahari Railway	Botswana	Narrow	9000			2700	2700	2700	900				
LAPSSET Corridor	Kenya, South Sudan, Ethiopia	Standard	970						500	470			
Nacala Corridor	Mozambique	Narrow	1836		936	900							
Tete-Nacala	Mozambique	Standard	3500			1750	1750						
Tete-Macuse	Mozambique	Standard	952							500	452		
Mombasa-Nairobi	Kenya	Standard	1600			800	800						
Nigerian Coastal	Nigeria	Standard	1836				900	936					
Zambia-Angola Cobalt belt	Angola	Narrow	360			360							
Djibouti-Addis Abeba	Ethiopia	Standard	1700		850	850							
Total		Narrow	30626	1943	2879	5903	4643	2843	1943	1943	1943	1943	1943
Total		Standard	19068	851	1701	4251	4301	1787	1351	1821	1303	851	851

A similar list of rolling stock project specifically for locomotives is given in Table 2 below. The acquisition of these locomotives will be running in parallel with the acquisition projects given above.

Table 2: Rail industry projects in Africa for acquisition of locomotives until 2024.

Source: Adapted from (Transnet Africa Strategy, 2015).

Future locomotive projects in Africa	# of locomotives
Trans-Kalahari	550
LAPSSET	59
Nacala Corridor	112
Tete-Nacala	110
Tete-Macuse	59
Mombasa-Nairobi	61
Nigeria Coastal	143
Zambia-Angola	22
Djibouti-Addis Abeba	66
TOTAL	1,182

Transnet knowing its current position in the market allows it to plan for the effective use of resources and time. Figure 6 below shows Transnet’s current offices across the African continent and the offices they plan to have by 2030.

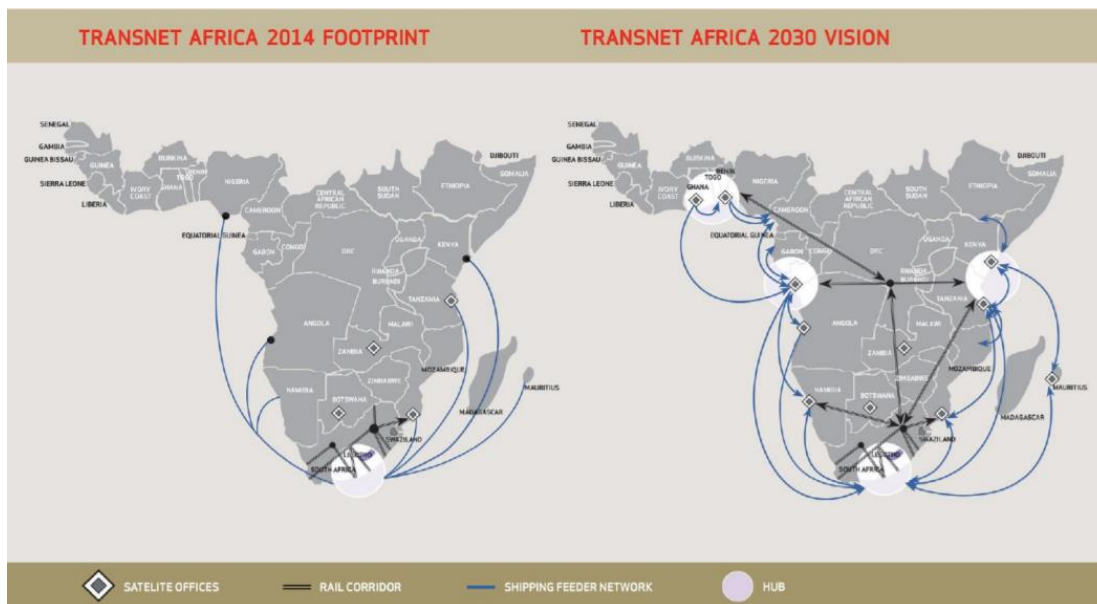


Figure 6: Current and future (2030) customers of Transnet on the African continent.

Source: From (Transnet Africa Strategy, 2015)

Figure 7 below shows a close up of the offices Transnet plans to have across Africa by the year 2030 (Transnet Africa Strategy, 2015).

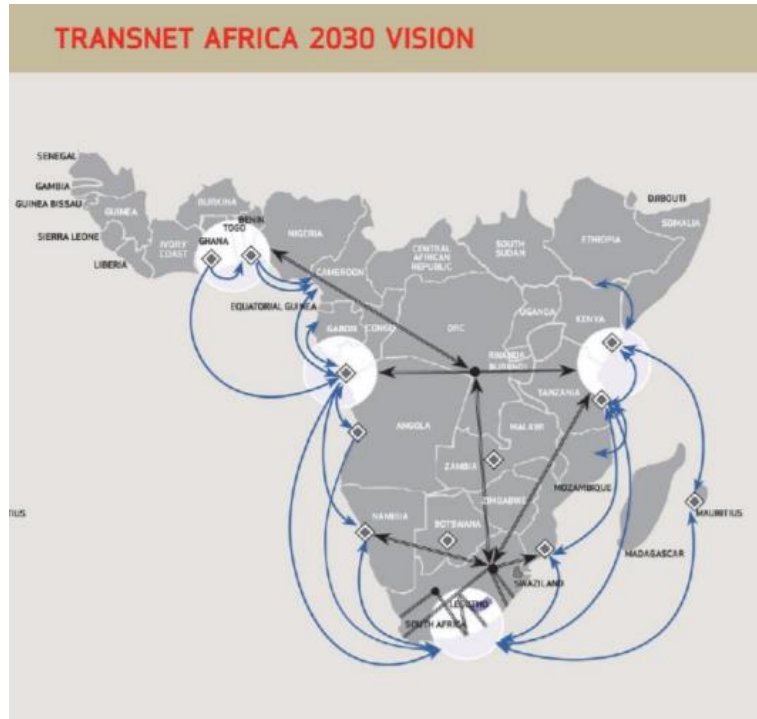


Figure 7: A closeup of future (2030) customers of Transnet on the African continent.

Source: (Transnet Africa Strategy, 2015)

Figure 8 below shows where TE's competitors are situated across the continent of Africa. Africa, unlike well-developed continents, is liquid and presents a lot of opportunities for Transnet to become a supplier of rolling stock. As can be seen, Transnet is a supplier mainly in the Sub-Saharan Africa while the northern parts of Africa are dominated by competitors and other areas left untapped. General Electric (GE) Transportation operates in South Africa as a subsidiary called General Electric South Africa Technologies (GESAT) and has supplied TFR with 143 locomotives. Electro-Motive Diesel Africa was formed in 2012 as a joint venture between Barloworld and Electro-Motive Diesel Inc (EMD). Electro-Motive Diesel Inc supplied TE with 50 locomotives between 2009 and 2010. Chinese companies CNR and CSR have a significant footprint in Sub-Saharan African including in South Africa (Transnet Africa Strategy, 2015).

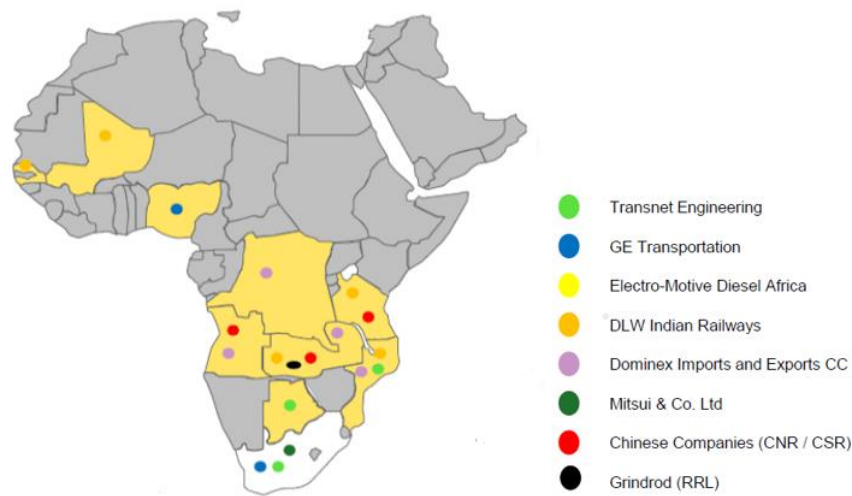


Figure 8: A mapping of Transnet's competitors on the African continent

Source: (Transnet Africa Strategy, 2015)

Figure 9 below provides a closer look at the organizational structure of Transnet's operating divisions and customers. Furthermore, shown on the figure are the main systems developed by the different departments in TE noting specific inclusion of bogies.

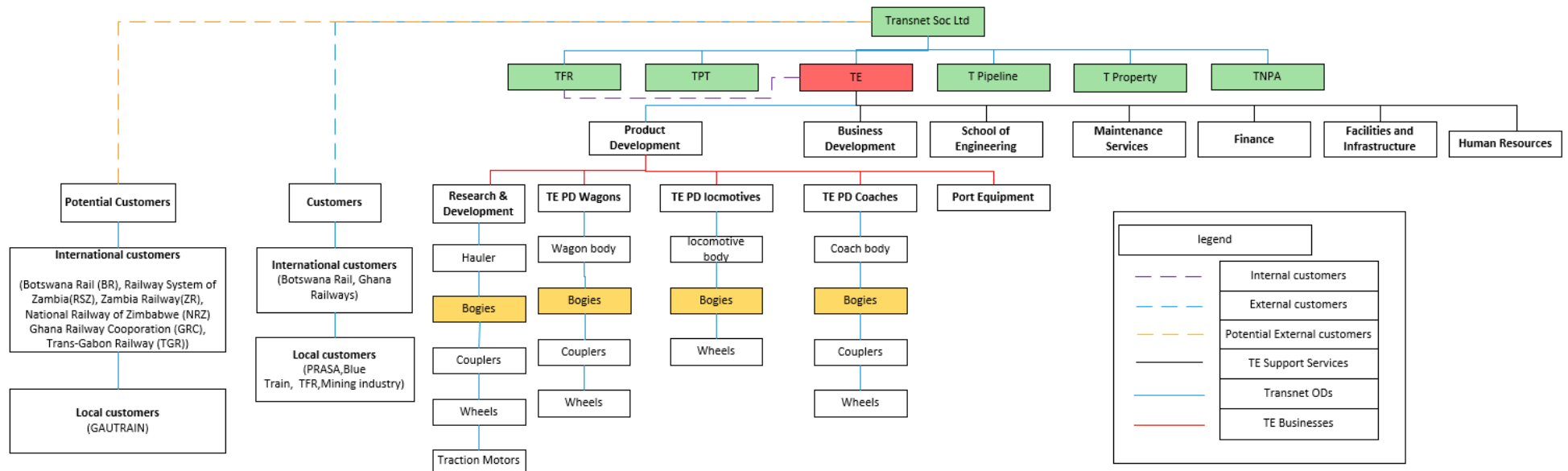


Figure 9: Transnet's organizational structure

Source: Author Adapted from (Sigonyela, 2012; Transnet-ir, 2020; Transnet HC Portal, 2021)

The hierarchy of the SoI relative to the Southern African Railway Industry is shown in Figure 10 below. The figure shows where the SoI sits in the hierarchy relative to other institutions, starting from TE PD to TE all the way to Southern African Railway Industry.

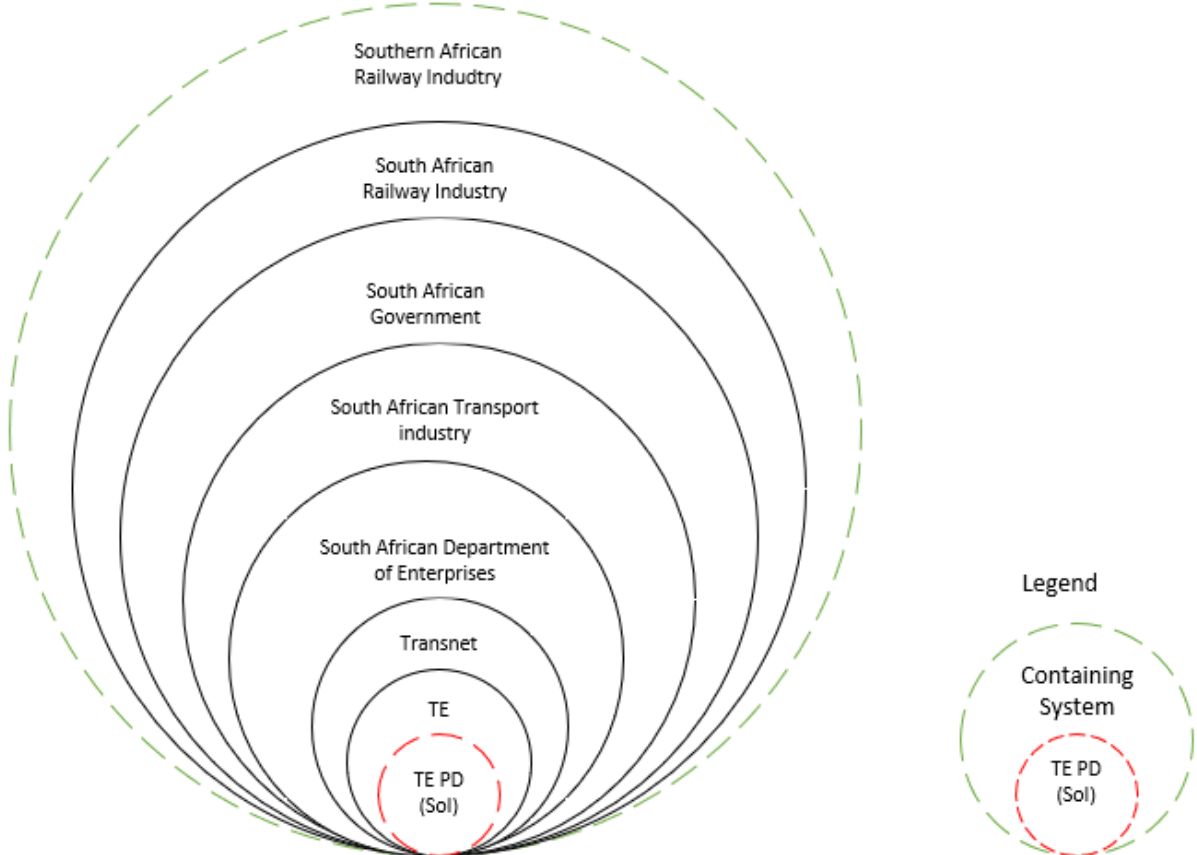


Figure 10: Hierarchy of the Sol
 Source: Author Adapted from (Sigonyela, 2012; Transnet-ir, 2020; Transnet HC Portal, 2021)

1.2 Problem Statement

Transnet has decided to transition from their Market Demand Strategy to their Transnet 4.0 strategy, which is focused on investing in the country’s freight system among others (Transnet-ir, 2018). The strategy aims to grow Transnet’s market share by improving its operational efficiency and reliability and become a R100 billion company (Transnet-4.0, 2017). TE’s responsibility to the Transnet is mainly engineering services, such as manufacturing, maintenance, and research and development of rolling stock (Shaw *et al.*, 2014). To increase TE’s product offering, TE has broadened its scope to be an OEM for bogie manufacturing. TE has since its inception focused on maintenance and manufacturing. To be an OEM, a new comprehensive and systematic process of acquiring bogies is needed. A framework is needed that will enable TE to acquire bogie through in-house development, Commercial Off the Shelf (COTS), or partnership with other OEMs.

1.3 The Purpose of the Study

The purpose of this study is to develop a systems engineering framework for the acquisition of bogies through lifecycle in TE PD. A system is a combination of interacting elements organized to achieve one or more stated purposes (ISO/IEC 15288, 2007); a framework is a particular set of rules, ideas, or beliefs that are used to address problems or to decide what to do (Collins Harper, 2022). Acquisition is a process that covers the phases of a system lifecycle, such as conceptualization, initiation, design, development, testing, contracting, production, deployment, logistics support, modification, and disposal as well as

suppliers or services to meet organizational needs ('Defense Acquisition Guidebook', 2010)(Défense Acquisition University Press, 2001). Procurement on the other hand is the process of purchasing exiting goods or services (DoD, 2007). Procurement more often than not forms part of an acquisition strategy of an organization depending on an organization's capacity and capability.

1.4 Problem Analysis

It is critical for one to identify the problem and have a good understanding of the problem so they can identify the causes. A structured analysis of the problem is discussed below as is the desired situation and how to get there. In order to understand the big picture, different tools of analysis are considered. One of the tools to analyse problems is the Five Whys method developed by Toyota Motor Corporate in the 1930s (EPM, 2019). This technique is used to identify the root cause of a problem by asking why there is an issue five times (EPM, 2019). Another technique is the SWOT analysis, invented in the 1960s by Albert Humphrey, who was a management consultant at the Stanford Research Institute (Lucidchart, no date). SWOT stands for: Strength, Weaknesses, Opportunities, and Threats (Puyt *et al*, 2020). A SWOT analysis can be used for product creation, service implementation, or to meet the challenges and objectives an organization faces head-on (Gaille, 2017). The Ishikawa diagram is a cause-and-effect method that was developed by Dr Kaoru Ishikawa in the 1960s (Ishikawa, 1976). It was developed for quality improvement of products by addressing the relating causes of the problem (Ishikawa, 1976). Systems thinkers believe that 90% of the real causes of the problems are not apparent to everyone and 10% is what people see and think are the real causes of the problem (Rogers, 2017). This theory of problem analysis is referred to as the Iceberg Model: it believes that the top part of the iceberg that can be seen is just 10% and the remaining 90% can't be seen and is the real cause of problems (Rogers, 2017). This model was developed in the 1970s by anthropologist Edward T. Hall to illustrate the cultural codes that exist within society (Harappa, 2020).

1.4.1 Problems Contextualization

Understanding the big picture of the railway industry and where it's going requires:

- understanding the environment in its entirety and not just the physical environment,
- identifying all stakeholders and their interest in the system,
- identifying problems, previous, current, and future problems and analysing them, and
- setting out contingency plans to address the problems, through lifecycle, and understanding the 'what' future and the 'how' future.

To contextualize the problem in TE PD, CATWOE and Brown Cow analysis tools will be used. The CATWOE method of analysis was developed by (Checkland *et al*, 2000) and is used to identify stakeholders and their viewpoints; identify the owner system of interest; give a view of the current situation and desired future. The CATWOE analysis uses six elements: Customer, Actor, Transformation, World View, Owner, and Environment. This is given in Table 3 below.

Table 3: TE PD root definition using CATWOE analysis

Source: Author adapted from (Checkland et al, 2000; Mulder, 2017)(Transnet Engineering ir, 2021)(Ash, 2021)Bombardier, 2022; CRRC Cooperation Limited, 2020; Siemens Mobility, 2020; Sigonyela, 2012; Transnet Africa Strategy, 2015)

<p>World view An overall view of the picture that gives an overview.</p>	<ul style="list-style-type: none"> - Diverse rolling stock supplier - Self sustainable and profitable organization - R&D Division that develops products and built and shares capability - To be self reliant on science and technology - Development of innovative rolling stock - Increase in commercialization of rolling stock - R&D personnel of 20% to overall staff
<p>Transformation The process of the inputs in order to achieve the desired outputs.</p>	<p>An efficient process of acquiring bogies through lifecycle.</p>
<p>Customer(s) All the people affected by the systems of product developed.</p>	<p>Current customers</p> <ul style="list-style-type: none"> -PRASA, Blue Train, TFR, Mining industry, Botswana Rail, Ghana Railways - Employees of the organization - End users of bogies. <p>Potential customers</p> <p>Gautrain, (Botswana Rail (BR), Railway System of Zambia (RSZ), Zambia Railway (ZR), National Railway of Zimbabwe (NRZ) Ghana Railway Cooperation (GRC), Trans-Gabon Railway (TGR))</p>
<p>Owner The person in control of the system or the product being developed.</p>	<p>Chief of Engineering in TE.</p>
<p>Actors Those responsible for the main activities of the system or product.</p>	<ul style="list-style-type: none"> - Principle engineers (Project owners) - Engineers (Executors) - Executive management - Project managers - End-users - Suppliers - Finance - Maintainers
<p>Environment The operational environment of the systems or product.</p>	<ul style="list-style-type: none"> - Financial constraints - Change in company strategies - Government regulations impacting processes - Economic recession - excess workforce

To better understand what the problem is, and where Transnet wants to be, the researcher used the Brown Cow Model. This technique is useful in understanding what the problem is and what is causing the problem. From there, it identifies the desired situation and what needs to happen to reach that situation, using technology, people, software, hardware, and all other resources (Robertson & Robertson, 2013). This technique was applied in this research, and the result is shown in Figure 11 below.

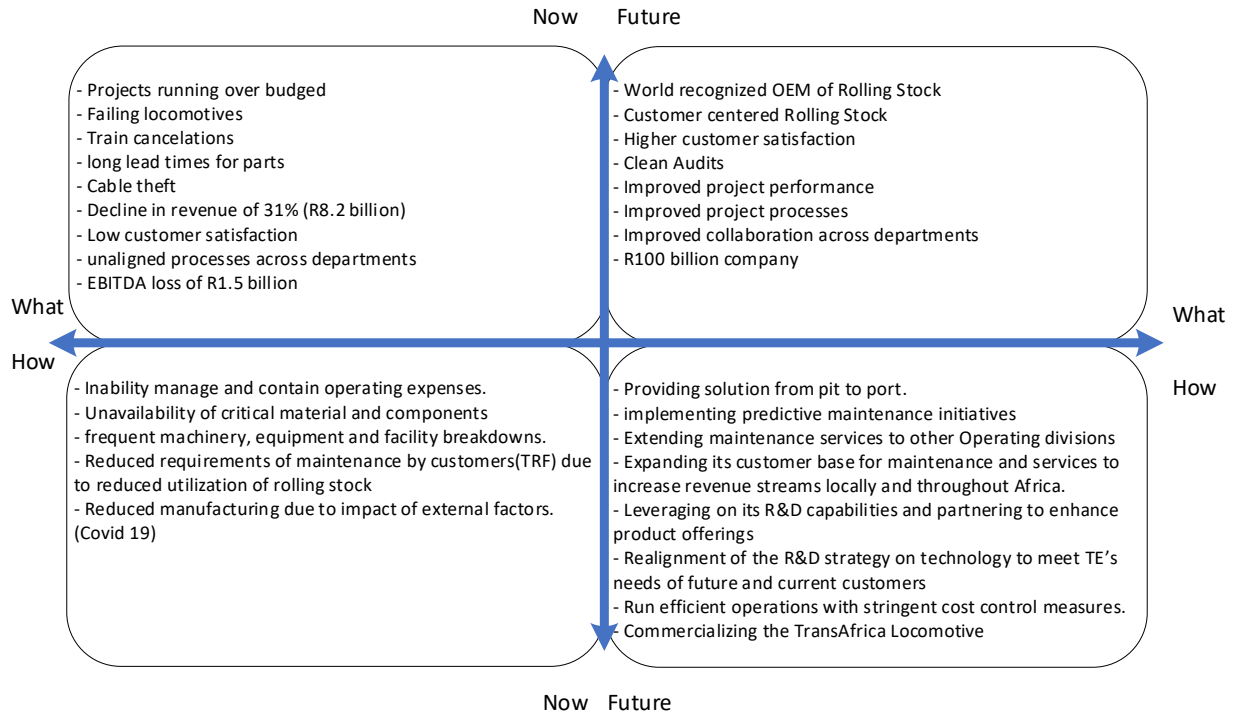


Figure 11: Current situation and future situation of TE PD

Source: Author adapted from (Robertson & Robertson, 2013; Transnet Engineering ir, 2021; Ash, 2021; Bombardier, 2022; CRRC Cooperation Limited, 2020; Siemens Mobility, 2020; Transnet Africa Strategy, 2015)

1.4.2 Research Gap

From the review of the literature, it is clear there has been research done identifying the pitfalls related to system acquisition in the railway industry and similar industries. There is research that focuses on the different phases of project lifecycles in order to have a comprehensive through life acquisition process. The project lifecycle has been amalgamated from acquisition lifecycle, system lifecycle, and product development lifecycle to be the overarching lifecycle process. This research also looks at literature in the transportation industry with focus on heavy vehicles such as rolling stock and aviation and identifies crucial factors that determine success or failure of a project. Then, the different lifecycles are amalgamated to develop an acquisition lifecycle through life of bogie. Systems engineering principles and methodologies as well as project management principles are included as enablers for the application of the framework. The combination of the acquisition lifecycle, acquisition factors, as well as systems engineering principles and project management principles make up the framework. The combination of everything will enable TE PD to improve its project performance through an improved acquisition process for bogies.

1.5 Research Question

The critical research question as well as the sub-questions the research is based on, and the objectives of the research, are covered in this section.

The critical research question and sub-questions for this research are;

1.5.1 Critical Research Question (CRQ)

- o How can systems engineering principles and methodologies be incorporated in the development of a framework for the acquisition through lifecycle of bogies in Transnet Engineering Product Development?

1.5.2 Research Sub-questions

- What are the current processes for the acquisition of rolling stock, including bogies, within TE PD?
- What systems engineering principles and methodologies can be adopted in the development of a systems framework for the acquisition through lifecycle of bogies?

1.6 Research Objectives

The objectives of this research are as follows:

1.6.1 Main Objective

- Establish a systems framework for the acquisition of bogies in Transnet Engineering Product Development

1.6.2 Sub-objectives

- Identify systems engineering principles and methodologies that can be adopted in the development of a systems framework for the acquisition through lifecycle of bogies
- Evaluate the current processes for the acquisition of rolling stock, including bogies, within TE

1.7 Summary of Research Methodology

The approach for this research was deductive and the philosophy is positivism. This allows the researcher to study real events and explain them logically (Leong, 2008). The study was conducted across cross-sectional and longitudinal time horizons, and the projects chosen were chosen with this in mind. The method of research was a mixed one, with three different instruments of research that gather both qualitative and quantitative data, namely: 1. Likert survey, 2. Archival research, and 3. semi-structured interviews. The research design graphical representation using an adapted research onion is shown in Section 3.1 (Saunders *et al*, 2009).

In order to conduct this research, the researcher had to obtain clearance from the Faculty of Engineering and the Built Environment (School of Mechanical, Industrial, and Aeronautical Engineering). The researcher also had to attend training and prove competency through an online test. Clearance number for this research report is MIAEC 104/21 and confirmation of the clearance is represented in APPENDIX A of this report. Ethics considerations are discussed in Section 3.5 of the report as well.

1.8 Summary of Chapter Overviews

The rest of the report is structured as follows:

Chapter 2: Literature Review

This chapter reviews the topics based on bogie system acquisition through life by means of different strategies such as: in-house design, OEM partnership, and COTS as well as enablers of the acquisition process. All aspects of an acquisition from legal, contracts, and tenders are considered. Systems engineering processes such as technical process, requirement management, and system development methodologies are discussed as is a SEMP. Project management and systems engineering management and the marriage between the two is also discussed. Different architectures of frameworks are discussed and adapted by the researcher to develop the first draft of the bogie acquisition framework. Value proposition from the customer's perspective is discussed to have a better understanding of the customers perception of value of a product. Supply chain party logistics and their integration of different services

are discussed to better understand the position of Transnet in logistics and to better understand the importance of TE in assisting Transnet to reach its goal as a world-recognized logistics company. Finally, the proposed framework is examined.

Chapter 3: Research Process

The researcher describes the research design and data analysis techniques used. The research uses the research onion for research design to explain techniques, methodology, research instruments, and the research approach and philosophy. Then, it details the data collection methods used and analysis process flow. Reliability and validity were kept in mind in the selection and design of the data collection instruments. The statistical tools used to determine the sample size for the surveys and the software used is then discussed. The collection of the research data from questions of the Likert survey, Archival research as well as semi-structured interviews considered the through lifecycle as well as systems thinking approach as it is vital for the framework to have a through lifecycle and systems thinking approach solution.

Chapter 4: Research Results

The results from the data collected from the research instruments is presented in this section, and reliability and validity of the data was considered throughout. The processed data is presented for easy reading of results.

Chapter 5: Analysis and Discussion

The results are analysed and compared to the literature from Chapter 2 in order to challenge the literature and close the research gap and the gap in TE PD acquisition process.

Chapter 6: Conclusions

Conclusions on the research and findings are presented in this section through a summary of the research. Then limitations of the research are also discussed, and recommendations and future work is presented.

2. CRITICAL LITERATURE REVIEW

This section focuses on the critical literature, which covers topics deemed relevant for acquisition of bogies through lifecycle. The IDEF0 Model shown in Figure 12 below will be used to provide a summary of the process followed to develop a Systems Framework for the Acquisition Through Lifecycle of Bogies in TE PD.

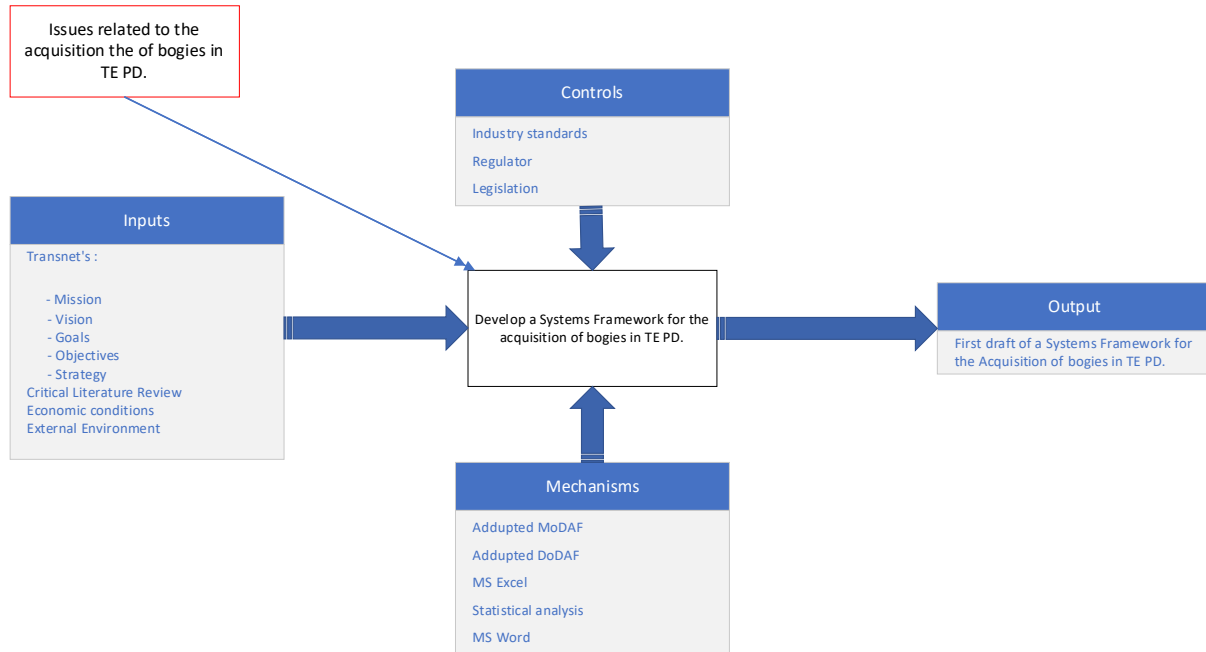


Figure 12: The IDEF0 process followed to develop the first draft of the System Framework for the Acquisition of Bogies for TE PD

Source: Adapted from (Edraw, 2021)

In order to develop a framework for the acquisition of bogies for TE, critical focus areas had to be identified; these were identified based on the organization, the industry in which this organization operates and the customers it serves as well as systems engineering methodologies and principles. The topics below were identified as critical focus areas for the development of the framework and are shown in Figure 13 below.

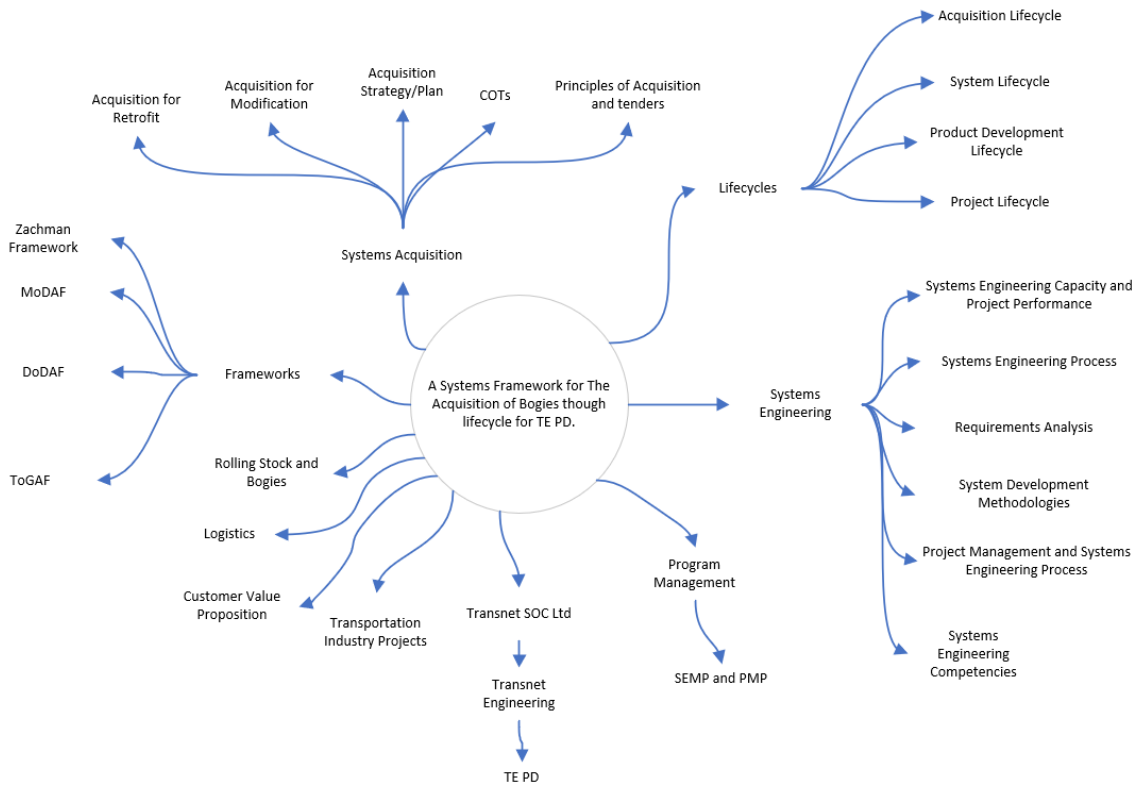


Figure 13: Focus areas for the development of the framework

Source: Author

2.1 Rolling Stock and Bogies

Figure 14 below shows the assembly of a typical railway vehicle (a locomotive in this instance), with its two main subsystems labelled: that is the vehicle body and the bogie. The main functions of the bogie are to: isolate the vibrations induced by the track on the vehicle body and occupants, connect the vehicle body to the track, transfer tractive forces between the body and the track, and allow the vehicle to move forward or backward.



Figure 14: Railway vehicle (Locomotive)

Source: Adapted from (Zavod, 2021)

Figure 15 below shows different bogie systems for all types of railway vehicles. These vehicles include wagons, coaches, and locomotives. Top left is a locomotive bogie; top right is a trailer coach bogie; bottom left is a motorized coach bogie; and bottom right is a wagon bogie.



Figure 15. top left: locomotive bogie (Allert, 2013), Top right: trailer coach bogie (Shubhamkar, 2020), Bottom left: motorized coach bogie (CRRC, 2016), Bottom right: wagon bogie (Tatravagónka, 2016)

Source: Bogie systems (Allert, 2013; CRRC, 2016; Shubhamkar, 2020; Tatravagónka, 2016)

Shown in Figure 16 below is a Computer Aided Design (CAD) model of a conceptual diagram of a bogie with different components. This type of a bogie is referred to as a trailer bogie as it is not motorized and is pulled solely by a locomotive.

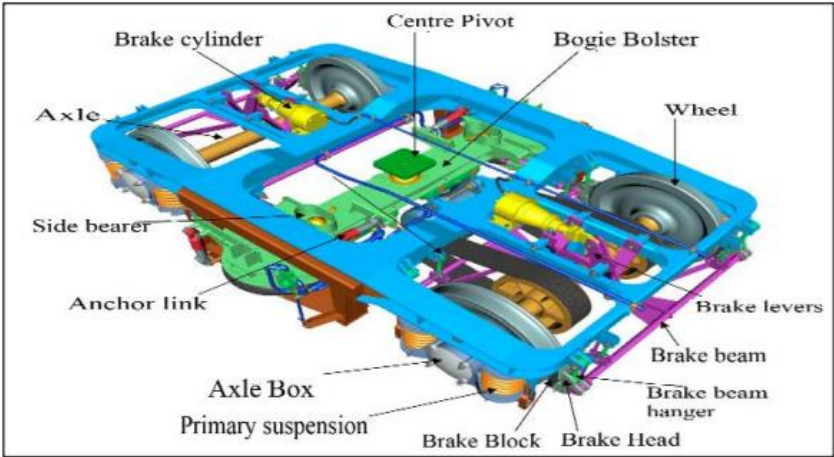


Figure 16: 3D CAD conceptual diagram of a bogie

Source: (Panja & Gangopadhyaya, 2015)

Figure 17 below shows a physical model of a more complex locomotive bogie system. This type of bogie presents structural and dynamic challenges because locomotives generally are much heavier than coaches and wagons. There’s also a dynamics challenge because a locomotive carries at least one person, and vibrations have to be tolerable during operation and meet standards.

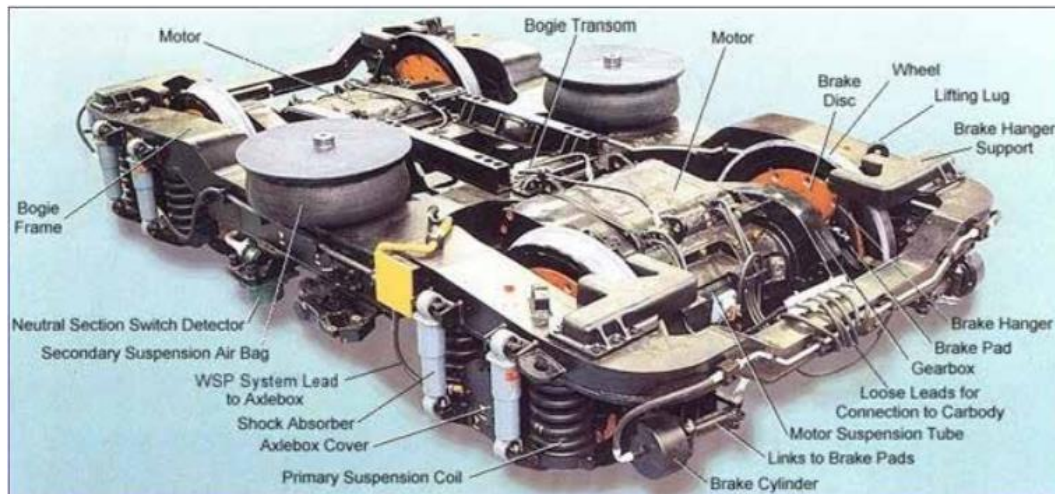


Figure 17: Physical model of a coach bogie

Source: (The Railway Technical Website, 2016)

2.2 Transportation Industry Projects that Failed

The Metroblitz was a self-steering bogie developed in the 1980s by Dr Herbert Scheffel. The self-steering capability enabled the bogie to run at high speeds with reduced flange contact (Pivnic, 2005b). This made it safer and faster, with reduced wheel wear. The bogie still holds the record for the fastest cape gauge train in the world, reaching speeds of up to 245 km/h (Lewis, 1996; Pivnic, 2005). The cause of demise of the Metroblitz is said to be poor cost recovery, causing disruption to slower trains on the network, infrastructure costs, and stiff competition from other modes of transport in the region (Leith, Paxton & Bourne, 1985).

California's Governor Jerry Brown had a dream of uniting California's coastal region and parts of the Central Valley after they were disjointed due to mismanagement and rising costs every year. The project was delayed by twelve years and cost \$100 billion dollars – from an initial estimated cost of \$35 billion. The delays were caused by management and political issues (CAGW Staff, 2020).

On 29 October 2018, Lion Air flight 610 Lion Air crashed into the Java Sea twelve minutes after take-off, killing 189 people. Five months after this crash, on 10 March 2019, Ethiopian Airlines flight 302 crashed six minutes after take-off, killing 157 people. What these crashes had in common was that they were both the Boeing 737 Max 8 design by Boeing (Hawkins, 2019).

(Perell, 2019) found that the crashes were due to the failure of a software that was a result of Boeing's executive team lowering its engineering standards. Boeing lowered its engineering standards to reduce costs, increase efficiency, and ultimately save money. In 1997, Boeing purchased McDonnell-Douglas and adopted a culture of ultra-corporate with relatively low engineering standards. Competition between two main jet manufacturers (Boeing and Airbus) was tight; to keep up with the competition, Boeing cut short the development time of the Boeing 737 Max 8 by using more powerful engines without redesigning the structure of the jet. This resulted in the engines having to be located unusually forward on the wings, which resulted in the jet having a tendency to pitch upwards, resulting in an unsafe situation that could lead to the jet stalling. To address this, Boeing designed what they called a Manoeuvring Characteristics Augmentation System (MCAS), which was a software that, once it noticed the angle of attack of the jet was dangerously high, would use autopilot to pitch the nose down the level the aircraft. Boeing did not even disclose the existence of the MCAS to pilots as they believed the system was robust enough to behave as expected in any situation. In the first crash, the system that measures the angle of attack was faulty and kept reporting the wrong angle of attack to the autopilot,

which kept pushing the nose of the jet down when it was actually already level. The autopilot continued to do this until the jet crashed into the Java Sea. After the first crash, they disclosed its existence but still insisted it was not necessary to retrain pilots. Boeing did not want to disclose that the MCAS was a new feature of the jet and required pilots to be retrained as it can simply be turned off for future similar situations. For the second crash, the system measuring the angle of attack was faulty again; pilots realized this and did what Boeing told them to do, which was to switch off the autopilot, which switched off the MCAS system. However, at this stage, the jet was travelling at such high speed that it was physically impossible for the pilots to manually level the jet and they eventually crashed. Boeing tried to put the blame on the pilots' training, saying American pilots would have acted differently, but found that the pilots followed procedure and were actually trained in America (Perell, 2019).

On 23 February 2008, a US Air Force stealth bomber known as the B-2 Spirit of Kansas, and worth \$1.4 billion, crashed and exploded, coming seconds to killing two of the only 300 pilots in the world who are certified to fly the B-2 Spirits aircrafts. This was after the stealth bomber aircraft had issues with its sensors due to moisture from rain after a night spent outside the hanger after a mission was delayed by 24 hours. The aircrafts operated for over 19 years without ever spending a night outside the hanger or being involved in any crashes. On the night of the delayed mission, the aircraft spent the night outside, and there was heavy rain that night. The sensors were affected by the rain and gave faulty readings during take-off; the expensive military aircraft crashed, but the two pilots managed to eject seconds before it exploded and burnt down. The aircraft was not easily controllable manually – even by the highly skilled pilots – due to its unusual shape. The National Transportation Safety Board (NTSB) pinpointed the issue as one of communication because the aircraft had the capability to absorb the moisture and recalibrate the sensors in a matter of seconds, but this feature of the aircraft was not communicated to the maintenance staff or the pilots (Sof E, 2022).

The process to develop a new product has increased risk, and factors affecting this process need to be identified and managed accordingly. Listed in Table 4 below are factors deemed to be critical for a New Product Development (NPD) process (Dwivedi & Karim, 2021).

Table 4: NPD process critical success factors

Source: Author adapted from (Dwivedi & Karim, 2021)

#	Critical Success Factors	Lester (1998)	Cengiz et al. (2005)	Floren et al. (2018)	Copper et al. (1995)	Fernandez et al. (2017)	Sun et al. (2004)	Suwannapom et al. (2010)	Holland et al. (2000)	Connell et al. (2001)	Total
1	Top management commitment	X	X	X	X	X	X	X	X	X	9
2	Presence of clear goals & milestones	X	X	X	X	X	X	X	X		8
3	User/customer involvement (i.e market research)	X	X	X		X	X	X	X		7
4	Involvement of cross-functional teams	X	X	X	X	X			X	X	7
5	Placement of structured NPD process	X	X		X		X	X	X		6
6	Talented team members with relevant experience to NPD Process & Activities			X	X		X	X	X	X	6
7	Establishment of an entrepreneurial culture	X		X	X				X	X	5
8	Effective communication amongst team members & Management	X			X			X	X	X	5
9	Alignment of NPD Process activities with strategy.			X	X				X	X	4
10	Focusing on innovation & Out-of-the-box ideas	X	X				X			X	4
11	Availability of financial requirements				X		X		X		3
12	NPD Process Speed		X				X				2

Table 5 below shows contributing factors for some acquisition project failures in the railway and aviation industries.

Table 5: Factors contributing to challenges faced during rolling stock acquisition and aviation industry

Source: Author adapted from (Leith, Paxton & Bourne, 1985; Hawkins, 2019; Perell, 2019; CAGW Staff, 2020; Mabusela, 2020; Sof E, 2022)

Factors contributing to project challenges	The Metroblitz	Afro 4000 PRASA	B-2 Spirit of Kansas	Boeing 737 Max 8	California \$100m high speed rail project
Stakeholder management/ID	✓	✓			✓
Requirements management	✓	✓	✓	✓	✓
Planning, monitoring, and control		✓		✓	✓
Industry standards		✓		✓	
Architectural design				✓	
Interface management		✓		✓	
System integrity					
System robustness				✓	
Human factors		✓	✓	✓	✓
Communication			✓		
Quality				✓	

Table 6: Ranking of factors that lead to project failure

Source: Author adapted from (Stewart, 2021)

Factor ranking	Factor leading to failure
1	Scope creep
2	Overallocated resources
3	Poor communications
4	Bad stakeholder management
5	Unreliable estimates
6	No or inadequate risk management
7	Unsupported project culture
8	The accidental project manager
9	Lack of team-planning sessions
10	Monitoring and controlling

Looking at the factors listed in Table 4, Table 5, and Table 6 above, it is evident that the an effective through-life management process that can deliver a fully integrated and capable system to customers to use up to the point of retirement and safe disposal is crucial.

2.3 Lifecycle Processes

Acquisition is the conceptualization, initiation, design, development, testing, contracting, production, development, logistics support, and disposal of the system, supplies, products, or services (including

construction) to satisfy agency/department needs, intended for use in or in support of the organization’s mission (Modigliani & Chang, 2014).

According to (Mo & Sinha, 2014), acquisition lifecycle is a set of knowledge that includes: system design, validation, testing, installation, commissioning, on-going operations support, mid-life upgrades, services and logistics, maintenance and repairs, and decommissioning.

(Défense Acquisition University Press, 2001) defines acquisition as the transformation of operational needs and requirements into an integrated system design solution. The solution is transformed through concurrent consideration of the phases of the system lifecycle of the product, such as: development, manufacturing, test and evaluation, verification, deployment, operations, support, training, and disposal.

2.3.1 Acquisition Lifecycle Process

The acquisition lifecycle is highly dependent on the system lifecycle as well as the nature of the product or service needed. The phases involved may be from cradle to grave depending on the capabilities of the organization. A decision will have to be made to acquire internally or outsource or to acquire a Commercially Off the Shelf (COTS) system depending on the situation. Section 2.7 looks further into the considerations to make under acquisition strategy/plan when making this decision.

An example of an acquisition model for the defence industry is shown in Figure 18 below. The process of acquisition generates viable concepts that are later further developed into production, deployed, and supported in the field of operation. Acquisition planning process identifies and describes the needs, the capabilities, and requirements as well as determines the method to be used to meet those requirements. Procurement forms part of the acquisition process. The acquisition process has several outcomes, which may include: a strategy for the acquisition; the selection of a supplier; communication methods with the supplier; declaration for the selection of the supplier; a signed agreement to acquire the product or services meeting the expressed needs; a product or services meeting the signed agreement, and finally a payment or other forms of compensation agreed on beforehand. An acquisition process in addition to company policies and procedure will have the following activities: 1. development of a plan, 2. preparation of a requisition, 3. communication of the requisition with potential suppliers, 4. Selection of a supplier, 5. negotiation of an agreement with supplier, 6. assessment of the execution of the agreement, 7. confirmation of the delivered product or services complies with agreement, and 8. make a payment or meet other agreed consideration to the supplier for the service or product (Défense Acquisition University Press, 2001).

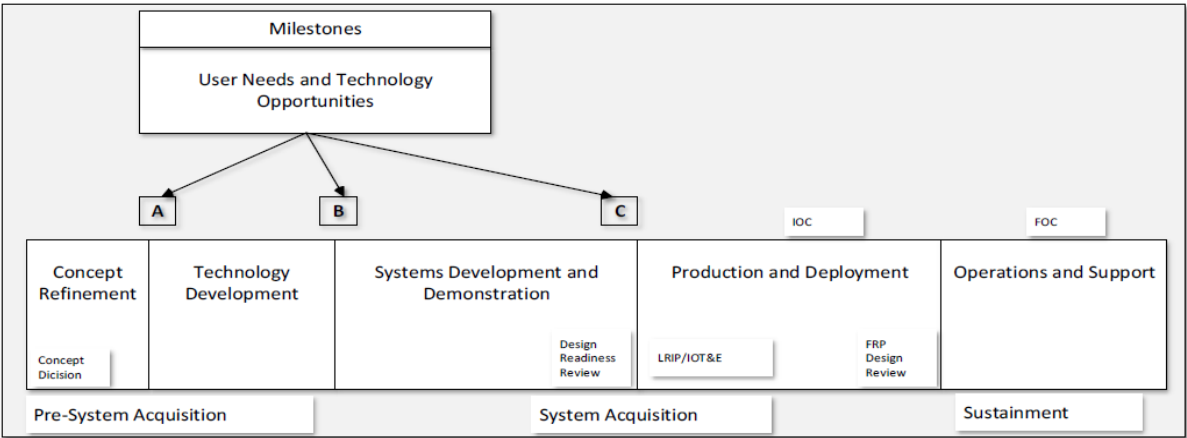


Figure 18: Acquisition lifecycle process

Source: Author adapted from (Défense Acquisition University Press, 2001)

The phases for the acquisition of a product or services according to different organizations are shown in Figure 20 below. Acquisition planning entails technical planning once there is a need for a product or a service. Requirements planning focuses on the definition of technical requirements which is informed by the different stakeholders’ expectations as well as technical requirements definition. Phase 3 to Phase 6 are contract activities, which may be internal to the organization or external depending on the situation.

The rubric shown in Figure 19 below will be used to rate the lifecycle processes going forward. It was modified to make it suitable for what is needed for bogie projects based on experience.

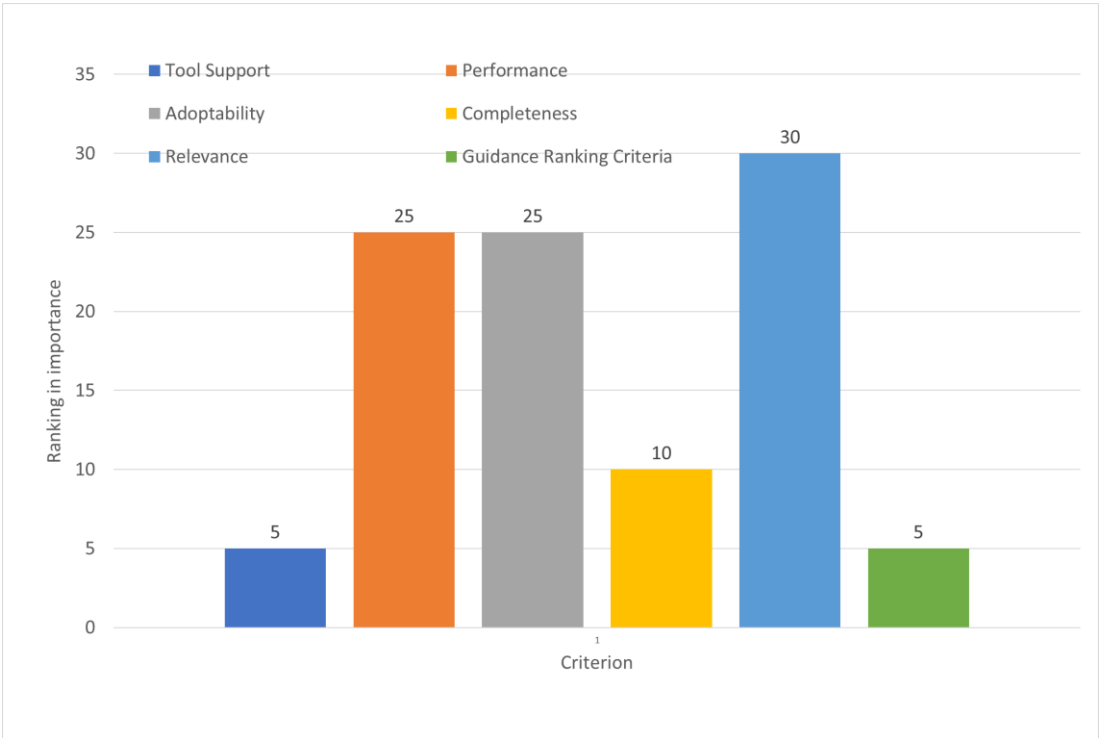


Figure 19: Lifecycle rating rubric

Source: Adapted from (Alghamdi, 2009)

Acquisition Lifecycles

	Phase 1: Material Solution Analysis						Phase 2: Technology Maturity and Risk Reduction.					Phase 3: Engineering and Manufacturing Development.					
	Analyze Requirements	Analysis of Alternatives	Develop Acquisition and Test Strategy.	Costs Estimation	Market Research	Risk Management	Mature Requirements	Systems Engineering	Competitive Prototypes	Mature Acquisition and Testing Strategy	Contract Preparation	Manage Program Backlogs	Release Planning Develop, Integrate, Test)	Manage Contract(s)	Contract Awards	Tract Metrics	Operations and Sustainment
Defense Acquisition Management System, May 22, 2009	Material Solution Analysis					Technology Development			Technology Maturity and Integration Risk Assessment. Competitive Prototyping		Engineering and Manufacturing Development		Engineering and Manufacturing			Operations and Support	
Acquisition Management and Support Services	Requirements		Pre-Award	Award	Post Award	Post Award	Requirements	Development							Support	Deployment	
GAO Analysis of MD 102/BAO -15- 292	Need				Analyze/Select				Obtain			Produce/ Deploy/ Support					
U.S Department of Health and Human Services	Form the Team		Define Mission Business Needs		Identify and Align Resources		Requirements Definition		Acquisition Strategy		Acquisition Planning			Performance Management			Compare Mission Requirements Mission Results
	Leadership Support	Build the Team	Assess Program Lifecycle/Risk	Considering Strategic Plans & Budget	Analyze Resources and Gaps	Internal/External Resources	Draft Requirements Roadmap	Consider Acquisition Forecasting	Business Strategy (Program/Project)	Acquisition Strategy/Risks	Execute Strategy	Implement Acquisition Plans	Award Contract(s)	Monitor Program Performance	Build & Manage Relationships	Manage Contract Performance	

Figure 20: Acquisition lifecycle process

Source: Author adapted from (NASA, 2007)

The acquisition lifecycle process chosen to be best suited in this case is the one developed by the US Department of Health and Human Services, (Billups, 2015) closely followed by the Acquisition in the Digital Age (AIDA) shown in Figure 20 above. A decision was made to use the one by US Department of Health and Human Services as it considers leadership support early on in the acquisition as part of the requirements. This is vital to ensure that, throughout the different phases of the acquisition, there will be support from decision makers. The rating is shown in Figure 21 below.

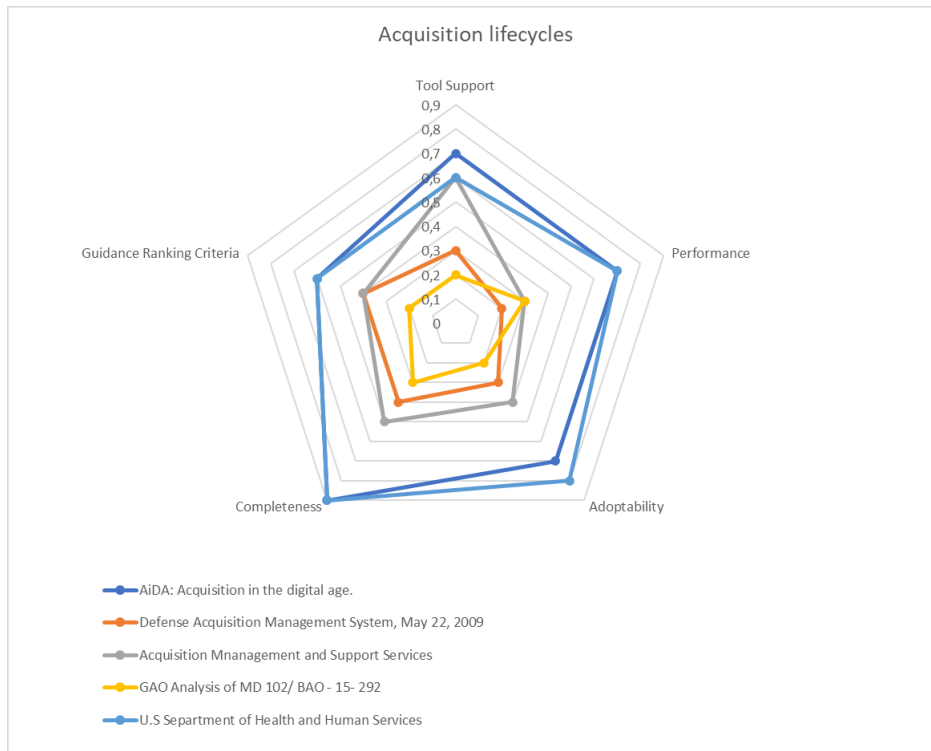


Figure 21: Acquisition lifecycle processes rating

Source: Author

2.3.2 Project Lifecycles Process

The project lifecycle process is a sequential essential process of project management and system engineering. It is about progressing from stake-to-stake, the decision gates, and other project timeline events (Forsberg, Mooz & Cotterman, 2005). (Project Management Institute, 2008) defines the project lifecycle as a collection of phases that are sequential and sometimes overlapping; their names and number are determined by the management and control needs of the organization or the organizations involved in the project, the nature of the project, and the field of application of the project. Project and project management happen in a complex environment that is broader than the project itself. Understanding this broader context ensures that the work is carried out in alignment with the goals of the enterprise and managed in accordance with the established practice methodologies of the organization. No matter the size and complexity of the project, the project cycle process can be mapped to the following four (4) phases: 1. starting project, 2. organizing and preparing, 3. carrying out the project work, and 4. closing the project (Project Management Institute, 2008). Project lifecycle processes for different institutions are shown in Figure 22 below.

Project Lifecycles

Projects Mind 1	Stage 0- Strategy	Stage 1 - Project Brief	Stage 2-Concept Design		Stage 3-Developed Design		Stage 4-Technical Design				Stage 4T- Tender		Stage 5 - Construction		Stage 6 - Handover & Close out			
	Gateway 0: Business Case	Gateway 1: Project Brief	Gateway 2: Concept Design		Gateway 3: Developed Design		Gateway 4: Technical Design				Gateway 4T: Tender		Gateway 5: Readiness for Service		Gateway 6: Post Construction Review			
Projects Mind 2	Requirements Analysis		System Design								Implementation			Testing	Deployment	Maintenance		
Information Technology Services	Identification		Initiation	Planning	Delivery (Execution, Monitoring & Control)										Closeout			
	1. Prioritization Criteria Worksheet.	2. Project Request Summary)	3. Project Charter	4. Planning Document , Project Schedules, Communication Plan)	5. Acceptance of Delivery						6. Approval to Proceed		Approval to Operate, Project Status		(Project Closeout Document)			
Project Estimating and Cost management	Conceptual Design				Evaluations & Approvals		Design				Installation and Checkout				Remove Old Equipment			Project Closeout
	System Requirements	Functional Analysis	Detailed Design	Resource Requirements	Engineering Evaluation	Management Approval	Requirements	Functional Analysis	Detailed Design	Resource Requirements	Procurement	Purchasing	Procedures	Installation	Modifications	Dismantle	Demolish	Remove

Figure 22: Project lifecycle processes for different organizations

Source: 1, Project Mind 1, 2. Project Mind 2, 3. Information Technology Services, 4. Project Estimating and cost management.

The project lifecycles processes above were rated based on the rubric in Figure 19. The chosen one is at the Project Estimating and Cost Management one.

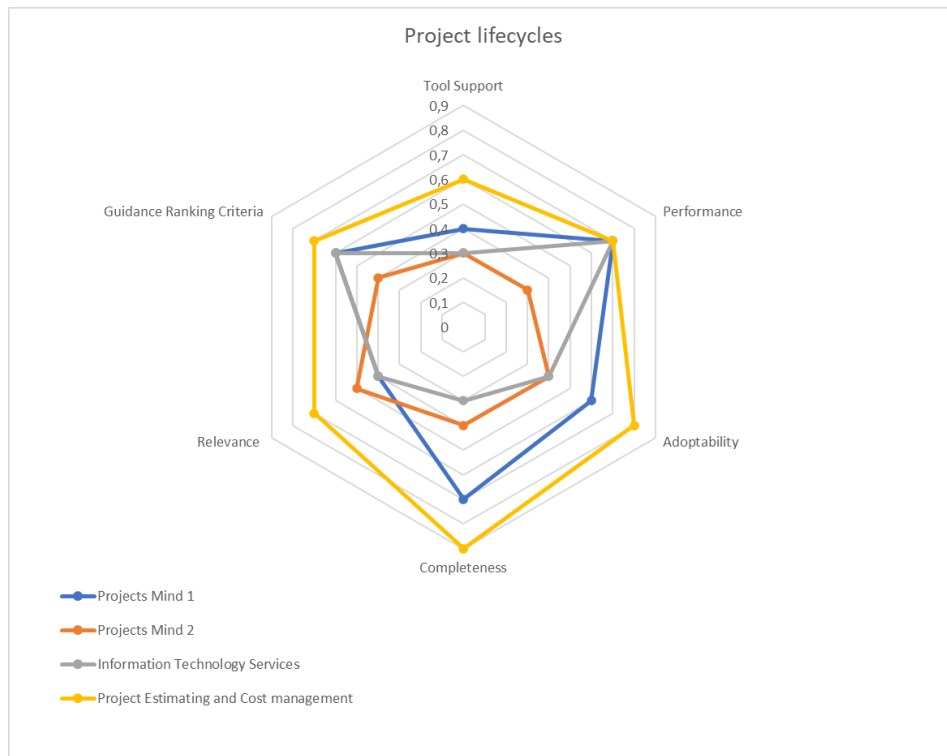


Figure 23: Project lifecycle processes rating

Source: Author

2.3.3 System Lifecycle Process

A system lifecycle process can be defined as a series of stages through which a system or any manufactured products go. Every man-made system passes through this process even if the lifecycle is not fully defined sometimes. In order to heed all impacts of the system, including the environmental impact of the SoI, the lifecycle of the system should not only consider development, production, utilization, and support stages but, early in the development process, should also consider retirement stage once decommissioning is done (INCOSE, 2015). A generic system lifecycle process has four (4) stages: 1. pre-acquisition, 2. acquisition phase, 3. utilization, and 4. retirement (Jone, 2009). Shown in Figure 24 below are different lifecycle processes from different institutions.

System Lifecycles

	Study Period				Implementation Period			Operations Period			
NASA	Formulation				Implementaion						
	<u>Pre-Phase A</u> Concept Studies	<u>Phase A</u> Concept Studies	<u>Phase B</u> Definition System Definition/Prelim Design		<u>Phase C</u> Design	<u>Phase D</u> Development	<u>Phase E</u> Operations		<u>Phase F</u> Disposal		
Defense Acquisition, Technology, and Logistics Lifecycles (DoD 5000.2)	Determination of Mission Need	Concept Refinement	Technical Developmet Phase		System Development and Demonstration Phase		Production and Deployment Phase	Operations and Support Phase (including Disposal)			
ISO 15288	Concept Stage				Development Stage			Production Phase	Utilization Stage ----- Support Stage	Retirement Stage	
Typical High-Tech Commercial Business	Product Requirements Phase	Product Definition Phase	Product Definition Phase		Product Development Phase	Engineer Model Phase	Internal Test Phase	External Test Phase	Production Phase	Manufacturing, Sales, and Support Phase	Disposal Phase
Visualizing Project Management, 3rd Edition, Cycle Template	User Requirements Definition Phase	Concept Definition Phase	System Specification Phase	Acquisition Planning Phase	Source Selection Phase	Development Phase		Verification Phase	Deployment or Production Phase	Operations/Maintenan ce or Sales/Support Phase	Deactivation and Disposal Phase

Figure 24: System lifecycle processes for different organizations

Source: 1. NASA, 2. DoD 5000,2; ISO 15288; Typical High-Tech Commercial Business, 5 The Essentials of Project Management, (Forsberg et al, 2005)

The above system lifecycle processes were rated to choose the most suitable one; the rating is shown in Figure 25 below. The lifecycle process developed by (Forsberg *et al*, 2005) was chosen due to its level of detail and adaptability. This lifecycle process is the last one on the list shown above.

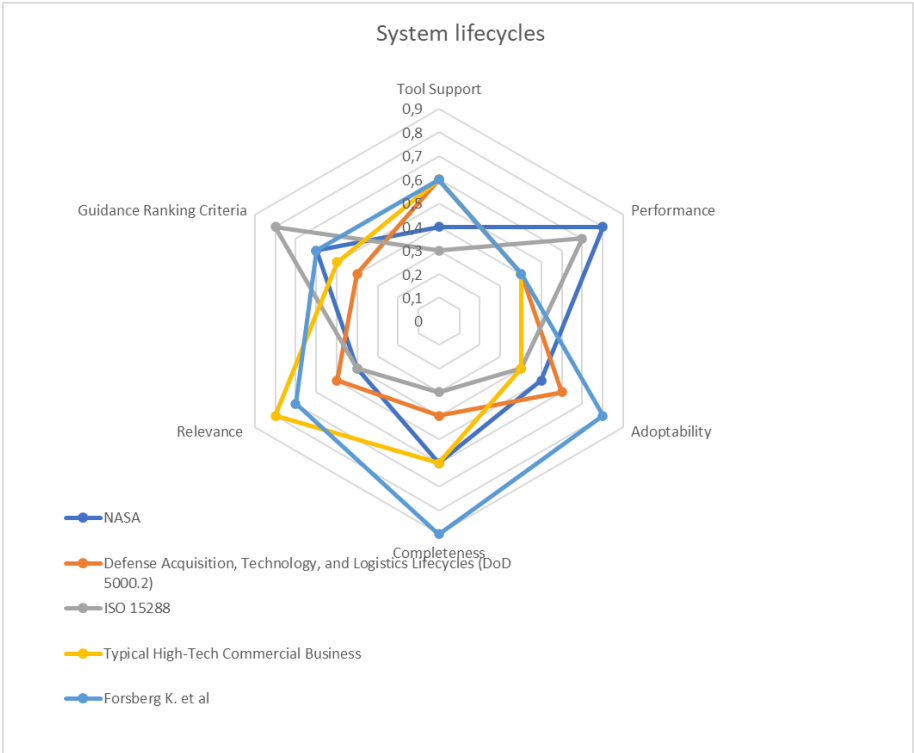


Figure 25: System lifecycle processes rating

Source: Author

2.3.4 Product Development Lifecycle

Any organization – regardless of its size, profits, or industry – will experience regular pressure to expand, innovate, or modify its services or product offering. New Product Development (NPD) is the core of an organization’s potential and innovation. Changes experienced in the market lead to changes in the specifications to be met by the new products, and existing knowledge is often inadequate to meet these requirements. Also, new products are necessary to have as they give organizations a competitive edge over others (Leenders, Van Engelen & Kratzer, 2003). The success of an organization has been proven to depend highly on its capability to come up with new products. In the 1970s, new products accounted for 20% of corporate profits; in the 1980s, this figure rose to 33%. In the 1990s, this figure rose to half of the profits (Slater, 1994). The challenge with new product development is the development process itself (Cengiz, Ayyildiz & Kirkbir, 2019). New products have shown a success rate at launch of less than 60% to 54.3% for the United Kingdom, 59% for the United States, 59.8% for Japan, 49% for Spain (Edgett, Shipley & Forbes, 1992). According to (Cengiz, Ayyildiz & Kirkbir, 2019), there are three (3) types of product developments: 1. innovative products, which aim to satisfy unsatisfied customer needs, 2. replacement products, which are significantly different from existing ones, and 3. imitative products; these will be new to the organization but not new to the customer. Shown in Figure 26 below are various product development lifecycle processes for different institutions

Product Development Lifecycle

Product Lifecycle Management (PLM) Software	Idea	Research			Development						Testing	Analysis	Introduction		
Product Management Lifecycle by	Ideation			Product Definition		Prototyping		Detailed Design			Validation/Testing		Commercialization		
	Idea generation	Capture Stakeholder narrative and explore ideas	Present ideas to steering committee	Define core functionality	Understand market size and revenue	Create Minimum Viable Product (MVP)	Update Business Plan	Refine Prototype	Detailed Product Design	Confirmation of Business Plan and GTM Plan	Validate the product in the customer's area of operation	Test the viability of the financials	Begin GTM Execution	Customer Success Involvement	Product Launched
Product Management Lifecycle by Project Focus	Innovation			Analysis		Development					Go-to-market		In-life	End-of-life	
	develop concepts	Proposal	Further explore	Validate need	Justify investment	Plan, Build, evaluate					Further testing and research	Prepare for the start-up	Ready for sale		Selling, quality management, & solving problems
Product Development Process by DANDY PEOPLE	Define the problem			Find solution				Deliver							
	Framing	Insights	Focus	Ideation		Prototype & test		Plan		Deliver			Evaluate		
	Impact goals, Project Hypotheses, Purpose	User interviews, Usability Testing	Personal and Roles	Design, 6 Thinking Hats		Rapid Prototyping	Usability Testing		User Scenarios	MVP	Visual design	Frontend Development	Backend Development	Usability testing	
Hannu Oja, Finland, International Conference of Engineering Design.	research				Development		Manufacturing			Use					
	Fuzzy front end	Technology push		Demand pull		Engineering	Applications	Parts, Assembly	Logistics	Installation	Service		Upgrade		Disposal

Figure 26: Product development lifecycle processes for different organizations

Source: Adapted from (Project Lifecycle Management; TC Gen; Project Focus; DANDY PEOPLE; Hannu Oja, ICED)

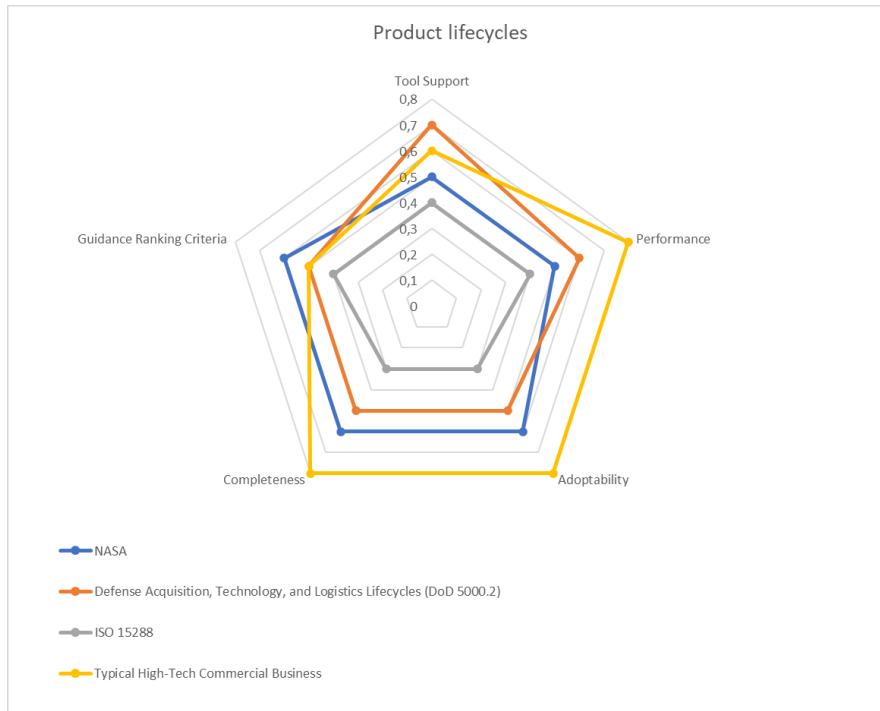


Figure 27: Product development lifecycle processes rating

Source: Author

2.4 Acquisition Strategy/Plan

Acquisition strategy/plan is defined as a comprehensive, integrated plan that identifies the acquisition approach and describes the business, technical, and support strategies that management will follow to manage program risks and meet program objectives. The purpose of the acquisition strategy is to define the work efforts related to each acquisition phase, important events during the acquisition program, reviews related to each phase, the awarding of contracts, activities related to testing, production lot/delivery quantities, and operational deployment objectives (SEBoK, 2020).

The creation of an acquisition strategy is a collaborative process that considers the product's lifecycle in its entirety. The efficiency of an acquisition strategy can be improved by lessons from the past. A good acquisition strategy can enhance the efficiency and effectiveness of the acquisition process.

The project manager together with procurement and legal office develop the project acquisition strategy or verify an existing one. The purpose of the strategy is to provide a business and technical outline for planning, directing, and managing a project and obtaining products and services via contracts (NASA, 2007).

Typical inclusions in the acquisition strategy are shown in Table 7 below.

Table 7: NASA's elements for the development of an acquisition strategy

Source: Adapted from (NASA, 2007)

Considerations	Elements
Objectives of the acquisition	<ul style="list-style-type: none"> - capabilities to be provided - major milestones
Acquisition approach	<ul style="list-style-type: none"> - single step launch - or evolutionary - using a single or multiple supplier - a competitive or sole source - lifecycle phases - system integration - Commercial-Off-the-Shelf (COTS) products
Business consideration	<ul style="list-style-type: none"> - limiting factors (Funding, schedule) - availability of assets and technologies - applicability of commercial items versus internal technical products developments
Risk management of acquired products or services	<ul style="list-style-type: none"> - major risks - risk sharing with suppliers
Contract types	<ul style="list-style-type: none"> - performance-based - level of effort - fixed-price - or cost reimbursable
Contract elements	<ul style="list-style-type: none"> - Incentives - performance parameters - rationale for decisions on contract types
Product support strategy	<ul style="list-style-type: none"> - oversight of delivered system - maintenance - and improvement

The information in the table above may be sourced from external companies, stakeholders, or future potential contractors using Request for Information (RFI).

2.5 Acquisition Processes

The end goal of an acquisition process is to obtain a product or service that meets the organization's needs and requirements. This is done through the successful implementation of process and reaching of the outcomes listed below (ISO/IEC 15288, 2007).

2.5.1 Acquisition Process Outcomes

For a successful acquisition process, the outcomes listed below must be met (ISO/IEC 15288, 2007):

- a. the establishment of a strategy for the acquisition,
- b. selection of a supplier,
- c. effective communication with the supplier and maintenance thereof,
- d. declaration of the justification for the selection of the supplier,

- e. establishment of an agreement to acquire a product or a service according to pre-defined acceptance criteria,
- f. a product or service meeting the acceptance criteria is accepted, and
- g. a payment or other pre-agreed on consideration is met by the acquirer.

2.5.2 Acquisition Process Activities

There is a list of activities to be completed by the acquirer in accordance with the acquirer's organizational policies and procedures with respect to the acquisition process. These activities are (ISO/IEC 15288, 2007):

- a. The establishment of a plan for how the acquisition will be conducted

This plan will depend on the product lifecycle model, a schedule, and its milestones as well as the selection criteria in a case where the supplier is external to the acquiring organization (ISO/IEC 15288, 2007).

- b. Preparation of a request for supply of a product or services

A definition of requirements shall be provided to one or more suppliers for the acquisition of a product or services. In a situation where the supplier is external to the acquiring organization, the acquirer can include with the request the business practices with which the supplier is expected to comply as well as the selection criteria (ISO/IEC 15288, 2007).

- c. Communicate the request for the supply of a product or services with the potential suppliers.

To achieve a harmonized or collective approach to common technical and commercial issues with an external supplier, the acquirer may include supply chain management partnering that exchanges information with related suppliers and acquirers (ISO/IEC 15288, 2007).

- d. Selection of a supplier

To ensure competitive solicitation, proposals to supply a product or services from potential suppliers are compared. In a situation where the proposal has extras not required by acquirer, according to the criteria, then the decision will be based on suitability once the proposals have been compared with each other and a preferred supplier chosen. A rating justification may be made available to each supplier to inform them why they were or were not chosen (ISO/IEC 15288, 2007).

- e. The negotiation of an agreement with the chosen supplier

Depending on the type of agreement between the parties involved, the type of contract entered into may vary from verbal understanding to a written contract. Based on the level of formality of the agreement entered into, there needs to be an establishment of the requirements, development and delivery milestones, verification, validation and acceptance conditions, exception handling procedures, change control procedures, and payment schedules. This will ensure that all parties involved understand the basis for executing the agreement. For the completion of the negotiation, the acquirer has to accept the terms of an agreement offered by the supplier (ISO/IEC 15288, 2007).

- f. Assessment of the execution of the agreement

There shall be confirmation that both parties are meeting their responsibilities as far as the agreement goes. There needs to be a regular monitoring and evaluation of the projected cost, performance, schedule risk, impact of undesirable outcomes to the organization. Once variations are deemed significant by any party, renegotiation is undertaken (ISO/IEC 15288, 2007).

g. Compliance of the delivered service or product with the agreement

Where exceptions arise during the conduct of the agreement or with the product delivered or service rendered, these are resolved according to the procedures established in the agreement (ISO/IEC 15288, 2007).

2.6 Acquisition for Retrofit

In order to prevent the system becoming obsolete after a given period of time, one can apply upgrades, which lower the risk with less investment, rather than develop a new system. These upgrades can sometimes add versatility and improve efficiency and performance. The term ‘retrofit’ is used to define this process (Pueo *et al.*, 2020). A bogie is considered a complex system due to the fact that it requires an arrangement of a number of related but various elements with convoluted relationships and interconnections (Wigmore, 2017). This process can be useful for bogies as they are very complex and expensive systems to develop.

Figure 28 and Table 8 show a generic process for conducting a retrofitting process and a generic process for undertaking modification of a mechanical system respectively.

Table 8: Elements and performance criteria

Source: (AustrianDEEWR, 2012)

ELEMENT	PERFORMANCE CRITERIA
1. Determine modification requirements.	1.1. Maintenance reports and system output information are analysed. 1.2. Defective components, subassemblies and design faults are identified. 1.3. Corrective action plan is developed.
2. Undertake standard modifications to mechanical systems and equipment	2.1. Modification options for overcoming parts failures and design faults are identified. 2.2. Failed components and sub-assembly replacements are selected from manufacturers' catalogue. 2.3. Modification designs are developed in conjunction with and approved by appropriate authority. 2.4. Modification is recoded according to standard operating procedures.
3. Evaluate modified mechanical system/equipment.	3.1 Alterations are evaluated for effectiveness and efficiency. 3.2 Effectiveness/efficiency is reported and recorded. 3.3. Results are checked against specifications. 3.4. Additional modification/changes, if required, are recommended.

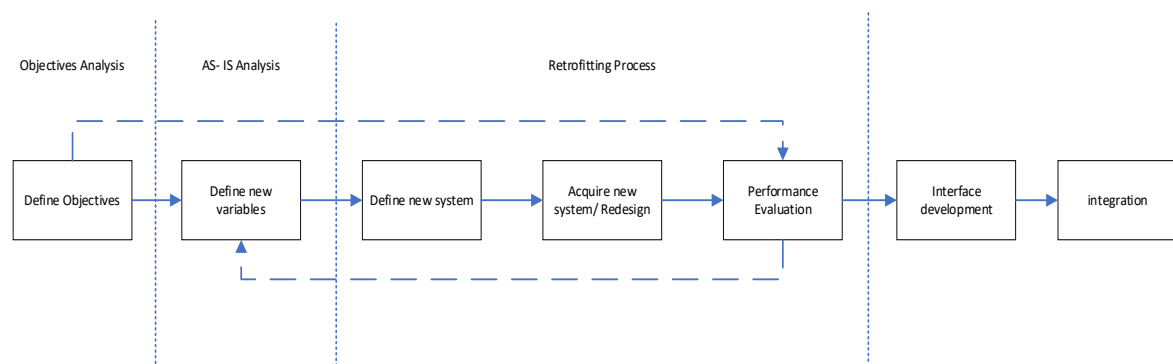


Figure 28: Generic retrofit process

Source: Adapted from (Carlo *et al.*, 2021)

2.7 Commercially Off the Shelf (COTS)

There are instances where a company needs to acquire a system off the shelf. There could be a number of reasons for doing this, such as lack of capacity internally to develop, strict timelines, and complexity of the requirements among others. In most cases, if an off-the-shelf product that meets the requirements is available and all stakeholders are satisfied with the plan, it is often more cost effective and a faster option.

When a company decides to go the COTS route, the following need to be considered (James, 2006):

- identification of supplier COTS capabilities,
- identification of unwanted functions, which are sometimes undocumented,
- possibility of reverse-engineering,
- recognition of the role of systems integrator and ownership of risk,
- parallel production and next version development processes,
- upgrades and obsolescence, and
- customer expectation management.

2.8 Principles of Acquisition Tenders and Contracts

One of the important principles in systems acquisition is acquisition tenders principles (Mo & Sinha, 2014). It is vital that proper procedure be followed when it comes to tenders as they are legally binding; not doing things right from the beginning can be costly in terms of time or finances.

Table 9: Principles of acquisition tenders

Source: Adapted from (Mo & Sinha, 2014)

Aspect	Description
Fairness	No tenderer must be given an unfair advantage or be disadvantaged. This means that all tenderers are given the same information and afforded an equal opportunity to succeed.
Confidentiality	Appropriate measures must be taken to protect the confidentiality of tenders and information related to tender evaluation. Internal distribution of information should be on a strictly need-to-know basis. Tenders should be treated as commercial-in-confidence.
Tenderer communications	All formal and informal communications with tenderers throughout the procurement process should be channelled through a single point of contact. A written record should be kept of all oral and written communications.
Tenderer classification	Clarification should be sought where information contained in a tender is unclear or open to different interpretation and is potentially relevant to the final decision. Clarification can be sought orally or in written format; in any case, an accurate written record must be kept of all questions and their answers. When tenderers respond to clarification questions, they must not be allowed to revise or enhance their original offer.
Probity	All officers involved with tender evaluation must practise a standard of probity and fair dealing, including ensuring an absence of bias or favouritism throughout the process and promptly declaring and managing any conflict of interest.
Documentation	A permanent and easy-to-follow audit trail must be maintained for all procurements. All key steps and decisions must be promptly and accurately documented in a logical sequence, using clear and concise language to ensure that the process can withstand challenge and external scrutiny.

Many project failures stem from breakdown in the customer-supplier relationship. Projects incur more risk when those involved in the process take the perspective of ‘winners vs losers’. A collaborative approach is one that pursues a shared-risk-reward relationship, where all sides win. (Project Management Institute, 2017). Useful contracting techniques are listed in Table 10 below.

Table 10: Useful contracting techniques

Source: Adapted from (Project Management Institute, 2017)

Technique	Description
Multi-tiered structure	Instead of formalizing an entire contract relationship in a single document, project parties can achieve more flexibility by describing different aspects in different documents. Mostly fixed items (e.g. warranties, arbitration) can be locked in a master agreement. Meanwhile, all parties list all items subject to change (e.g. service rate, product descriptions) in a schedule of services. The contract can reference them in the master service agreement. Lastly, more dynamics items such as project scope, schedule, and budget can be formalized in a lightweight statement of work. Isolating the more changing elements such as a contract into a single document simplifies modifications and thus flexibility.
Emphasize value delivered	Vendor relationships are often governed by fixed milestones or ‘phase gates’ that are focused on intermediate artefacts as opposed to a full deliverable of incremental business value. Often the improvement of the product using feedback is limited by these controls. When milestone and payment terms are structured based on value-driven deliverables, the project’s agility is enhanced.
Fixed-price increments	Instead of locking the entire project scope and budget into one agreement, a project can be broken down into micro deliverables. This allows the customer to have more control of how the money is spent. The supplier has more control over the financial risk and avoids mistakes such as over-commitment to a single feature or deliverable.
Not to exceed time and material	Sometimes customers incur unwanted risk from traditional time and material approach. The alternative is to limit the overall budget to a fixed amount. The customer has more freedom to incorporate new ideas and innovation into the project, which were not in the original plan. Customers will have to manage to a given capacity, replacing original work with new work to incorporate new ideas. Closer to the allocated time, work will have to be monitored and, if deemed helpful, contingency hours could be planned into the maximum budgeted.
Graduated time and materials	A shared financial risk is another alternative that can be considered. The supplier is rewarded with a higher hourly rate when delivery is earlier than the contracted deadline. If the supplier delivered later than the agreed deadline, they suffer the penalty of a reduced rate.
Early cancellation option	Where the supplier delivers sufficient value with only half of the scope completed, the customer should not be bound to pay the remaining half if they no longer need it. A contractor can instead offer the customer to buy the remainder of the project for a cancellation fee. In this way, the customer limits the budget exposure and the supplier earns revenue for services that are no longer required.
Dynamic scope option	When projects have a fixed budget, a supplier may offer the customer the option to vary the project scope at specified points in the project. This will allow the customer to adjust the features to fit the capacity if needed.
Team augmentation	Suppliers’ services can be directly incorporated into the customer’s organization for the most collaborative contracting approach. This method of funding teams instead of a scope preserves customers strategic discretion on what work should actually be done.

During the early stages of contracting, a system engineering approach may be used to identify stakeholders and compiling contracts. Figure 29 below shows the collaborative approach needed from stakeholders for a contracting process.

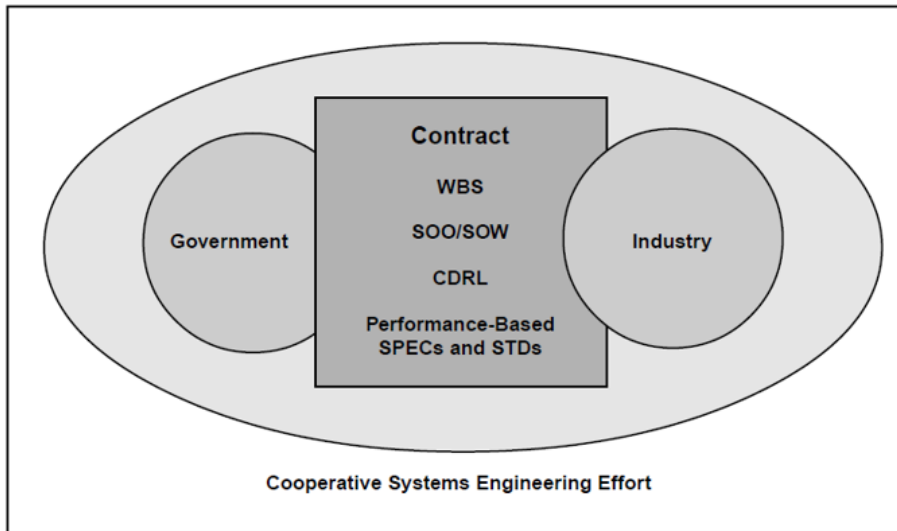


Figure 29: Contracting process stakeholders.

Source: (Défense Acquisition University Press, 2001)

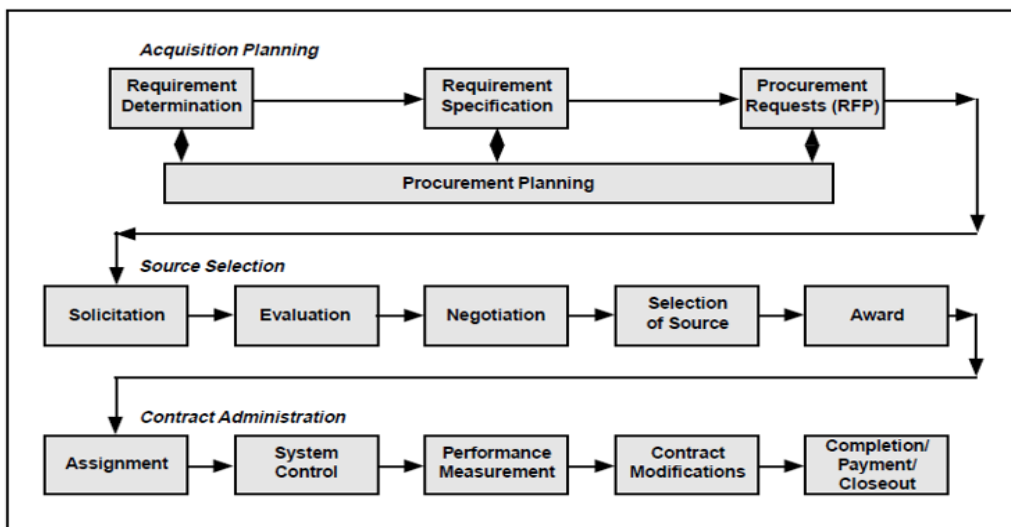


Figure 30: Contracting process

Source: (Défense Acquisition University Press, 2001)

2.9 Frameworks

According to the *Collin's Dictionary*, a framework is a particular set of rules, ideas, or beliefs that are used to deal with problems or to decide what to do (Collins Harper, 2022). The attributes of a framework are summarized in Table 11 below. Essentially, a framework is a flexible structure that can be altered and used to fit the system for a project (Wood, 2013).

Table 11: Attributes of a framework

Source: Adapted from (Wood, 2013)

Attribute	Framework
Structured	Flexible (allows for adaptation and modification)
Standards	Helps decide what to do (Not detailed)
Consistent outcome predictability	Low
Defect resistant	Low
Can embed other methodologies	Yes
Can be tailored to environment and culture	Yes
Level of expertise needed to effectively use	Yes
Effort level to implement	High
Ease of governance and compliance oversight	Medium to high
Support rapid planning	High
Provides metrics for estimating	Medium
Provides phases and steps	Yes
Provides underlying principles, philosophy, and rationales	Maybe

2.9.1 Enterprise Architecture

The purpose of an enterprise architecture is to serve as a conceptual blueprint that defines the operations and structure of an organization or an enterprise (Alexander, 2020). An enterprise is defined as a venture undertaken for commercial gain. An enterprise can sometimes be referred to as a company or a firm by extension (Collins Harper, 2022). An architecture is defined as a structure of components, their relationship, and the principles and guidelines governing their design and evolution over time (DoD, 2007).

An enterprise architecture is meant to determine how an organization can achieve its current and future objectives effectively through the practice of analyzing, planning, designing, and finally implementing the analysis for the enterprise for which it was developed. The use of enterprise architecture saw a rise in the 1980s as there was a rapid technology growth and companies had to respond with a revised business strategy in order to transition seamlessly. Enterprise architecture will vary with each organization, and within an organization, they may vary in different parts of an organization (Alexander, 2020).

Enterprise architecture within a business will assist in articulating the challenges and business risks while helping different departments of a business understand the broader business model. Having a common understanding of the broader business will help unify and coordinate departmental processes in an organization. Enterprise architecture aims to promote team alignment and standardization through common environments across teams and organizations (Alexander, 2020).

2.9.2 Architecture Framework Models and Methodologies

Enterprise architectures are typically implemented as frameworks with the choice of the framework chosen based on how well it suits the organization (Alexander, 2020). Below are frameworks commonly used in industries.

2.9.2.1 The Zachman Framework

This framework covers six architectural points as well as six primary stakeholders that assist in defining and standardizing IT architecture components (Alexander, 2020). The Zachman Framework provides a descriptive, holistic representation of the enterprise to assist in providing insights and understanding

(Gerber & Roux, 2020). John Zachman described the Zachman Framework for Enterprise Architecture (ZFEA) as a logical, comprehensive structure for classifying and organizing the descriptive representations of an enterprise that are significant to the management of the enterprise as well as to the enterprise’s systems, manual and automated (Gerber & Roux, 2020). According to Zachman, different disciplines and the manufacturing processes contributed to the ZFEA. The ZFEA was made well known by the breakthrough of the realization that there are different perspectives relevant to the product that exist, which then Zachman applied to the enterprise (Gerber & Roux, 2020). The ZFEA was designed after noticing the various designed artefacts could be classified according to interrogatives, namely, *What? How? Where? When? Why?* These make up the columns of Figure 31 below (Gerber & Roux, 2020). The rows capture the specific audience perspectives and transformation. This makes the ZFEA a 6 X 6 two-dimensional schema model that represents the design of a descriptive representation of an enterprise (Gerber & Roux, 2020).







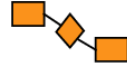
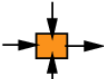
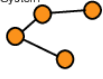
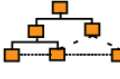


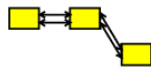
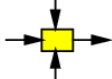
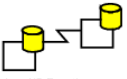
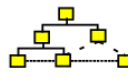


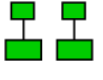











	DATA <i>What</i>	FUNCTION <i>How</i>	NETWORK <i>Where</i>	PEOPLE <i>Who</i>	TIME <i>When</i>	MOTIVATION <i>Why</i>
SCOPE (CONTEXTUAL) <i>Planner</i>	List of Things Important to the Business  ENTITY = Class of Business Thing	List of Processes the Business Performs  Function = Class of Business Process	List of Locations in which the Business Operates  Node = Major Business Location	List of Organizations Important to the Business  People = Major Organizations	List of Events Significant to the Business  Time = Major Business Event	List of Business Goals/Strat Critical Success Factor  Ends/Means=Major Bus. Goal/
ENTERPRISE MODEL (CONCEPTUAL) <i>Owner</i>	e.g. Semantic Model  Ent = Business Entity Rein = Business Relationship	e.g. Business Process Model  Proc. = Business Process I/O = Business Resources	e.g. Business Logistics System  Node = Business Location Link = Business Linkage	e.g. Work Flow Model  People = Organization Unit Work = Work Product	e.g. Master Schedule  Time = Business Event Cycle = Business Cycle	e.g. Business Plan  End = Business Objective Means = Business Strategy
SYSTEM MODEL (LOGICAL) <i>Designer</i>	e.g. Logical Data Model  Ent = Data Entity Rein = Data Relationship	e.g. Application Architecture  Proc. = Application Function I/O = User Views	e.g. Distributed System Architecture  Node = I/S Function (Processor, Storage, etc.) Link = Line Characteristics	e.g. Human Interface Architecture  People = Role Work = Deliverable	e.g. Processing Structure  Time = System Event Cycle = Processing Cycle	e.g. Business Rule Model  End = Structural Assertion Means = Action Assertion
TECHNOLOGY MODEL (PHYSICAL) <i>Builder</i>	e.g. Physical Data Model  Ent = Segment/Table/etc. Rein = Pointer/Key/etc.	e.g. System Design  Proc. = Computer Function I/O = Data Elements/Sets	e.g. Technology Architecture  Node = Hardware/System Software Link = Line Specifications	e.g. Presentation Architecture  People = User Work = Screen Format	e.g. Control Structure  Time = Execute Cycle = Component Cycle	e.g. Rule Design  End = Condition Means = Action
DETAILED REPRESENTATIONS (OUT-OF-CONTEXT) <i>Sub-Contractor</i>	e.g. Data Definition  Ent = Field Rein = Address	e.g. Program  Proc. = Language Stmt I/O = Control Block	e.g. Network Architecture  Node = Addresses Link = Protocols	e.g. Security Architecture  People = Identity Work = Job	e.g. Timing Definition  Time = Interrupt Cycle = Machine Cycle	e.g. Rule Specification  End = Sub-condition Means = Step
FUNCTIONING ENTERPRISE	e.g. DATA	e.g. FUNCTION	e.g. NETWORK	e.g. ORGANIZATION	e.g. SCHEDULE	e.g. STRATEGY

Figure 31: The Zachman Framework for Enterprise Architecture

Source: (Hattingh et al., 2020)

There are seven (7) rules associated with the ZFEA, and they are as follows (Hattingh *et al.*, 2020):

Table 12: The seven rules of ZFEA

Source: Author adapted from (Hattingh *et al.*, 2020)

Rule #	Description
1	Columns have no order.
2	Each column has a simple basic model.
3	The basic model of each column is unique.
4	Each row represents a distinct view.
5	Each cell is unique.
6	Combining the cells in one row forms a complete description from that view.
7	The logic is recursive.

2.9.2.2 Ministry of Défense Architecture (MoDAF)

The British Ministry of Defence Architectural Framework (MoDAF) is an architectural framework that enables the standardization of conducting Enterprise Architecture. MoDAF was developed by the UK Ministry of Defence to support planning and change management (Caruso *et al.*, 2010). It does this by simplifying complex issues through capturing information in a rigorous, coherent, and comprehensive way. MoDAF is an internationally recognized architectural framework. A conclusive set of rules and templates, which are referred to as ‘views’ are provided; when these views are completed, they provide a view of the business being investigated through the use of various charts, graphs, and text. A viewpoint on the business is offered by each of the different views in order to support different stakeholder needs or the area of interest. There are seven (7) categories that make up the views (Caruso *et al.*, 2010).

Table 13: The seven different categories that make up the views of the MoDAF

Source: Author adapted from (Caruso *et al.*, 2010)

View Category	Abbreviation	Description
All Views	(AV)	These views extend all the views by providing context, summary, or information at the overview level.
Strategic Views	(StVs)	These are used to define the desired outcomes or goals of the organization and the capabilities required to achieve the set goals.
Operational Views	(OVs)	These are used to describe the tasks and activities, operational elements, and information exchanges required to conduct business and operational activities.
Service-Oriented Views	(SOVs)	These are used to describe the services required to support the tasks and activities described in the Operational Views.
Systems Views	(SVs)	These views are used to describe what happens when the Operational and Service-Oriented Views are implemented, defining the solution.
Acquisition Views	(AcVs)	These views are used to describe what is needed and how long the projects that will deliver the solution will take.
Technical Views	(TVs)	Applicable standards, rules, policy, and guidance are contained in the Technical Views category.

A summary of the content of the architecture and any related term/characters/abbreviations used are provided by All Views (AVs) (Caruso *et al*, 2010).

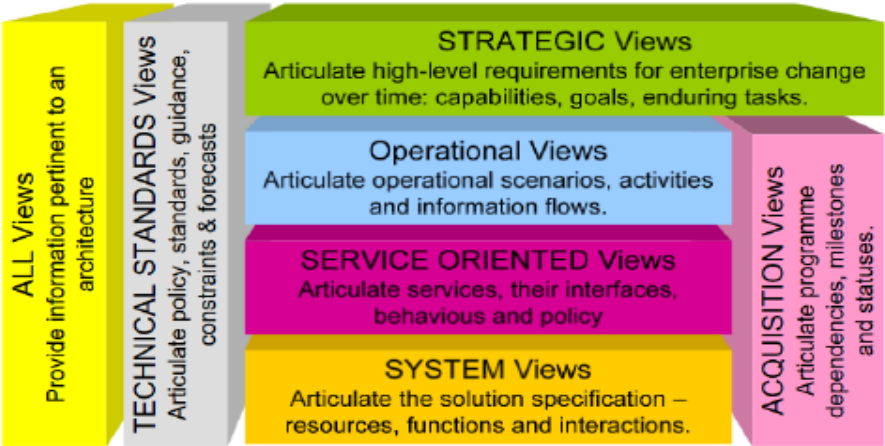


Figure 32: MODAF v1.2 views

Source: (Caruso, Jakova and Varrone, 2010)

2.9.2.3 Department of Défense Architecture Framework (DoDAF)

To comply with law, the Department of Defence (DoD) is required to implement architectures, but more importantly, from a practical perspective, experience has shown that the management of large organizations that employ sophisticated systems and technologies needed to achieve their missions require a structured, repeatable method for evaluating their use of investments and alternative sources of investments as well as to achieve their missions (DoD, 2007). Effective implementation of organizational change, the creation of new systems, and the deployment of new technologies can be achieved through the implementation of DoD Architecture Framework (DoDAF) to develop architectures. The comparison of architecture descriptions across programs, mission areas, and the entire enterprise is enabled by the use of DoDAF. DoDAF is also useful in supporting the decision-making processes (DoD, 2007).

The evolution of the DoDAF started in 1996 in response to the Clinger-Cohen Act to define and develop a better means and process for ensuring that the Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (CCCISR) capabilities are interoperable and meet the needs of the war fighter. The latest DoDAF v2.0 is still being scoped to include further guidance on planning, development, managing, maintenance, and governing architecture through a coherent semantic and structured metamodel. This version of the DoDAF is ‘data-centric’ and facilitates the use of architecture by a wider variety of decision makers and uses additional information on federation to improve the enterprise decisions (DoD, 2007).

A timeline of the evolution of the DoDAF is shown in the Figure 33 below.

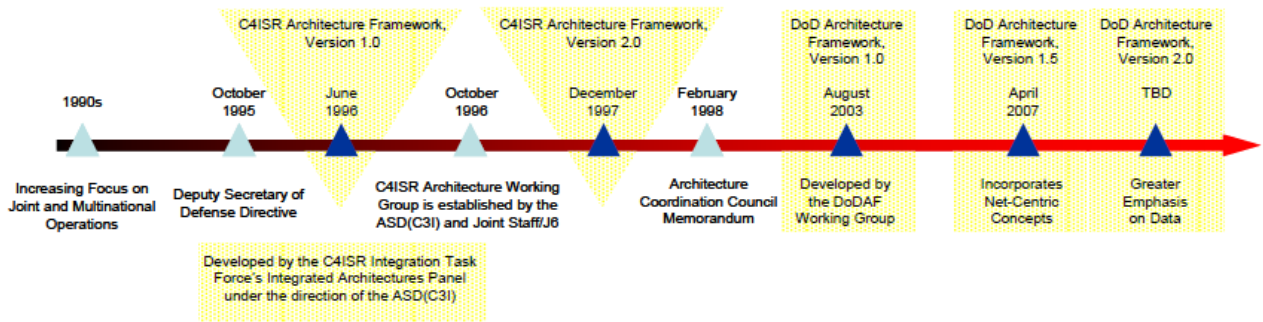


Figure 33: The evolution of the DoDAF.

Source: from (DoD, 2007)

The viewpoints of the DoDAF are shown graphically in Figure 34 below.

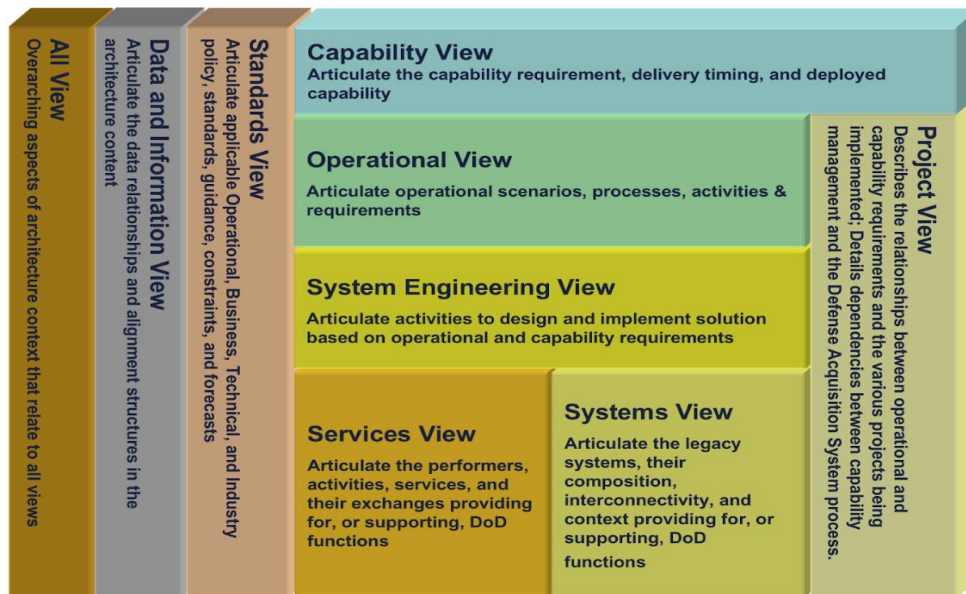


Figure 34: DoDAF version 2.02 Architecture Viewpoints

Source: from (Bellman, 2018)

2.9.2.4 The Open Group Architecture Framework (TOGAF)

The Open Group Architecture Framework (TOGAF) was developed by the Open Group to provide access to integrated information within and among enterprises, based on open standards and global interoperability. It was developed and made free to everyone (Caruso *et al*, 2010). TOGAF is similar to MoDAF in that it seeks to help organizations produce well-integrated solutions, clearly defines interfaces, reduces complexity, and better manages technology. Shown graphically below is a model of the TOGAF (Caruso *et al*, 2010).

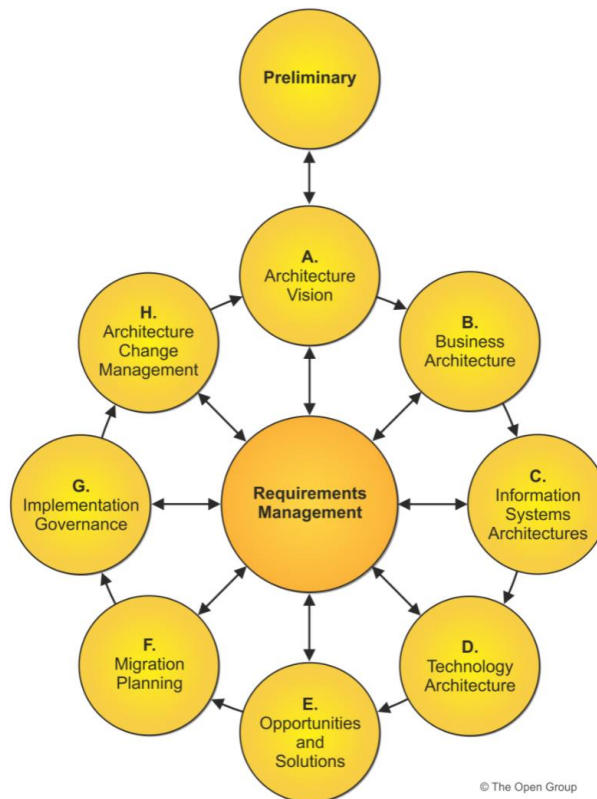


Figure 35: TOGAF Model

Source: (Caruso et al, 2010)

2.9.3 Framework Selection

The four considered frameworks can be further categorized into two main types: System-of-Systems (SoS) Architecture and Enterprise Architecture Frameworks (EAF). The Zachman Architecture Framework and the TOGAF are enterprise architecture methods as they focus more on the business and the enterprise aspects of a large enterprise. The MoDAF and DoDAF, in contrast, are SoS Architecture Frameworks as they tackle the technical aspects of a system through the use of viewpoints that influence a specific system (Alghamdi, 2009).

The research for this paper focuses on the acquisition of a SoS, and it is on this basis that a choice for the development of a framework for this research is made between MoDAF and DoDAF.

Viewpoint	Description	MODAF	DODAF
All Viewpoint (AV)	Extends all views by providing context, summary, or overview-level information	✓	✓
Operational Viewpoint (OV)	Shows what is going on in the real world that is to be supported or enabled by systems represented in architecture	✓	✓
Systems View (SV)	Describes existing and future systems	✓	✓
Technical Standards View (TV)	Lists standard (commercial off-the-shelf, government off-the-shelf system parts or components	✓	✓
Strategic Viewpoint (StV)	Overall vision of the organization to support military operations	✓	✗
Acquisition Viewpoint (AcV)	Shows how projects and capabilities are dependent on one another across DLOD	✓	✗
Service Oriented Viewpoint (SOV)	Describes the services required to support the processed in OV	✓	✗

Figure 36: Graphical representation of the key differences between MoDAF and DoDAF

Source: (Caruso et al, 2010)

2.9.4 Acquisition of Bogie Framework Viewpoints

To develop the framework for the acquisition of bogies for TE PD, MoDAF and DoDAF architecture frameworks were modified to pick viewpoints that are relevant to bogies; they were then combined to show the viewpoints in Figure 37 below.

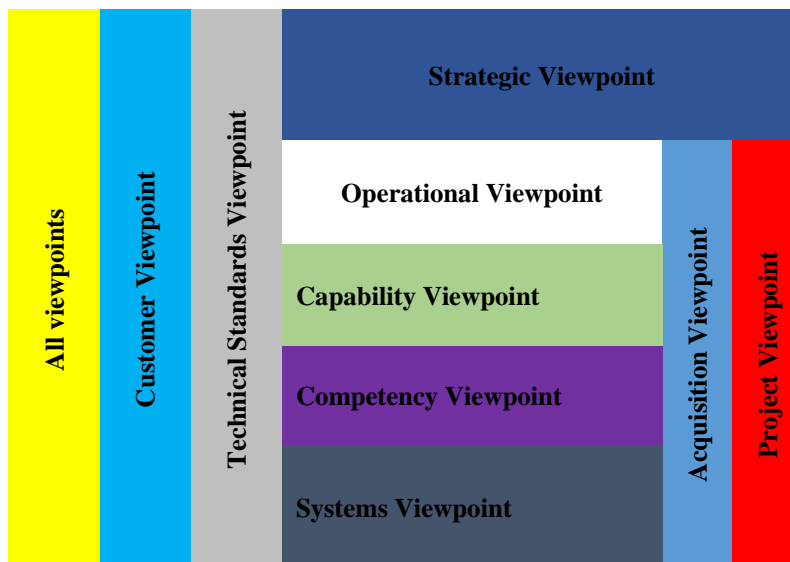


Figure 37: Viewpoints for a systems framework for the acquisition of bogies in TE PD

Source: Author adapted from (Caruso et al, 2010)

2.10 Systems Engineering

This section highlights the impact of systems engineering on projects' success and covers systems engineering topics that are relevant to the research to incorporate into the framework.

2.10.1 Systems Engineering Capacity and Project Performance

There are two main approaches to developing a system: bottom-up and top-down. In the latter, the process ends with system elements as functional entities, and their physical realizability is not guaranteed. During this process, requirements are always satisfied at every step of the process since it is an inherent part of the process. In the bottom-up approach, known elements assure physical realization but no assurance of satisfaction of requirements (Blanchard & Fabrycky, 2014). The performance of projects has improved with the introduction of systems engineering principles to the processes. 15% of projects with lower systems engineering capacity show higher performance while 56% of projects with higher systems engineering capacity show higher performance. The data also shows a reduction in lower performance of projects as projects with lower systems engineering capacity has 39% of its projects in the lower performing category when compared to the 31% of projects with higher systems engineering capacity. There is a significant increase in higher project performance for projects with a higher implementation of systems engineering (Elm *et al.*, 2008). The data is shown in Figure 38 below.

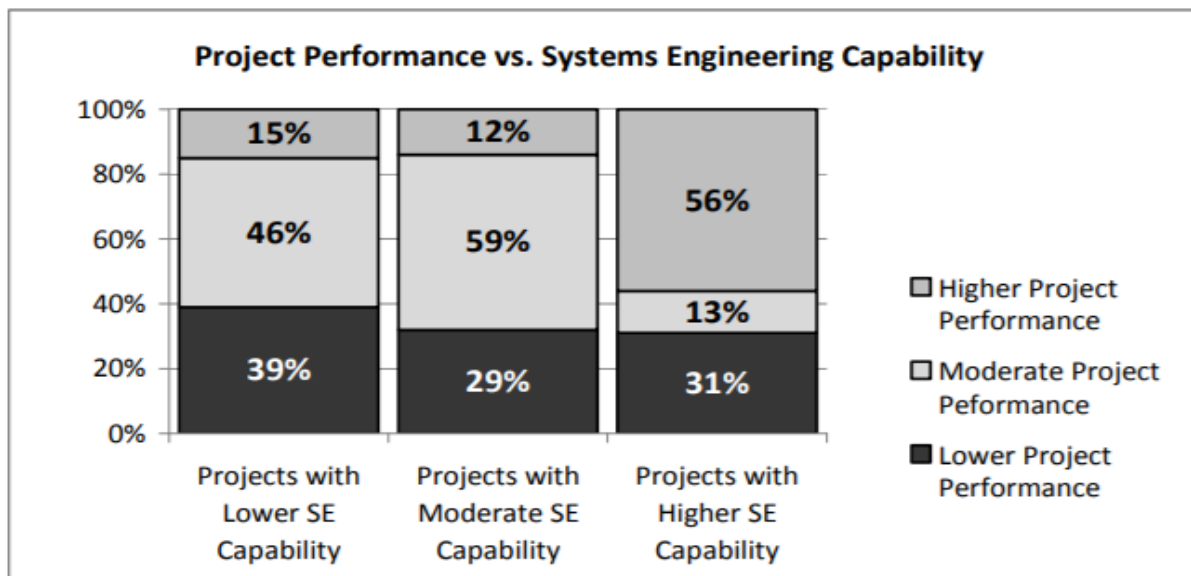


Figure 38: Systems engineering capacity vs project performance

Source: From (Elm *et al.*, 2008)

2.10.2 Systems Engineering Process

A summary of a high-level framework of the activities and principles from elements of systems approach is shown in Figure 39 below. The term *systems approach* is used to describe a systems-thinking approach to solving a problem. This is because the approach goes further than the boundary of the SoI in seeking a solution. This approach uses systems science as well as concepts inherent in the engineering problem-solving in a holistic system's view that considers the larger context of the systems including, engineering and operational requirements, stakeholders, and the system's entire lifecycle (SEBoK, 2020). For a system to be successful, systems thinking should not only be applied to the system itself and its context but should be applied in considering how the work will be done, the team doing the work, and the enterprise (SEBoK, 2020).

Essentially, all three systems competencies (systems thinking, holistic lifecycle view, and systems engineering management) are needed for the successful execution of projects.

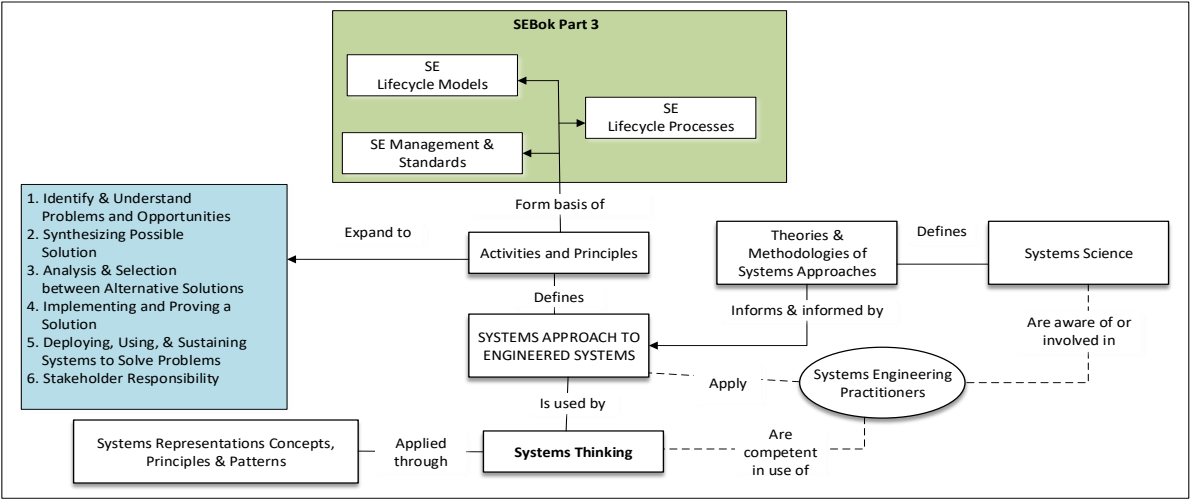


Figure 39: Systems engineering and systems approach

Source: adapted from (SEBoK, 2020)

Systems engineering processes can be applied at any level in the hierarchy of a systems structure, with a selected few being applicable throughout the lifecycle of the system to manage and perform the stages of the system’s lifecycle. These processes require the involvement of all stakeholders for them to be successful (ISO/IEC 15288, 2007).

The processes are in four main categories: agreement processes, enterprises processes, project processes, and technical processes. These processes are shown in Figure 40 below.

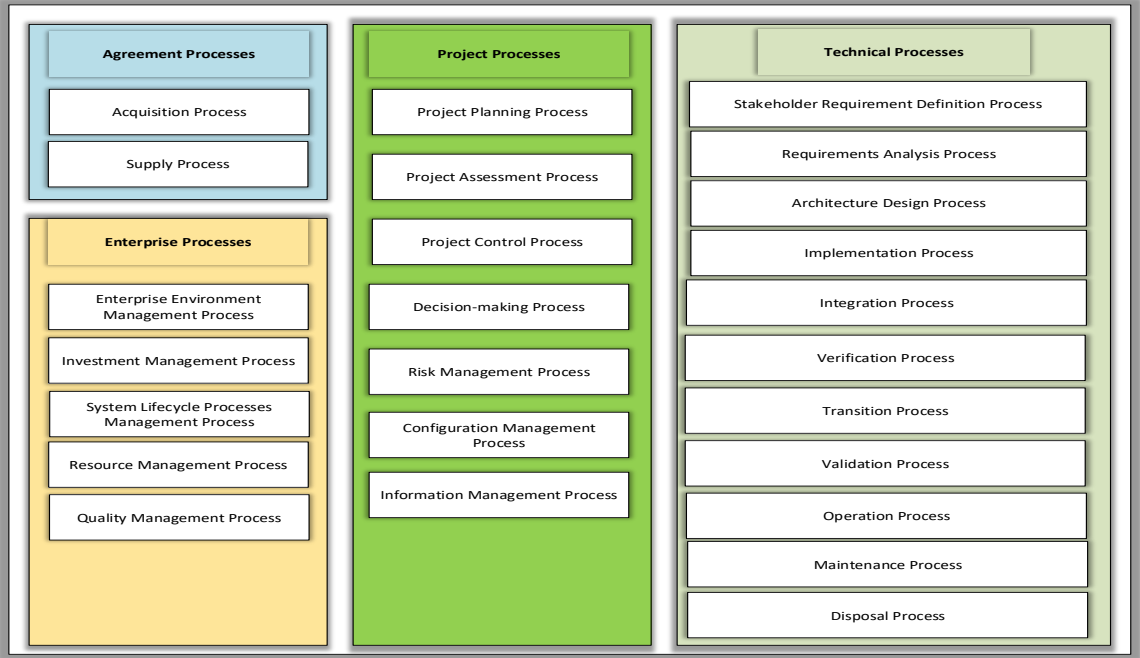


Figure 40: System processes

Source: author adapted from (ISO/IEC 15288, 2007)

Agreement Processes

The agreement process provides means that are required between two parties to establish an agreement. When the acquisition process is used, it provides the means necessary for doing business with a partner to develop products to be used in an operational system. When the supply process is used, it provides means for conducting a project that delivers a product or service to an acquirer (ISO/IEC 15288, 2007). Regardless of the bogie acquisition strategy opted for, agreements will be part of the process and will need to be carefully considered and planned for.

Enterprise Processes

These processes enable an enterprise to acquire and supply products and services that they are able to develop through initiation, support, and control of projects. Resources and infrastructure are necessary inputs for the success of the projects and enable the organization to satisfy its objectives and establish agreements (ISO/IEC 15288, 2007). Processes that enable TE PD to deliver bogies and rolling stock will need to be identified and put to use to acquire operations ready and capable bogies.

Project Processes

Project plans are established during these processes and are used to measure actual achievements and progress of projects as well as to control the execution of the project to ensure fulfilment. These processes may be applied at any phase of the lifecycle and at any level of the hierarchy of the project. The level of risk and complexity associated with the project will determine the level of rigour and formality with which these processes are applied (ISO/IEC 15288, 2007).

Technical Processes

Here the requirements for a system that are transformed into an effective product are defined. The requirements allow for the reproduction of the product when necessary, to use the product to provide the required services, to sustain the provision of the services, and to dispose of the product at the end of life. These processes enable the organization and the project function to deliver an optimum product and reduce risk that comes from the technical decisions made and actions (ISO/IEC 15288, 2007).

2.10.3 Systems Lifecycle vs Project Lifecycle

TE has, since its inception, focused on providing maintenance services to PRASA and TFR. As it aligns itself with its new strategy of strengthening its advanced manufacturing business as well as being an OEM of all rolling stock, the traditional Project Lifecycle Process has to be revised to account for the increased risk of developing products that are new to the organization. Figure 41 below shows Transnet's Project Lifecycle Process (PLP), shown in red rectangular box, relative to the system lifecycle (Shaw *et al.*, 2014).

The PLP developed by Transnet Capital Projects is better suited for major infrastructure projects that are worth \$15 million or more. The PLP is project focused while System Lifecycle (SLP) focuses on the system domain. The PLP is deficient in its technical processes and does not focus adequately on the requirements in the early stages of the project (Transnet Capital Projects, 2008; Mabusela, 2020).

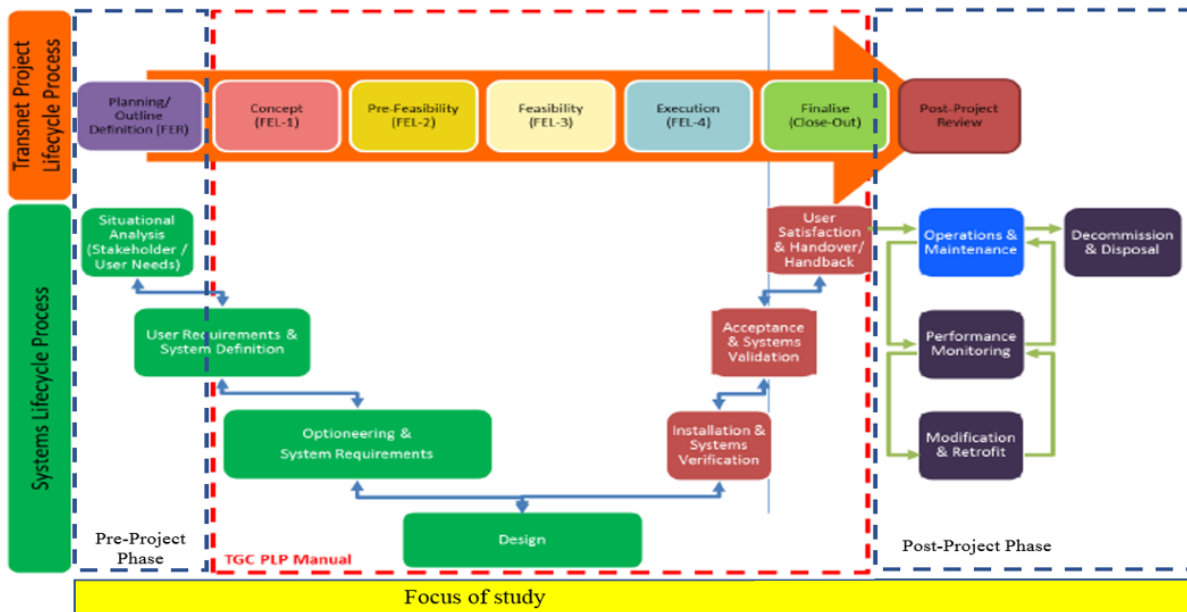


Figure 41: Systems lifecycle process, Transnet’s PLP, and research focus area

Source: Author adapted from (Madzibane, 2018; TCSE, 2018)

In order to be an OEM, an organization needs to develop its new systems from research done. These types of projects have a higher level on uncertainty and high level of risk (Youker, 2017). In order to have an effective and successful transition from being mainly maintenance strong to being an OEM, TE and TE PD in particular need to adapt its product development processes as shown in Table 14 below.

Table 14: Maintenance Organization vs OEM Organization

Source: Author (Mabusela, 2020)

Characteristics	Maintenance Organization	OEM Organization
Purpose	Responsibility varies from one organisation to another but typically aims to keep assets in a good and safe condition for operation.	Design, develop and certification of new products. Provision of full-life support
Material management	Can plan for spare parts and material pre-order.	Dependent on design, cannot be pre-ordered.
Typical organisational HR structure	A larger number of craft workers than managers.	Larger middle management due to the presence of specialists.
Type of worker/ level of sophistication of work	Blue-collar – Manual labour	White-collar – Desk work
Performance and production measure	Availability of assets, mean time between failure, failure/ breakdown frequency, production rate index	Design effectiveness, quality of the product, time-released to market, design efficiency, cross-functional integration effort etc.
What ranks higher (Time, quality or cost)	Speed is critical, downtime can cost millions of Rands a day depending on the organisation.	Time to market ranks higher than cost. Quality is also important.
Example of project management process	Maintenance Management Function (MMF)	Project Management framework, stage-gate framework etc.
Turnarounds	Shorter	Longer
Degree of new technology/ technology change	Low	High
Examples of applied models	Missile maintenance, self-diagnosis, co-generation system maintenance etc.	Waterfall, Double diamond, ADDIE etc.

2.10.4 Requirements Analysis

Countless studies have shown that poorly defined requirements are the single biggest contributor to cost overruns, scope creep, and loss of capability in both systems and software projects. The cost is recorded to range from 10% up to 80% of the total project cost (Halligan, 2012). When this is compared to the cost of conducting a proper Requirements Analysis (RA) process, it is found that the cost is typically between 0.1% to 2% of the total project cost (Halligan, 2012). A generic but effective RA process was developed by Robert Halligan in 2012 and is shown in Figure 42 below.

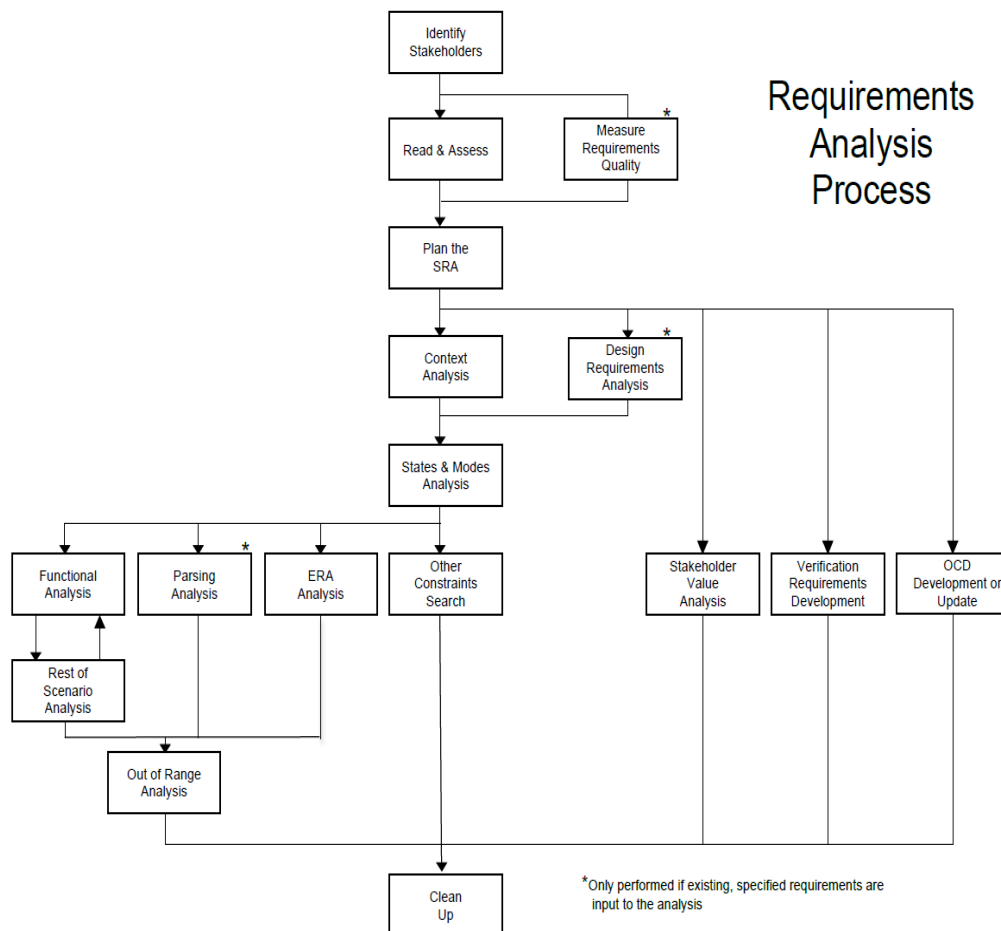


Figure 42: Generic requirements analysis process

Source: (Halligan, 2012)

Stakeholder Identification: This step identifies all the potential ‘owners’ of the requirements or those who can contribute to communicating these requirements. These owners are encouraged to make their contribution during the design process and are invited for signing off requirements (Halligan, 2012). Once the stakeholders are identified, it is important to rank them in their order of importance or influence as this ranking will be useful when it comes to stakeholder value analysis, which will prioritize the requirements and their weighting based on who the owner of those requirement is (Vos & Achterkamp, 2006).

Documents Review: Here any documents that could be related to the intended use, requirements, and the goals of the system are examined, and any key issues with other stakeholders are resolved before proceeding ahead (Halligan, 2012). This includes regulatory requirements of area of operation or potential clients.

Context Flow Analysis: This step is concerned with the outside world beyond the system boundary across the life of the system from cradle to grave. It is during this step that all derived requirements are identified and sometimes result in some stakeholders adding requirements that they could have missed (Halligan, 2012).

Context Analysis: This step identifies or validates mostly interface and environmental requirements throughout the life of a system. Some stakeholders and/or entities that the system will interface with are identified during this analysis. Normally, the tool used here is referred as a context diagram (Halligan, 2012).

States and Modes: A state of system is defined as a characterization of a system or product at a given time while a mode is defined as a set of related features or functional capabilities possessed by a system or product (Baduel *et al*, 2018). The process of analysing the states and modes establishes a big-picture dynamics of the system. This step often identifies major requirements issues as well as to given the investors an opportunity to conduct a ROI analysis (Halligan, 2012).

Functional Analysis: This process models the functional aspects of the system based on the different operational scenarios. This leads to the capture and validation of the functional and performance requirements (Halligan, 2012). To do this, a Functional Flow Block Diagram (FFBD) is used to capture the different scenarios, and the result is an Operational Concept Description (OCD) that the stakeholders must sign off on.

Rest of Scenario Analysis: This is an iterative process done parallel with functional analysis to assist in identifying and validating environmental requirements, physical requirements, resources requirements, and external interface requirements (Halligan, 2012).

Entity Relationship Attribute Analysis (ERA): This process input serves to identify and validate information content of external interface requirements as well as some functional requirements. This process is more suitable for data-oriented systems (Halligan, 2012).

Parsing Analysis: This process quantifies the level of quality of the requirements. The text of a requirement is scrutinized to identify errors, incompleteness, inconsistency, lack of clarity, ambiguity, lack of verifiability, and infeasibility (Halligan, 2012).

Out-of-Range Analysis: This process identifies requirements that may result from defective inputs or outputs or unexpected conditions of use/support/disposal. If done correctly, this process will produce a system that is effective in the real world and not just in an ideal world (Halligan, 2012).

Other Constraints Search: Legal requirements and applicable regulations, policy, governing standards, and directives are identified at this stage (Halligan, 2012).

This process of requirements analysis is one of the most important in ensuring that bogies are acquired to offer maximum value not only to TE PD but to all stakeholders. It is one of the most crucial processes of the acquisition process and needs to be conducted with through life in mind.

According to Robert J Halligan and INCOSE Requirements Working Group workshop of 2015, the attributes of a quality requirements statement or a set of requirements statements can be identified according to Table 15 below.

Table 15: Characteristics of a requirement and characteristics of a set of requirements

Source: Author adapted from (Halligan, 1993; Wheatcraft, 2015)

Characteristics of a requirement statement.	Characteristics of a set of requirement statements.	Attributes of requirements statements.
1. Correctness 2. Completeness 3. Consistency 4. Clarity 5. Non-Ambiguity 6. Connectivity 7. Testability 8. Singularity 9. Modifiability 10. Feasibility	1. Complete 2. Consistent 3. Feasible 4. Bounded	1. Alignment with need 2. Alignment with design 3. Alignment with evidence

Even though each requirement statement’s quality is determined using a parsing template, the decision to proceed to development phase is influenced by the quality of the entire set of requirements. Once a set of requirements have a quality of 0.8 and above, it is safe to start with development (Halligan, 2012).

Table 16: Requirements quality ranges

Source: Author adapted from (Halligan, 1993)

Metric	Very poor set of requirements, requiring substantial development	Fair set of requirements, may just be suitable for purposes of solicitation, depending on the SOW and type of contract envisaged	Requirements at SRR suitable for carrying forward into development	Requirements suitable for establishment of the Functional Baseline
RQ-	0.01-0.3	0.3-0.7	0.95-0.99	0.99+

The (IEEE P1220, 2001) states that the following fifteen (15) tasks must be followed to elicit all the necessary requirements before the development of a system. These are listed in Table 17 below (Défense Acquisition University Press, 2001).

Table 17: Requirements analysis task areas

Source: From (Défense Acquisition University Press, 2001)

1. Customer expectations	9. Life cycle
2. Project and enterprise constraints	10. Functional requirements
3. External constraints	11. Performance requirements
4. Operational scenarios	12. Modes of operation
5. Measure of effectiveness (MOEs)	13. Technical performance measures
6. System boundaries	14. Physical characteristics
7. Interfaces	15. Human systems integration
8. Utilization environments	

According to the Project Performance Institute (PPI), there are eight (8) different types of requirements and they are listed and explained in Table 18 below (PPI, 2015).

Table 18: Different types of requirements

Source: adapted from (PPI, 2015)

Requirement Type	Criterion
Design	These requirements direct the design in a certain direction, by either including items or excluding items.
Physical	It states the required physical characteristics of the system as a whole.
Resource	Provides limitation in terms of usage or consumption by an item of an externally provided resource.
Functional	This type of requirement states what the item is intended to do.
State/Mode	States the required states and/or modes of the item and the transition between the states, one mode to another. A state is a condition of being while a mode is a group of functions.
External interface	It states the required characteristics at a localised point, or region, at areas of connection to all things external to the item.
Performance	It states how well a function is to be performed by the item.
Other quality	This one captures any other required quality of the item that does not form part of the ones listed above.

Initially the system is described by the technical requirements at system level provided by the user/client. These requirements capture performance, function, and interface requirements as given by the user/client. These requirements are recorded in the System Specification, which serves as the primary document for system-level functional baseline (Défense Acquisition University Press, 2001). The system level requirements are then allocated to the items that make up the system and this results into design criteria for each item in the system. A set of these requirements for a given item is referred to as a performance specification (Défense Acquisition University Press, 2001). Performance specifications are combined with interface definitions, process description, and drawings document the 'Design To' baseline. Once all the design requirements have been recorded for all the system items, detailed design follows. The detailed design process describes the system from top to bottom, with all of its items to meet the design requirements. Once detailed design is complete, the final baseline is defined and is referred to as the product baseline (Défense Acquisition University Press, 2001). The product baseline is documented by the data package, process, and material specifications. These five (5) types of requirements specifications are summarized in Table 19 below (Défense Acquisition University Press, 2001).

Table 19: Requirement specifications types

Source: Adapted from (Défense Acquisition University Press, 2001)

applicable level	Specification	Content	Baseline
Primary Requirements Document (System level)	System Specification	Defines mission or technical performance requirements. Allocated requirements to functional areas and defines interfaces.	Functional
Item level	Item Performance Specification	Defines the performance characteristics of the Configuration Items and Computer Software Configuration Items. Also forming this baseline are drawings and detailed design requirements.	Allocated "Design To"
Item level	Item Detail Specification	Form, fit, function as well as verification are detailed in the specification. Items, process, material specification start the Product Baseline effort, but the final audited baseline includes all the items in the Technical Data Package (TDP) as well.	Product "Build To" or "As Built"
Item level	Process Specification	Defines the process to be followed during fabrication.	
Item level	Material Specification	Defines the production of raw materials or semi-fabricated material used in fabrication.	

In order to establish uniform practices for preparation of standards, inclusion of verification methods for each requirement, to assist in the elicitation of each requirement, and to assist in the analysis of each specification content, the military standard MIL-STD-961D was developed. Format, content, configuration item, software, process, and material specifications are all established in the MIL-STD-961D. Through system engineering processes, these program-specific standards are developed; their hierarchy is shown in Figure 43 (Défense Acquisition University Press, 2001).

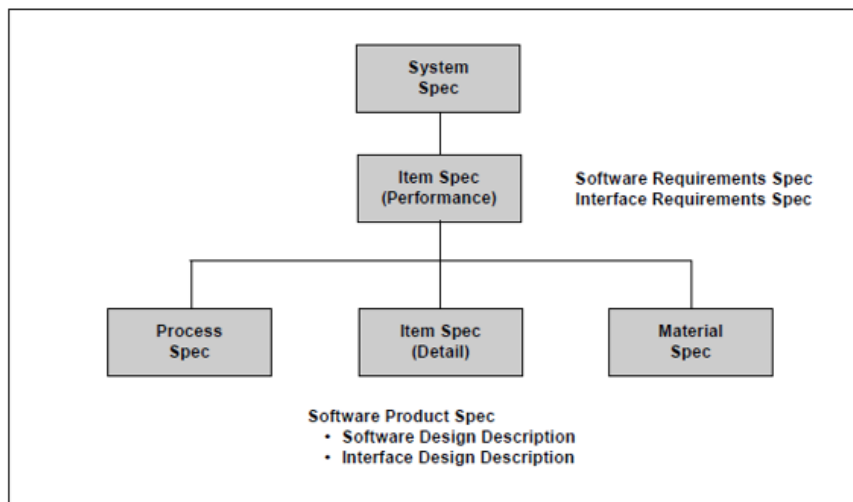


Figure 43: Specification hierarchy

Source: (Defense Acquisition University, January 2001)

2.10.5 System Development Methodologies

A systems engineering process is suggested as the best approach to bring products, systems, and structures into being that will be cost-effective and competitive (Blanchard & Fabrycky, 2014). There are different lifecycle processes used in different industries for system development. The choice of the cycle used depends mostly on the quality of the requirements and to some extent on the experience of

the team, availability of resources, nature of the system being developed, and time constraints. Below is a brief description of development cycles used in systems engineering.

2.10.5.1 Sequential/Waterfall Model

The Waterfall Model was first introduced by Royce in 1970, mainly for the software development industry. This development process is a sequential process that starts once all the requirements have been identified and are unlikely to change. Each step is done in order, and there is no going back to verify the previous step once it is done and signed off. Each step provides input to the next step, and only one product is delivered at the end of this process (Blanchard & Fabrycky, 2014; Innovative Architects, 2020).

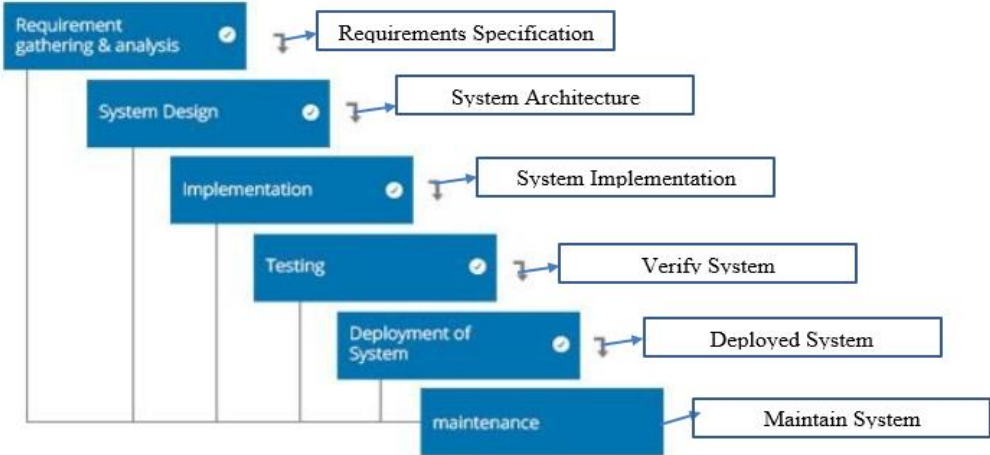


Figure 44: Waterfall system development process

Source: Adapted from (Guthrie, 2020)

2.10.5.2 Incremental Model

The Incremental Model is a combination of two or more Waterfall Model developments. Each step is followed sequentially, and at the end of the process, a system is delivered to the user. Unlike in the Waterfall Model, the requirements for the Incremental Model are separated into models and system developed and delivered for every module of requirements. This results in multiple systems delivered to the end user, and these systems are integrated to form a complete system (Naveen, 2015).

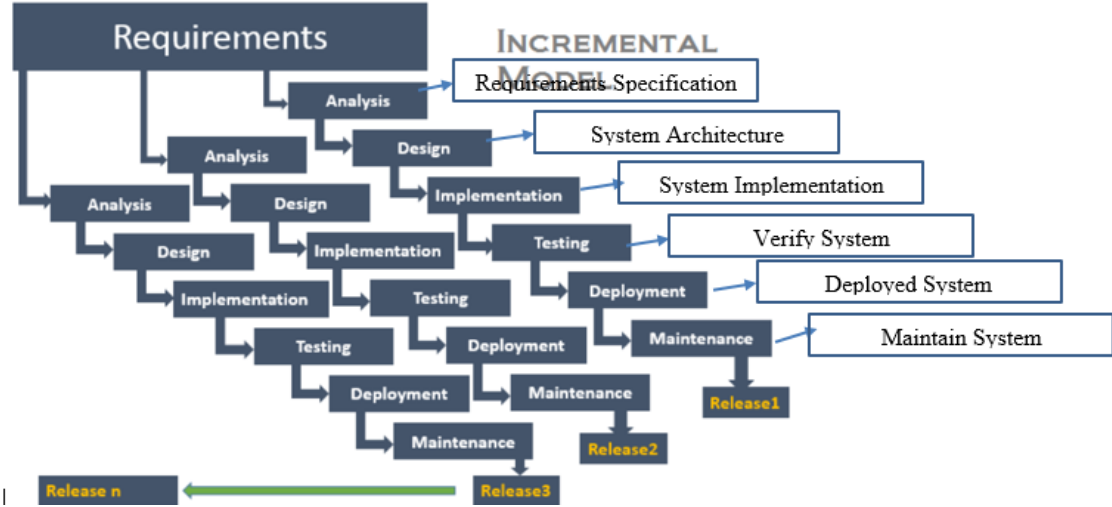


Figure 45: Incremental Model

Source: Author Adapted from (Naveen, 2015)

2.10.5.3 Spiral Model

The Spiral Model was developed by Boehm in 1986, using the work done by Hall in systems engineering from 1969 (Blanchard & Fabrycky, 2014). This model is concerned with high risk development. It starts by examining potential risks due to lack of a complete set of requirements while the project is still in its early stages. Once the risk is assessed, a decision is made to continue to the next phase to make plans to address the identified potential risk (Guthrie, 2020). Unlike the Incremental Model and Waterfall Model, the Spiral Model addresses requirements and solution concurrently (Fairley, 2021).

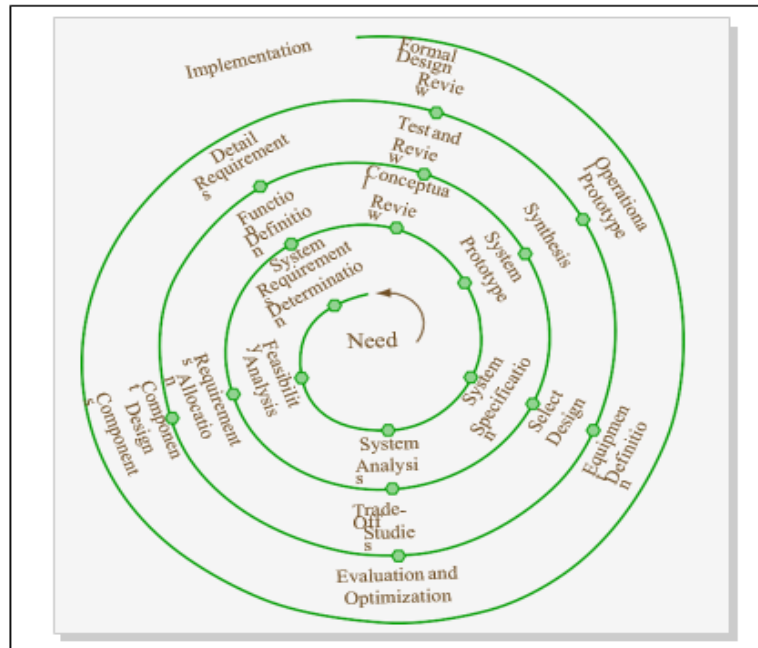


Figure 46: Spiral Model

Source: (Fairley, 2021)

2.10.5.4 Vee Model

(Forsberg *et al.*, 2005) describe what they refer to as ‘the technical aspect of the project cycle’ using the Vee Model. The process starts with the user needs on the upper left and ends with a user-validated system on the upper right. Verification and validation are done at component level and final validation at system level. It is at this testing stage that the original requirement specifications are consulted. The system architecture is resolved on the left-hand side through the decomposition and definition of activities. This assists in creating details for the design (Blanchard & Fabrycky, 2014). Figure 47 below shows a diagram of the Vee Model. The Concept of Operation (ConOps) is developed once needs assessment has been done and before some preliminary project planning. The primary functions of the ConOps are to: 1. establish the rationale for the system; 2. refine the vision, goals, and objectives of the proposed system; 3. develop representative operational scenarios and illustrate the proposed system will do under those circumstances; 4. to ensure that the needs and expectations of the stakeholders are captured early in the system development process; 5. ensure that the system’s functionalities are linked to the mission, goals, and objectives of the participating agencies; and 6. begin the traceability of the systems engineering process. (Dion *et al.*, 2015). In the Vee Model, systems engineering processes are applied alongside the system life cycle phases. The bogie acquisition framework to be developed in this research paper considers the entire lifecycle process from cradle to grave.

Phase (-1)	Phase (0)	Phase (1)	Phase (2)	Phase (3)	Phase (4)	Phase (5)	Phase (6)
Interfacing to the Regional Architecture	Concept Exploration & Benefits Analysis	Project Planning & SEMP Framework	Planning of Developments and Updates	Development & Implementation Integration, verification.	Validation, Operation, and Maintenance &	Changes and Upgrades	System Retirement, Replacement

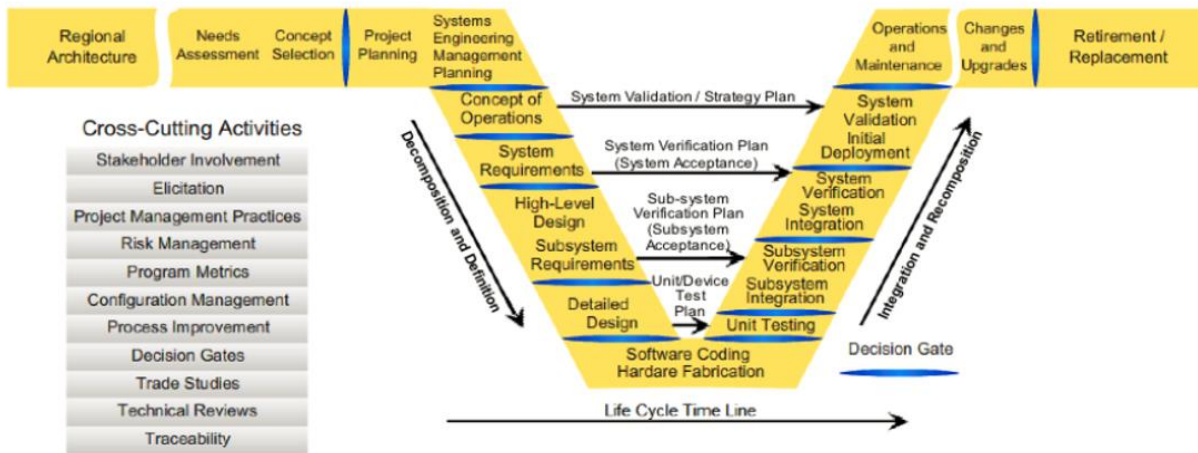


Figure 47: Vee Model

Source: Adapted from (Dion et al., 2015)

2.10.6 Requirements Functionality Synthesis (RFS) Loop

The RFS Loop is an iterative and recursive problem-solving process that is applied in a sequential manner throughout all stages of the development (Défense Acquisition University Press, 2001). Its main focus is: 1. requirements analysis, 2. functional analysis and allocation, and 3. design synthesis. The RFS loop is used to: 1. transform stakeholder needs and requirements into a set of system product and process description, 2. generate information for decision makers, and 3. provide input for the next stage of development. The three fundamental systems engineering activities that make up the RFS loop are all balanced by techniques and tools that are collectively called systems analysis control. The output of this process is used to describe how the subsystems join to form the system (Défense Acquisition University Press, 2001). An illustration of the RFS look is shown in Figure 48 below.

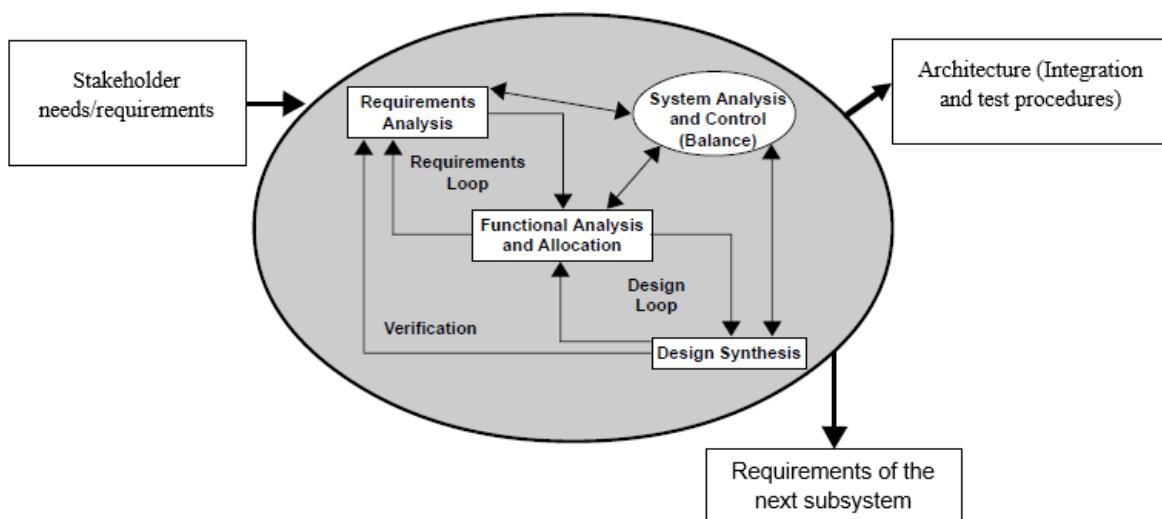


Figure 48: RSF Loop

Source: Adapted from (Défense Acquisition University Press, 2001)

Requirements will be accepted during the development of the system for the lifecycle stage, and it will happen for different layers of the system. These different kinds of acceptance for the system lifecycle are listed in Table 20 below.

Table 20: Requirements acceptance

Source: Author

Type of acceptance	Layer	Brief Description	Acceptance Method	Responsible Person/s
Single Requirement or Set of Requirements Acceptance.	System, subsystem, component	The acceptance of requirements based on the quality.	Parsing	Systems Engineer
Requirements Acceptance for Testing	System, subsystem, component	During the verification process where the extent to which the requirement is to be met is quantified and method of measurement and testing is provided	Physical testing (testing method, testing equipment, acceptance evidence, deviation, etc.)	Client/Customer
Requirements Acceptance for validation.	system layer	Making sure the requirements address the needs of the client in their operating environment.	User adoption	Client/Customer

2.10.7 Project Management and Systems Engineering Process

If one were to look at the roles project management/control and systems engineering, one would find that project management’s function is the planning, overseeing, and directing the numerous activities that are required to achieve the project requirements, goals and objectives for the customer and all other stakeholders. All this has to be done within the constraints of specified cost, quality, and time constraints (NASA, 2007). Systems engineering, however, is a methodical, disciplined approach for the design, realization, technical management, operation, and retirement of a system (NASA, 2007). Systems engineering has the challenging task of producing a balanced system in the face of multiple interests that are sometimes conflicting. Using the systems engineering competencies, the systems engineer must develop the skills and instinct for identifying and focusing the efforts on assessments to optimize the overall design without favouring a system or subsystem over others. The systems engineer’s role is to review and evaluate all the technical aspects of the project in order to ensure that the systems/subsystems engineering processes are functioning properly and that the concept evolves into the final product (NASA, 2007). The disciplines of Systems Engineering and Project Management are closely related but differ in their role when it come to a project. There are areas where these two disciplines overlap; normally this happens when there is complexity and uncertainty when it comes to defining the scope of the project (Madzibane, 2018). A graphical notation of the two disciplines and their overlap is shown in Figure 49 below.

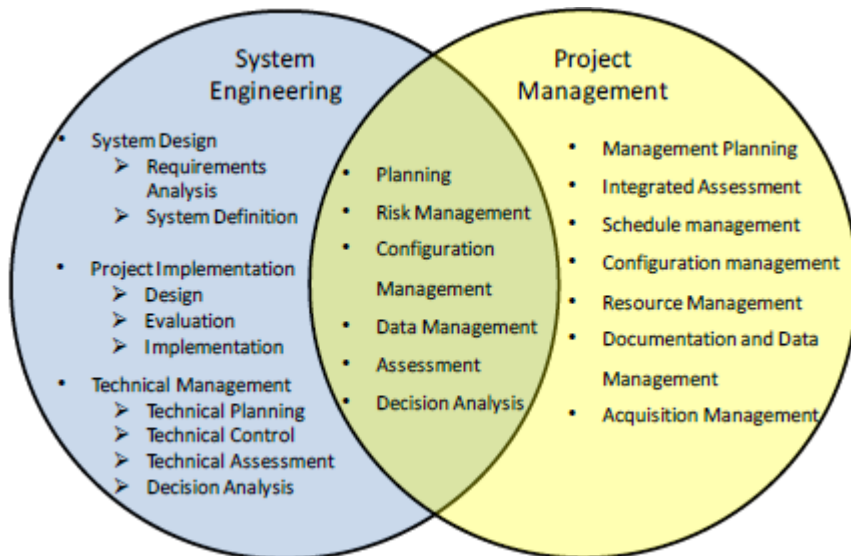


Figure 49: Systems Engineering and Project Management

Source: (NASA, 2007; Madzibane, 2018)

The Japanese Aerospace Exploration Agency (JAXA) has developed a graphical representation of the extent of involvement of systems engineering and project management through lifecycle. It is worth noting that systems engineering is involved for the whole lifecycle of the system and is mostly used in the beginning stages of a project while project management starts at the design stages and ceases once the system is launched.

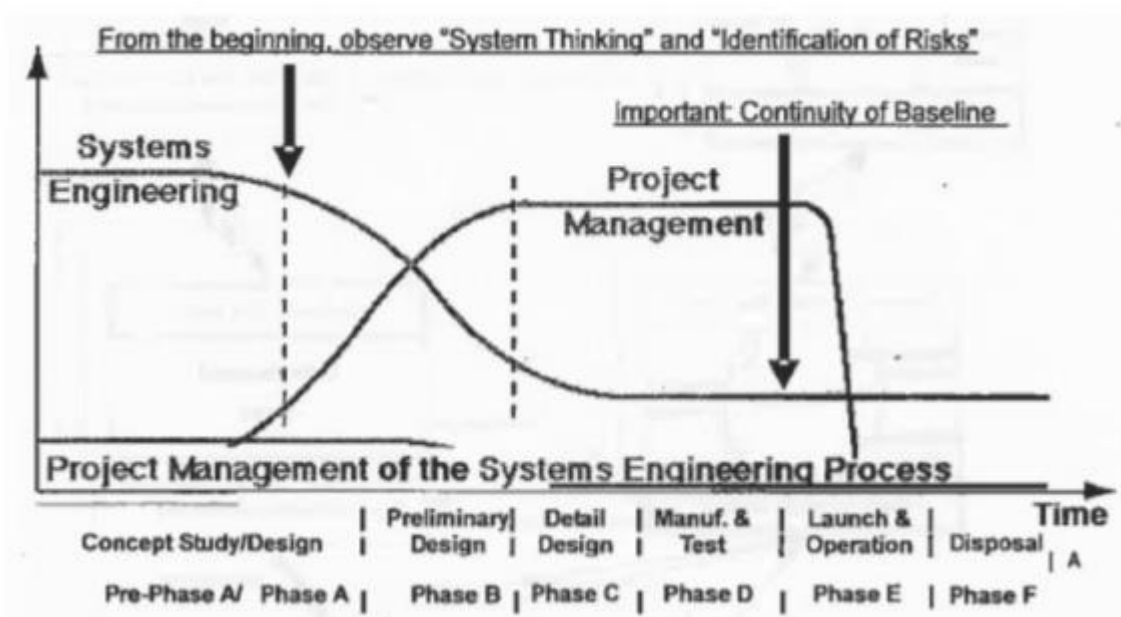


Figure 50: Systems engineering and project management through lifecycle

Source: (NASA, 2007; Madzibane, 2018)

2.10.7.1 Project Management Plan (PMP) and Systems Engineering Management Plan (SEMP)

A Project Management Plan (PMP) is a formal document that is approved and defines how the project is executed, monitored, and controlled. This plan may provide a summary of the project, be detailed or

be made up of more subsidiary management plans and other planning documents (PM_PrepCast, 2012). Inputs to the PMP are listed in Table 21.

Table 21: PMP inputs

Source: Author adapted from (Project Management Institute., 2008; PM_PrepCast, 2012)

PMP Inputs	PMP Outputs
<ol style="list-style-type: none"> 1. Project charter 2. Outputs from planning process 3. Enterprise environmental factors 4. Organizational process assets 	<ol style="list-style-type: none"> 1. Scope management Plan 2. Schedule management Plan 3. Quality management Plan 4. Resource management Plan 5. Communication management Plan 6. Project change management Plan 7. Risk management Plan 8. Procurement management Plan

The development of the PMP across the project lifecycle is shown in Figure 51 below.

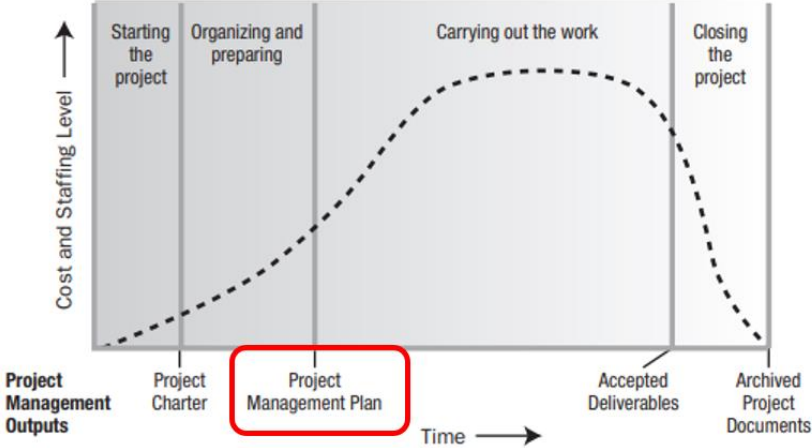


Figure 51: Development of the PMP across project lifecycle

Source: Adapted from (Project Management Institute., 2008)

The Systems Engineering Management Plan (SEMP) is a foundational document that is used for technical engineering activities conducted during a project. It conveys information to all the personnel on the technical integration methodologies and activities for a project defined by the scope of the project plan (NASA, 2007). The SEMP is a subordinate document to the PMP document as the PMP defines how the project will be managed to achieve the project goals and objectives within the defined constraint associated with the program while the SEMP provides the technical aspects of the program (NASA, 2007).

Table 22: PMP inputs

Source: Adapted from (Forsberg et al, 2005; TCSE, 2020)

SEMP Inputs	SEMP Outputs
<ol style="list-style-type: none"> 1. Customer specification 2. Request for Proposal (RFP) 3. Applicable standards 4. System specifications 5. Previous developed specifications for similar systems 6. Integration of specialisms 7. Concurrent engineering 8. Enterprise engineering 9. Lifecycle process definition 10. Planning, monitoring, and controlling 	<ol style="list-style-type: none"> 1. Defined System-of-Interest 2. Planned interface between PMP and SEMP 3. Through Lifecycle Thinking 4. Stakeholder viewpoints and requirements 5. Conceptual design 6. Functionality and interfaces 7. Integration, verification, and validation 8. Transition to operation 9. Configuration management and change control

2.11 Customer Value Proposition

(Thomson, 2013) defines value proposition as a point where a company’s product intersects with its customer’s desires. It is the fit between ‘what’ it makes and why people buy ‘what’ it makes. It is the focal point between business strategy and brand strategy. Shown in Figure 52 below is a canvas for identifying the customer value proposition for a new product or new enterprise. The canvas gets an enterprise quickly to the ‘minimum viable clarity’ prior to developing a new product (Thomson, 2013).

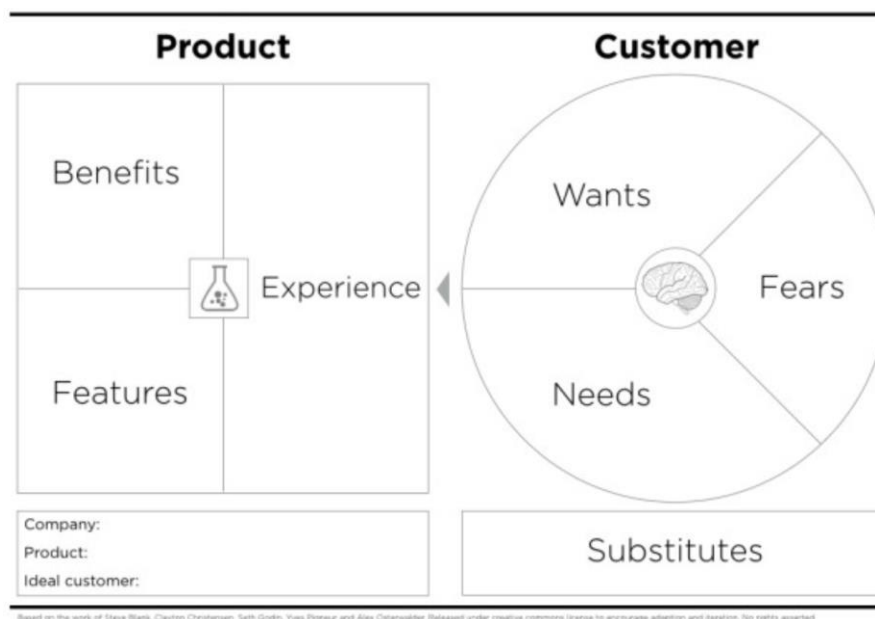


Figure 52: Customer value proposition canvas

Source: (Thomson, 2013)

The product side of the canvas focuses on benefits, features, and experience. The benefits are what the company does for the customer to make their lives easier. These are the core of the value proposition. They are identified by answering the question ‘What does your product do?’ Features are factual descriptions on how the product works and are the functioning attributes of the products. New services offered by new innovative products are important for the value proposition. The question to answer to

identify features is ‘How does your product work?’ Lastly, experience is what the customer feels from owning your company’s product. Customer experience is identified through asking questions such as ‘What does it feel like to use our product?’ (Thomson, 2013).

The customer side the canvas focuses on wants, needs, fears, and substitutes. Wants are the emotional drivers of making a decision and are influenced by what the customer wants to have. To identify them, ask ‘What are the emotional drivers of purchasing?’ The needs are rational things the customer needs to be done. In some instances, the customer may not be conscious of all the needs and these have to be identified by the designer; these are called latent needs. There are two questions to answer in order to identify these: ‘What are the rational drivers of purchasing?’ and ‘What are the hidden needs?’ Fears are driven by the fear of missing out, making a mistake or giving up optionality. These fears exist even if your product is better than that of your competitors. The question to ask to identify fears is ‘What are the risks of switching to my product?’ A product doesn’t only have to be better than that of your competitors but has to be better than all exiting substitutes as well. For example, other modes of transportation. To identify these, ask ‘What do people currently do instead?’ (Thomson, 2013).

The value proposition canvas is the perfect way of validating an organization’s assumptions about its product and can be used to drive the value proposition. A thorough study of the user’s needs, wants, and perception of TE PD rolling stock, bogies in particular, needs to be undertaken. This will assist in presenting the best value proposition to customers and TE PD knowing its position in the market and possible substitutes to their products.

2.12 Supply Chain Party Logistics

The supply chain management in logistics has different levels of integration. The levels of integration are referred to as party logistics. An illustration of the different levels is shown in Figure 53 below. The different services they offer are also shown in the illustration.

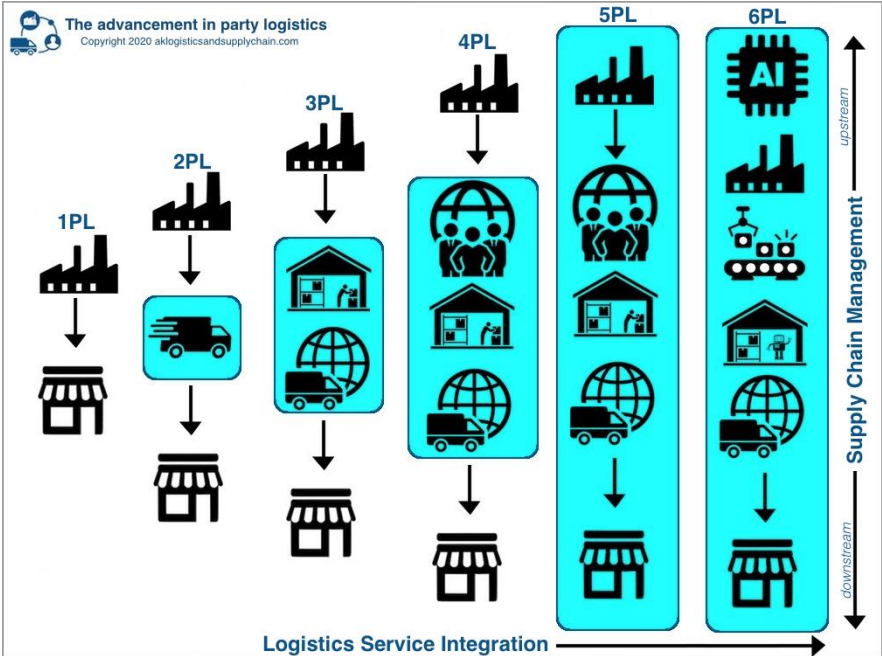


Figure 53: X Party logistics

Source: AK Logistics Supply Chain

Listed in Table 23 are the different supply chain party logistics and the description of their different levels of supply chain service integration. The levels highlighted in green are the operating levels for

Transnet for its different customers as it continues to digitize and integrate Industry 4.0 to operate at logistics level 6PL and higher.

Table 23: Description of party logistics

Source: Adapted from (Kenned, 2020)

ID	Name	Description of integration of supply chain
1PL	1 st Party Logistics	An enterprise or individual that transports and delivers their own goods, using their own vehicles; no other companies are involved in the movement of the goods.
2PL	2 nd Party Logistics	This refers to an enterprise that uses services of other companies as subcontractors to move their goods. A 2PL logistics provider is ‘asset-based’, and they own their means of transport.
3PL	3 rd Party Logistics	A 3PL logistics provider offers the following integrated services: 1. transport and freight forwarding, 2. warehousing including inventory management and cross docking, and 3. packing and labelling. This means a manufacturer can outsource its transport, storage, and packing and distribution to a single 3PL company. Most 3PL companies have the flexibility to offer their services separately, depending on their customer’s needs.
4PL	4 th Party Logistics	A 4PL enterprise is an independent or neutral lead logistics solutions provider. They liaise or coordinate multiple 3 PL logistics service providers in order to provider a customer with a tailored services that best serves the customer. This means they offer their clients all the services offered by a 3PL service provider but over and above that they offer: 1. project management, 2. logistics strategy and analytics, 3. impartial service advice, and 4. a single point of contact.
5PL	5 th Party Logistics	This kind of logistics service provider offers a fully integrated logistics solution that encompasses the whole supply chain from beginning to end using multiple outsourced service providers. Though the use of IT solutions, this kind of service provider can provide full visibility in ‘real-time’. This type of service provider is best suited to e-commerce.
6PL	6 th Party Logistics	A 6PL logistics service provider is fully integrated and partially automated through the use of Artificial Intelligence (AI). Although this logistics type is still fairly theoretical, it has the potential to offer significant technological advancements such as incorporating AI to monitor the whole supply chain using trends, ordering patterns and forecasting models and proactively send instructions to deliver stock or report any anomalies.

2.13 Systems Framework for the Acquisition of Bogies for TE PD

The first draft of the framework is based on the Zachman Framework and the modified MoDAF shown in Section 2.9.4 in Figure 37 on page 43. The MoDAF is concerned with architecture of the SoS while the Zachman Framework is concerned with the enterprise architecture methods (Cloete-Hopkins, 2011; Retief, 2019). From the lifecycles considered in Section 2.3, the lifecycles that are most appropriate for this research that were selected based on the criteria discussed previously will be combined to develop the framework. Going down the left-hand side, the different lifecycles offer different viewpoints. The artefacts across the columns, which are based on the different phases of a lifecycle, are what contribute to delivering the parts that make up the framework.

Viewpoints		Pre-Project Phase										Project Phase						Post-Project Phase										
		Conceptual Design										Evaluations & Approvals		Design			Installation and Checkout			Remove Old Equipment								
Viewpoints	Project Lifecycle Project Estimating and Cost	System Requirements										Functional Analysis	Detailed Design	Resource Requirements	Engineering Evaluation	Management Approval	Requirements	Functional Analysis	Detailed Design	Resource Requirements	Procurement	Purchasing	Procedures	Installation	Modifications	Performance Evaluation	Dismantle	Project Closeout
	Acquisition Lifecycle U.S. Department of Health and Human Services	Form the Team		Define Mission Business Needs		Identify and Align Resources		Requirements Definition		Acquisition Strategy			Acquisition Planning			Performance Management												
	Product Lifecycle Typical High-Tech Commercial	Product Requirements Phase			Product Definition Phase				Product Development Phase		Engineer Model Phase			Internal Test Phase		External Test Phase		Production Phase		Manufacturing, Sales, and Support Phase		Disposal Phase						
	System Lifecycle Visualizing Project Management	User Requirements Definition Phase							Concept Definition Phase			System Specification Phase			Acquisition Planning Phase	Source Selection Phase	Development Phase	Verification Phase	Deployment or Production Phase	Operations/Maintenance or Sales/Support Phase		Deactivation and Disposal Phase						
	All Viewpoints											Concept of Operation (ConOps)		Overview and summary of the project		Interrelated Dictionary		TE vision and mission										
Systems Engineering Viewpoint	Stakeholder Requirements Definition Process		Requirements Analysis Process		Architecture Design Process		Implementation Process		Integration Process		Verification Process		Transition Process		Validation Process		Operation Process		Maintenance Process		Disposal Process							
Project Systems Management	High-level Operational Concept Graphic		Operational Performance Attributes (Modes)		Operational Node Relationship Description		Operational Information Exchange Matrix		Organizational Relationships Chart		Operational Activity Model		Operational Rules Model		Operational Event Trace Description													
Technical Viewpoint	Business Benefits		Enterprise Capability Taxonomy		Enterprise Goals		Enterprise Objectives		Enterprise Mission		Enterprise Governance		Enterprise Policies															
Strategy Viewpoint	Applicable Standards Profile		Applicable Standards Forecast		Previous Designs		Suppliers' Technical Standards																					

Time →

Figure 54: A Systems Framework for the acquisition through lifecycle of bogies for TE PD projects

Source: Author

Listed in Table 24 to Table 34 below are the different viewpoints of the framework with detailed description, sources, and possible stakeholders responsible for executing that respective viewpoint and applicable systems engineering principles and methodologies.

Section A: All Views

Table 24: All viewpoints (AV)

Source: Author

All Viewpoints (AV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
AV-01	Overview and Summary	It provides and executive level summary information of the framework to be used to acquire a bogie or bogies for TE PD. It will provide a summary of the processes involved in acquiring the bogie/s through lifecycle.	(MOD Homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	All Systems Engineering Competencies and Principles as well as Project Management Principles.
AV-02	Integrated Dictionary	Provides terms and explanations to be used in this framework as well as description and catalogues of all elements and relationships between them.	(MOD Homedefence, 2010)	Lead Systems Engineer and relevant stakeholders.	Model Based Systems Engineering (MBSE) Tools.
AV-03	Concept of Operation (ConOps)	The ConOps serves as a foundation for the Systems Engineering Processes. It serves as the foundation to the development of the system and should be accessible to all stakeholders to ensure that everybody's needs are catered for by the bogie. The ConOps addresses the five main questions; Who?, What?, Where?, Why?, and How?.	(U.S. Department of Transportation, 2005) (MOD Homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Model Based Systems Engineering (MBSE) Tools. Functional Flow Block Diagram (FFBD), System Lifecycle, User Operational Concept Description(OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview
AV-04	TE vision and mission	TE's mission and vision which is informed by Transnet's vision and mission are considered throughout the framework in parallel with all other processes. It is covered in more detail in the Strategic Viewpoint in StV-03 and StV-05.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020)	Lead Systems Engineer	Systems Engineering Management Plan (SEMP)

Section B: Lifecycles

Table 25: Lifecycle viewpoint (LCV), project lifecycle process

Source: Author

Lifecycle Viewpoint (LCV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-01	Project Lifecycle Process	<p>The Project Lifecycle Process is the overarching lifecycle process that the other lifecycles (LCV-02, LCV-03, and LCV04) form part of. This is because the project does not end when the bogie is delivered but the clients using the bogie product of TE PD has to be supported and eventually the bogie has to be retired and disposed of.</p> <p>Phase 1: Project Initiating This is the initiation part of the project where a Business Case is developed and stakeholders are identified. The needs of the project are identified and a Project Charter is created. The Project Charter contains details of ; Project constraints, goals, scope project manager, budget, expected timelines. A register for stakeholders is created containing their roles, designation, influence, and communication requirements. There are mainly three ways bogies projects start in TE PD, 1. Business Development (BD) identifies upcoming Railway projects and position TE PD to tender (pushing product into the market), 2. BD identifies projects already at tender stage and bit to supply bogies (Market pull). It is at this stage the Acquisition strategy to be used is identified (in-house, OEM partnership, or COTs). LCV-02 has started at this stage.</p> <p>Phase 2: Project Planning This is one of the most important phases of the project as the success of a project is highly influenced by how much planning was done before execution. The Project Management Plan (PMP) from SMV-01 viewpoint is created. The PMP will include; 1, Success factors (Schedule, budget, and other factors), 2. The scope, 3. Deliverables, 4. Schedule, 5. Budget, 6. Human resource plan. (The nature of the project will influence the team selection between TE PD or TE PD R&D), 7. Quality management Plan, 8. Risk management plan, 9. Procurement Management Plan, 10. Change Procedure. LCV-03 viewpoint starts during this phase as the user requirements are gathered.</p> <p>Phase 3: Project Execution Here the project manager and the project team are executing the acquisition. The team composition will depend on the acquisition strategy opted for. If it's COTs then TE PD will mostly be managing the acquisition or if it's an in-house development then team will be TE PD employees and suppliers, or if it a partnership then it's a bit of both. The project manager will be producing the project status updates and communicating with stakeholders. This phase LCV-04 execution.</p> <p>Phase 4: Monitoring and Control This phase exists to ensure that Phase 3 above is executed and executed as needed. So they happen concurrently. Using the viewpoints referred to in this research as the enablers, this phase monitors and control the success factors defined in Phase 1 which are, schedule, Budget, and quality.</p> <p>Phase 5: Project Closure This phase of the project is the most ignored maybe because the bogie system is not longer with TE PD and has been delivered to the client. The bogie systems needs support while in operation which may mean modifications or retrofitting and this is possible until the bogie system is retired. The design, development, testing, and commissioning may be done but support continues. Lessons learned and release of resources will occur gradually through the project lifecycle.</p>	<p>(PMBok, 2008)</p> <p>(Kevin Fordberg PhD et al, 2005, p 840)</p>	<p>Project Manager and Lead Systems Engineer with participation of all stakeholders.</p>	<p>All Systems Engineering Competencies and Principles as well as Project Management Principles. All other Viewpoints</p>

Table 26: Lifecycle viewpoint (LCV), acquisition lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-02	Acquisition Lifecycle Process	<p>This lifecycle process starts from leadership buy-in on the project to a point where a bogie is delivered and commissioned at the client. It includes LCV-03 and LCV-04.</p> <p>Form the Team: Once a need has been identified by BD from LCV-02 Phase 1 and the nature of the project known, a team is built based on skills required.</p> <p>Identify and Align Resources: Identify the resources required internally and externally once the nature of the opportunity is identified. Is it a push or pull to the market type of project and identify any gaps.</p> <p>Requirements Definition: Develop a requirements definition roadmap and acquisition forecasting. This is where viewpoint SETPV-02 on Requirements Analysis becomes useful.</p> <p>Acquisition Strategy: Then based on the timelines from an opportunity identified either by BD or the department initiating the project, the acquisition strategy is decided on and the team to bring the bogie to physical existence is built. This team will be built based on the level of risk and available technical skills.</p> <p>Acquisition Planning: The strategy will also include: Objectives of the acquisition: <ul style="list-style-type: none"> • Capabilities to be provided • Major milestones Acquisition approach taken: <ul style="list-style-type: none"> • Single step launch or incremental. • competitive or sole source • System Integration • Commercial-Off-The Shelf (COTs) Business Considerations: <ul style="list-style-type: none"> • Limiting factors (Funding, schedule) • Availability of assets and technology Risk Management: <ul style="list-style-type: none"> • Major risk associated with the bogie acquisition strategy taken. • Identify and manage risk shared with partners and suppliers </p> <p>Contract Type: The contract to be entered into with bogie OEM development partners or COTs partners needs to be decided on. <ul style="list-style-type: none"> • Incentives associated with the timelines • Performance parameters </p> <p>Products support strategy: The type of support TE PD is going to offer to its customers is planned for at this stage. From delivery to maintenance to modifications and improvements. <ul style="list-style-type: none"> • Oversight of delivery of system • Maintenance • Improvement </p> <p>Performance Management: Once the contracts have been awarded execution starts. All the plans made are implemented and performance is monitored based on the milestone agreed on in the contracts and the timelines. Contract management is a significant part of this phase. Bogie development, integration, testing, deployment, customer support, and maintenance are also monitored during this phase.</p> <p>Compare Requirements and Results: Each phase will have its own requirements and those will be monitored throughout. Lessons learned will be recorded as well.</p>	<p>(MITRE, September 2013)</p> <p>(ISO/IEC/IEEE 15288-2002)</p> <p>(NASA, December 2007)</p>	All stakeholders lead by Lead Systems Engineer	Principle of acquisition tenders and contracts, Acquisition Process Activities, Acquisition Outcomes, bogie lifecycle

Table 27: Lifecycle viewpoint (LCV), system lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-03	System Lifecycle Process	<p>The system lifecycle of a bogie looks at the phases that a bogie goes through in its life. Knowing this cycle before hand is important as it informs the LCV-04 viewpoint which looks at the different phase of developing the physical system being the bogie.</p> <p>User Requirements Definition: This phase is important as it will determine the feasibility of the project and define the scope of the project as well. Requirements will be gathered from all stakeholders especially the user of the bogie to ensure they gain value in the bogie system.</p> <p>Concept Definition Phase: Here concept and concept alternative are development with approval from the user. The architecture, lifecycle budgetary and ownership cost estimations.</p> <p>System Definition Phase: Once concepts have been created from the previous phase, the system is defined in more detail and the context in which it operates. The interfacing requirements of the bogies with rail and vehicle body are identified. Available technology for the concept is investigated as well as risk reduction efforts. the technical feasibility is explored at this stage as well.</p> <p>Acquisition Planning Phase: Once the feasibility is concluded as well as the study phase of the project are done, the acquisition phase starts where schedule and budget are estimated. The method of acquisition is defined and if it's internal or external, at this stage as well as suppliers. The final step of this phase is approval to go ahead with the acquisition of the proposed system.</p> <p>Source Selection Phase: This phase is about the selection of a contractor through a fair and open process. The aim is to select contractor which provides best value from the reposes to the Request For Proposal (RFP). For internal (TE) development the process will not include RFP. It will start from choosing the team based on the required technical skills as well as timelines.</p> <p>Development Phase: Be it an internal development or partnership with other OEMs, this phase is concerned with the bringing to physical existence the first designed bogie. From design to development, then integration.</p> <p>Verification Phase: The verification process of the bogie is done mainly by testing. The bogie as well as standard components are tested according to EN, AAR and UIC standards as well as the URS. Some verification will be done by demonstration, visual inspection, or analysis.</p> <p>Production Phase: Once the bogie has been tested and validated, and designed capabilities agreed on by the customer, mass production of the bogie system then starts and further marketing in order to respond to market opportunities.</p> <p>Operational, Maintenance, and Support Phase: Developed training manuals and maintenance manuals are put to use in the operational and maintenance phase. Support may be offered in a form of modifications and retrofits as well during operation.</p> <p>Retirement/Disposal Phase: The final phase is to decommission the bogie and retire it safely. Plans have to be put in place to ensure all the value from the bogie is extracted and it is disposed of in a safe manner not impacting the environment negatively.</p>	<p>(ISO/IEC/IEEE 15288-2002)</p> <p>(Jone B.L, 2009)</p> <p>(INCOSE, 2015)</p>	<p>Lead systems Engineer, Client, Design Team</p>	<p>All Systems Engineering Competencies and Principles as well as bogie lifecycle.</p>

Table 28: Lifecycle viewpoint (LCV), system/product development lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name		Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-04	Product/System Development Lifecycle Process	<p>Described in this process are the stages that will be followed to develop and manage an integrated bogie. This process forms part of the acquisition lifecycle process (LCV-02) which forms part of the overarching Project lifecycle process (LCV-01). This structured sequential has phases that are only complete once the requirements and milestones of each phase are met and delivered on. These are the typical phase to successfully deliver a bogie.</p> <p>Concept Stage: Product Requirements Phase: This phase is concerned with the gathering all requirements from stakeholder requirements to system requirements at system and component/element level. This will include inherent and derived requirements. This process is done with LCV-03 in mind. Product definition Phase: Once requirements have been gathered, a Concept of Operation (OCD) is developed which will share a common understanding between TE and the client of how the bogie will operate.</p> <p>Development Stage: Product development Phase: The concept is then developed further according to the design specification and integrated according the viewpoint SETPV03 to SETPV-05 below. Different kinds of engineering models are developed during this phase to analyse the design in different scenarios and tested according to EN,UIC, and AAR standards. Internal Testing: The internal testing phase will be done at a component level as well as at system level according to EN,UIC, and AAR standards depending on the type of bogie being tested. If the bogie is narrow gauge then testing will be done internally but if it's standard gauge then it will be externally. External Testing is done by partners such as TTCI and UP based on the specifications developed in SETPV-06 below. Then the bogie validated in the expected environment of operation as stated in viewpoint SETPV-08.</p> <p>Production Stage: Production: Once production tools creation is done, it is time for mass production of the bogies and integration into to the rest of the vehicle and infrastructure.</p> <p>Utilization/Support Stage: Once the bogie has been integrated to the rest of the vehicle and official hand over is done, it's time to support the clients through maintenance, modification, retrofit and any other support they may need. This phase is executed according to viewpoint SETPV-09 and SETPV-10.</p> <p>Retirement Stage: Once the bogie has served its life according to the design and agreed life expectancy, it will be decommissioned and retired in a safe manner and ensures all the value out of the bogie has been derived. Any potential retirement costs have be identified as well.</p>	(Cengiz et al, 1998) (Leenders et al, 2003)	Lead systems Engineer, Client, Design Team, Project Team	LCV-03 Viewpoint, Strategic viewpoint (StV), Project Management and Systems Engineering Management (PSMV) viewpoint.

Sections C: Enablers

Table 29: Technical standards viewpoint (TV)

Source: Author.

Technical Standards Viewpoint (TV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
TV-01	Applicable Standards Profile	This section defines the technical and non-technical standards that apply to the acquisition of bogies for this framework. It also describes the guidance and policy applicable to acquiring bogies in TE PD and Transnet as a whole.	(MOD Homedefence, 2010)	Project Team, Lead Systems Engineer, Client, Railway Industry Regulators, Government Regulators	Context Diagram, Work Breakdown Structure (WBS), System Lifecycle.
TV-02	Applicable Standards Forecasting	Identify expected changes to technical standards identified in TV-01 above for the expected duration of the project until disposal phase of the bogie system.	(MOD Homedefence, 2010)	Project Team, Lead Systems Engineer, Client, Railway Industry Regulators, Government Regulators	Project Plan
TV-03	TE PD Previously acquired Bogies	Identify lessons learned from previous bogie acquisition project and avoid previous pitfalls going forward.		Project Team, Lead Systems Engineer	
TV-04	Suppliers Technical Standards	Compile a list of standards that will be required for materials, services, standard components for completion of the project.		Project Team, Lead Systems Engineer	

Table 30: Project management and systems engineering management viewpoint (PSMV)

Source: Author.

Project Management and Systems Engineering Management Viewpoint (PSMV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
PSMV-01	Project Management Plan (PMP)	The PMP document serves as a formal document that is approved and defines how the project will be executed, monitored, and controlled through the lifecycle to acquire a bogie/s by TE PD.	(PM PrepCast, 2010) (Kevin Forberg PHD et al, 2005)	Project Manager	The Five Project Management Essentials. <ul style="list-style-type: none"> • Organisational Commitment • Project Communication • Teamwork • Project cycle • The ten Management Elements
PSMV-02	System Engineering Management Plan (SEMP)	The SEMP is the foundation document that is used for technical engineering activities conducted for the duration of a project through lifecycle. It conveys information to all personnel on the technical integration methodologies and activities for project defined by the project scope on the project plan.	(NASA, December 2007)	Lead System Engineer	Systems Engineering Principles; <ul style="list-style-type: none"> • System Design • Systems Thinking • System Lifecycle • Project Implementation • Technical Management

Table 31: Strategic viewpoint (StV)

Source: Author.

Strategic Viewpoint (StV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Reponsible Stakeholder/s	Applicable Systems Tools
StV-01	Business Benefits	This viewpoint insures that the acquisition process objectives are inline with TE PD's vision and mission so that the project enjoys the support of top management and gets funding and all the support it needs.	(US Department of Health and Human Services,)	Lead Systems Engineer, TE Top Management	Business Case, Return on Investment, MoEs
StV-02	Enterprise Capability Taxonomy	This captures capability taxonomies in TE PD and represents them in a model of a hierarchy of capabilities. The attributes of capability required for TE PD to be able to acquire bogies successfully are; <ul style="list-style-type: none"> • People • Process • Products • Documentation • Technology • Facilities A capability audit has to be conducted within TE PD and then followed by a gap analysis. Once this is done, these attributes shall be planned out in a timeline format to ensure that the shift from TE being a pure manufacturing organisation to being a world recognised OEM of rolling stock is achieved.	(PWC report, 2014) (Transnet Integrated Report, 2020) (BUSA 7470A, 2020) (MOD Homedefence, 2010)	TE Leadership, Process Improvement (PI), Lead Systems Engineer, Human Resource (HR)	Systems thinking, System Lifecycle, Work Breakdown Structure (WBS)
StV-03	Enterprise Goals	Transnet has set a goal to be a R100 billion company through its new Transnet 4.0 strategy. TE PD has to quantify in monetary terms its contribution to the target from their bogie programs.	(Transnet Integrated Report, 2020)	TE Leadership	
StV-04	Enterprise Objectives	In an effort to assist to contribute to Transnet's goal stated in StV-03 above, TE as the Engineering division of the organisation will contribute through; <ul style="list-style-type: none"> • Innovating new products • Improving maintenance (Introducing condition monitoring through 4IR) • Growing the Manufacturing business. acquiring new products such as bogies. The above list of objectives are important inputs into the framework as they influence how bogies will be acquired in TE. Inhouse designs, Partnership with other OEM while growing TE's capabilities or COTs.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020) (PWC Report , 2014)	TE Leadership, Lead Systems Engineer	
StV-05	Enterprise Mission	Transnet's mission is to link economies, connect people, and grow Africa. Transnet through its ports is one of the main entry points into Africa through the Seas and one of the biggest economies in Africa. It has set its plans to grow its footprint in Africa not only as a logistics company but as an OEM supplier of rolling stock as well. The Acquisition of Bogies by TE PD is a big part of realizing this mission.	(Transnet Integrated Report, 2020) (PWC Report , 2014)	Minister of Enterprises, Group CEO	
StV-06	Enterprise Governance	All applicable governing legislation such as PFMA, King IV, P2,12 and 13, and the Companies Act and others relevant to the acquisition of bogies have to be identified. This includes applicable legislation required by potential clients in which the acquired bogies will be operated.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020)		Rich Picture, Requirements Analysis, Stakeholder management, CATWOE

Table 32: Systems engineering technical process viewpoint (SETPV)

Source: Author.

Systems Engineering Technical Process Viewpoint (SETPV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
SETPV-01	Stakeholder Requirements Definition Process	This process identifies all Stakeholders and their interest and role in the Bogie. The stakeholders are then ranked in order of importance based on their influence on the bogie's development or operation. Their needs/requirements are then identified and the measure of effectiveness (MoEs) related to the needs/requirements.	(ISO/IEC/IEEE 15288-2002) (Robert J. Halligan, 2012)	Lead Systems Engineer, Client, as well as contribution from other stakeholders.	System Lifecycle, Requirements Analysis, Rich Picture, Context Diagram, Systems thinking
SETPV-02	Requirements Analysis Process	A ConOps will need to be developed for the bogie and once this is done more requirements are likely to be identified as the ConOps is verified by the different stakeholders. These requirements will form part of the inherent requirements such as; 1. Design, 2. Physical, 3. Resource, 4. Functional, 5. States and Modes, 6.External Interfaces, 7. Performance, 8. Other Qualities. From these different types of requirements, five Requirements Specifications; 1. System Specification, 2. Item Performance Specification, 3. Item Detail Specification, 4. Process Specification, and 5. Material Specification.	(ISO/IEC/IEEE 15288-2002) (Robert J. Halligan,19930) (Robert J. Halligan, 2012) (Defense Acquisition University, January 2001)	Lead Systems Engineer, Client, as well as contribution from other stakeholders.	OCD, ConOps, System Lifecycle, Functional Analysis (RFS Loop), Rich Picture, Context Diagram, Trade-Off Analysis,
SETPV-03	Architecture Design Process	System architecture design process activities of the bogie enable the creation of a global solution based on principles, concepts, and properties logically related and consistent with each other. The solution architecture and design of the bogie system have features, properties, and characteristics that satisfy as far as possible the problem or opportunity expressed by a set of system requirements (From SEV-02 above) and are implementable through the correct use of the bogie as detailed in the output of process OV-03 viewpoint below. The Output of the SETPV-03 are; 1. Architecture Definition Strategy,2. System Architecture Description, 3. Document Tree, 4. Preliminary Interface Definition, 5. Preliminary Technical Performance Measure (TPM) needs, 6. Preliminary TPM Data, 7. Architecture Traceability, 8. Architecture Definition Records.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Communication management Plan Project change management Plan Risk management Plan Integration management Plan Stakeholder Management Plan
SETPV-04	Implementation Process	The process of realizing the bogie standard components that satisfy the system requirements according to SETV-02, architecture SETV-03, and design. The following are the outputs of this process; 1. Implementation Strategy, 2. Implementation Enabling Systems Requirements, 3. Implementation Constraints, 4. System Elements, 5. System Elements Documentation, 6. Operator/Maintainer Training Manuals, 7. Implementation Traceability, 8. Implementation Reports and 9. Implementation Records.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Quality management Plan Resource management Plan Communication management Plan Project change management Plan Risk management Plan Procurement management Plan Stakeholder Management Plan
SETPV-05	Integration Process	The purpose of the Integration Process is to synthesize the specified standard components of the bogie to make up the complete bogie system that satisfies the system requirements, architecture, and design. The outputs of this process are; 1. Integration Strategy, 2. Integration Enabling System Requirements, 3. Implementation Constraints, 4. Integration Procedure, 5. Integration system or standards components , 6. Interface definition update identification , 7. Integration Reports, 8. Integration Records	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Quality management Plan Resource management Plan Communication management Plan Project change management Plan Risk management Plan Procurement management Plan Integration management Plan Stakeholder Management Plan

Table 33: Systems engineering technical process viewpoint (SETPV) continued

Source: Author.

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
SETPV-06	Verification Process	The purpose of this process is to provide objective evidence that the acquired bogie system or standards components making up the bogie fulfil the bogie's specified requirements (defined in SETPV-01 above) and characteristics. The outputs of this process are: 1. Verification Strategy, 2. Verification enabling system requirements, 3. Verification constraints, 4. Verification Procedure, 5. Final RVTM, 6. Verified bogie system, 7. Verification Report, and 8. Verification Records	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-07	Transition Process	This process is concerned with the establishment of the bogie's capability to provide services specified by the stakeholders (SETPV-01 and SETPV-02) in the operational environment. The outputs of this process are: 1. Transition strategy, 2. Transition enabling system requirements, 3. Transition constraints, 4. Installation procedure, 5. Installed bogie system, 6. Trained operators and maintainers, 7. Transition report, 8. Transition record.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-08	Validation Process	The purpose of the validation process is to provide objective evidence that the bogie system when in use, fulfils its business or mission objectives and stakeholders needs/requirements, achieving its intended use in its intended operational environment. The outputs of this process are: 1. Validation Strategy, 2. Validation enabling system requirements (Validation requirements forms part of SETPV-01 and SETPV-02), 3. Validations constraints, 4. Validation Procedure, 5. Validation requirements, 6. Validated bogie system, 7. Validation report, and 8. Validation record (Note: Industry requirements standards for bogies are EN 16363, EN 16749, UIC 512 and will supplement the URS)	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, Safety Certification Authority, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-09	Operation Process	The Operation process is to use the bogie system for the purpose for which it was developed. The outputs that enable this to happen are: 1. Operational strategy, 2. Operational enabling system requirements, 3. Operational constrained, 4. Operational report, and 5. Operational record.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Operator, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Model Based Systems Engineering (MBSE) Tools, FFBD, System Lifecycle, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview.
SETPV-10	Maintenance Process	In order to sustain the capability of the bogie system to provide its service as intended, maintenance has to be carried out regularly. This process enables this and the following are the outputs of this process: 1. Maintenance strategy, 2. Maintenance enabling system requirements, 3. Maintenance constraints, 4. Maintenance procedure, 5. Maintenance report	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Maintainer, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Maintenance theory, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Reference Documents,
SETPV-11	Disposal Process	This process is concerned with the ending of the existence of the bogie system and its standard components for its specified intended use. During this appropriate handling of the retirement process of the bogie is identified and any potential disposal needs are identified.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Owner, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Reference Documents, Regulatory Requirements

Table 34: Operational viewpoint (OV)

Source: Author.

Operational Viewpoint Viewpoint (OV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
OV-01	high-Level Operational Concept Graphic	<ul style="list-style-type: none"> A graphical illustration of different operational scenarios has to be developed based through lifecycle of the bogie. The graphical illustration will serve as a tool for discussion of the expected operation of the bogie. It can be used to provide a common way to more detailed information in published architectures. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Model Based Systems Engineering (MBSE) Tools, FFBD, System Lifecycle, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview.
OV-02	Operational Performance Attributes. (MoEs)	<ul style="list-style-type: none"> Performance characteristics of the bogies have to be defined during this process. The extent to which the bogie performs during operation has to be measured using Measure of Effectiveness (MoEs) and they are defined during this process. They also assist in determining the required design effort to meet the needs of the stakeholders. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	MoEs, Requirements Analysis
OV-03	Operational Node Relationship Description	<ul style="list-style-type: none"> A description of the bogies operational behaviour is defined using a User Operation Concept Description (OCD) and provides common understanding between client and TE PD on how the bogie is expected to operate. It is during this process that the capabilities of the bogies are defined and agreed on by stakeholders. Different documents for Standard Operating Procedure for different stakeholders (Maintainer, Operator, Manufacturer, Integrator, Transporter, Tester) are eventually compiled and provided to the relevant stakeholders. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Scenarios, States and Modes, FFBD,
OV-04	Operational Information Exchange Matrix	Any interoperability of the bogie is defined during this process and the requirements to this effect defined and managed.	(MOD homedefence, 2010)	Client/Customer, Design Team, Lead Systems Engineer	Definition of Interoperability Requirements
OV-05	Operational Rules Model	<ul style="list-style-type: none"> Doctrinal operational procedures from the client are defined during this process and their rationale captured. Business Rules for the major stakeholders as well as those within TE are defined at this stage. Operational constraints within TE and for the major stakeholders as well as those within TE are defined at this stage. 	(MOD homedefence, 2010)	Client/Customer, Design Team, Lead Systems Engineer, Support service (Procurement, HR, Finance), Infrastructure Owner, Operator	Systems Thinking
OV-06	Operational Event-Trade Description	<ul style="list-style-type: none"> Identification of non-operational requirements related to the bogie occurs during this process. The captured expected behaviour is analysed during this process and trade-offs made and agreed on by all stakeholders. Scenarios for testing during operation are defined during this process as well as methods of testing, tools for testing, data recording and presentation, as well as evidence that requirements have been met and allowable variances. <p>(Note: The trade-off shall consider the cost and schedule impact of testing that results from the Work Breakdown Structure (WBS))</p>	(MOD homedefence, 2010)	Client/Customer, Lead Systems Engineer	Scenarios, States and Modes, FFBD, MoEs, Requirements Analysis, Verification Requirements

3. RESEARCH PROCESS

The research design in terms of techniques, methodology, instruments, approach, and philosophy used for this research is detailed in the section below.

3.1 Research Design

The research design for this paper was based on the research methods developed by (Saunders *et al*, 2009). This method is explained using the research onion, which is shown in Figure 55 below. This method serves as a framework for the research design for this research, and it explains the philosophies used, approaches, instruments, Methodologies, time horizons, and techniques and procedures (Saunders *et al*, 2009).

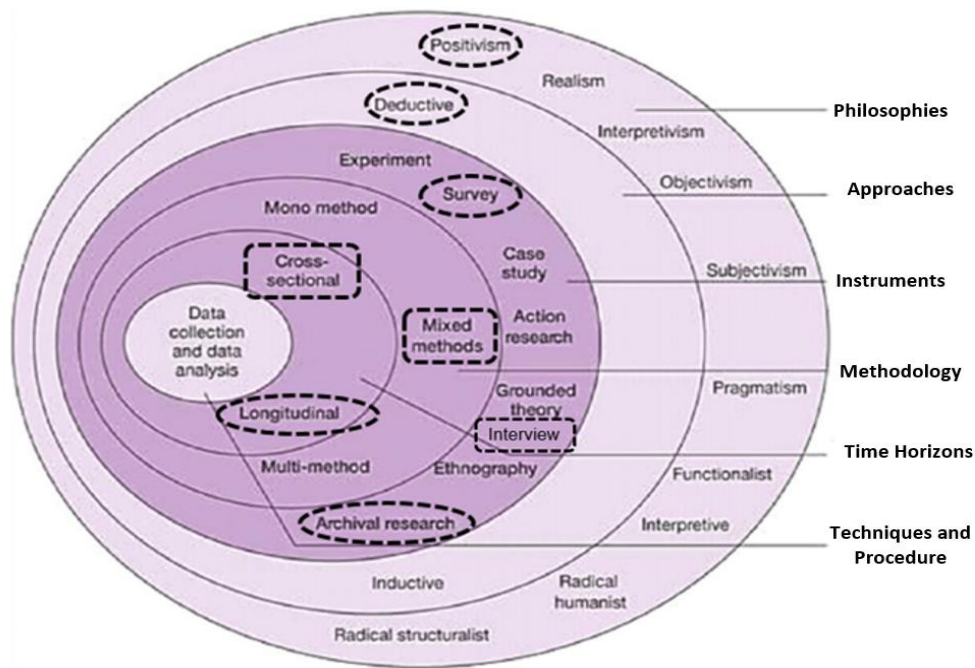


Figure 55: The research onion used for the study

Source: Author adapted from (Saunders *et al*, 2009)

3.2 Research Philosophy and Approach

A positivism philosophical approach with a deductive approach was used for this research. This approach allows the researcher to study real events empirically and explain them using logical reasoning (Leong, 2008). Data was collected about the procedures used in acquiring rolling stock and identifying the systems frameworks and systems principles to formulate a framework for the acquisition of bogies for TE PD.

3.3 Methodological Choice

This research used mixed methods for data collection to gather qualitative and quantitative data cross-sectional and longitudinal time horizons. The instruments used to collect the data were a Likert survey, archival research, and semi-structured interviews. The data collection and analysis strategy is shown in Figure 56 below (Creswell & Creswell, 2018).

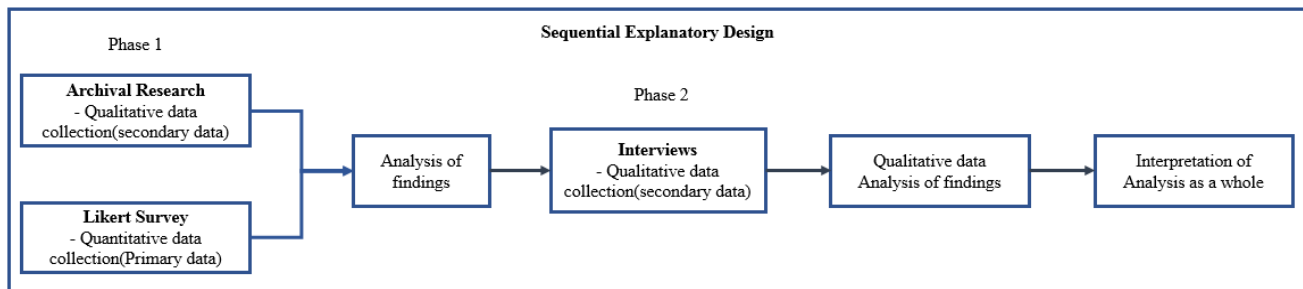


Figure 56: Mixed methods research data collection and analysis strategy

Source: Author adapted from (Creswell & Creswell, 2018)

3.3.1 Archival Research

Data was collected from documents located in TE’s different businesses, TE PD Coaches, TE PD Wagons, TE PD Locomotives, TE R&D Mechanical, TE R&D Electrical as well as an integrated online system. There has been a total of thirteen (13) bogie projects in Transnet Engineering since the 1970s, eight (8) of which are archived and five (5) of which are active projects. Of these projects, five (5) are wagon bogie projects, seven (7) are coach bogie projects, and one (1) is a locomotive bogie project. For this research, six (6) projects were considered for a cross-sectional view that looked at a single point in time across different departments, and nine (9) projects were considered for a longitudinal time horizon that looked at the same projects over a period of time for both active and archived bogie projects. The reason for not conducting the study on all thirteen (13) projects is because the record keeping in the 1970s was not as detailed, so most of that data cannot be located and people who worked on those projects are no longer with the company and cannot be contacted.

Projects that were considered were projects with approved business cases and funded by TE’s Capital Expenditure budget from the 1980s until 2022. The archival research looked at the process followed for each project by looking at project documents used and the factors considered through lifecycle of the project as well as study the lifecycle of the projects themselves.

The qualitative data gathered from the sources mentioned above were converted to quantitative data and analyzed further by coding it. The documents considered are stated in ISO 26702:2007 (ISO/IEC 15288, 2007) for all applicable systems processes according to Figure 40 on page 45.

Table 35: Project for cross-sectional and longitudinal horizon time zones

Source: Author

Department	Vehicle type	Number of projects	
		Cross-sectional view projects	Longitudinal view projects
TE R&D Mechanical	Coach	1	1
	Locomotive	-	-
	Wagon	1	1
TEPD	Coach	2	2
	Locomotive	-	1
	Wagon	1	2
TE PD Coaches	Coach	1	4
TE PD Wagons	Wagon	-	3

3.3.2 Likert Survey

For the Likert survey, the sample set shown in Table 36 below was used. An appropriate scale for rating the responses was decided on. Because not all Transnet Engineering employees are involved in rolling stock, the sample size was calculated based on the employees relevant to the study. A total of 70 surveys were sent out; a minimum of 40 respondents is required to consider the survey a success. This makes it

a respondent rate of 57.1%. The norm for a survey to be considered a statistically significant one needs a respondent rate of at least 47.5%, which translates to 32 respondents for the given sample size (Cochran, 1997) . The minimum required respondent rate for the key respondents is also above the calculated minimum of 47.5% except for junior engineers.

Table 36: The required sample set for the survey

Source: Author

Profession	Designation	Number of Surveys Issued	Desired Response Rate
Mechanical Engineering	Principle Engineer	5	80%
	Senior Engineer	8	50%
	Engineer	10	50%
	Junior Engineer	5	40%
Electrical Engineering	Principle Engineer	1	100%
	Senior Engineer	3	66.7%
	Engineer	5	40%
	Junior Engineer	5	20%
Systems Engineering	Principle Engineer	2	100%
	Senior Engineer	3	66.7%
Integration Engineering	Principle Engineer	1	100%
	Senior Engineer	2	50%
	Engineer	2	50%
	Junior Engineer	2	50%
Metallurgy Engineering	Principle Engineer	1	100%
	Senior Engineer	2	50%
Software Engineering	Principle Engineer	1	100%
	Senior Engineer	2	50%
Industrial Engineering	Senior Engineer	1	100%
	Engineer	2	50%
Industrial Engineering	Senior Engineer	2	50%
Project Lead	Project Manager	5	80%

3.3.3 Semi-structured Interviews

Semi-structured interviews were conducted with subject matter experts, and questions were informed mainly by the results from the survey as well as the archival research. The experts who were interviewed participated in the surveys and have Transnet experience.

Table 37: Sample set for the semi-structured interview

Source: Author

Experience Required	Formal Training Required
<ul style="list-style-type: none"> - 20+ years experience - Transnet experience 	<ul style="list-style-type: none"> - Mechanical engineer with speciality structural design
<ul style="list-style-type: none"> - 30+ years - Rolling stock development - Research and Development - Transnet experience 	<ul style="list-style-type: none"> - Mechanical engineer, Honours level BEng degree
<ul style="list-style-type: none"> - Experience of 20+ years and 15+ project management experience preferable - Experience 	<ul style="list-style-type: none"> - Systems Engineer, Masters at least - Mechanical engineer - PMI training

The purpose of the interviews is to:

- Validate the bogie acquisition issues identified from the critical literature review and survey responses.
- Validate the Systems Framework for the Acquisition of Bogies Through Lifecycle for TE PD projects.

3.4 Reliability and Validity

The validity and reliability of the research findings were dependent on the research methodology that followed. As explained in Sections 3.1, 3.2, and 3.3, the research design was based on the research onion (Saunders *et al*, 2009) that the researcher adapted to use a positivism philological approach with an inductive approach. It involves the study of real events and use of empirical data and explains it using logic (Leong, 2008). Mixed methods were used to collect the qualitative and quantitative data and they are Likert survey, archival research, and semi-structured interviews. The consistency of the data collected from survey asking the same questions differently in the survey and comparing the survey responses to the archival research of the current process.

The interviews were conducted on a one-on-one basis, with each taking just over an hour. The one-on-one basis ensured the openness, pragmatism, independence, and honesty validity. The responses of the interviewees were compared to their answers from the surveys, and questions were asked in different ways at different times during the interview to ensure consistency. The researcher encouraged the interviewees to provide examples for some of their answers without revealing the identity of those involved or the projects they were working on. This method of conducting research is suggested by (Leedy & Ormrod, 2018) to eliminate contradiction and ensure validity and reliability of information.

3.5 Ethical Considerations

In order to ensure that the research was conducted ethically as required by the Faculty of Engineering and the Built Environment (School of Mechanical, Industrial, and Aeronautical Engineering, 2022) policy, the researcher had to undergo online training and a test to demonstrate understanding of the ethics policy of the University before obtaining ethics clearance. Ethics clearance confirmation is presented in APPENDIX A of this report. Ethics clearance number for this research is MIAEC 104/21.

4. RESEARCH RESULTS

Results of the Likert survey, archival research, and semi-structured interview are given in the section below. Because the data collected in this research is qualitative and quantitative, it is mixed methods in nature (Leedy & Ormrod, 2018). The researcher's process for research was predetermined before conducting the actual research and is discussed in Section 3. A positivism philosophical approach with a deductive approach was implemented for the research.

4.1 Survey Results

The survey questions were derived from the acquisition factors identified from the literature review. Respondents were asked to give their opinion on how they experienced these factors in bogie or rolling stock projects they have been involved in while in TE PD. The questions were structured such that the responses from respondents can be tested for consistency by asking same question in different ways at different time on the survey. The opinions were given in the form of a rating scale and open questions.

The results of the survey reflect the perception of some of the employees involved or previously involved in bogie projects at TE PD. As mentioned before, according to (Cochran, 1997), a response rate of a least 47.5% (32 respondents) is required to make the survey statistically significant, but for this research a response rate of 57.1% (40 respondents) was identified based on the size of employees involved with rolling stock in TE PD. The actual response rate achieved was 60% (42 respondents); the categories of the respondents is shown in Table 43 in APPENDIX B. Distribution of the results is shown in Figure 57 below and open questions are shown in Table 44 in APPENDIX B. Software called Survey Monkey was used to create and share a link for the survey and to collect the data. Then, Microsoft Excel was used to process the data and plot graphs to increase readability. Responses from the open questions were retrieved from Survey Monkey and presented in table format in Microsoft Excel then transferred to Microsoft Word.

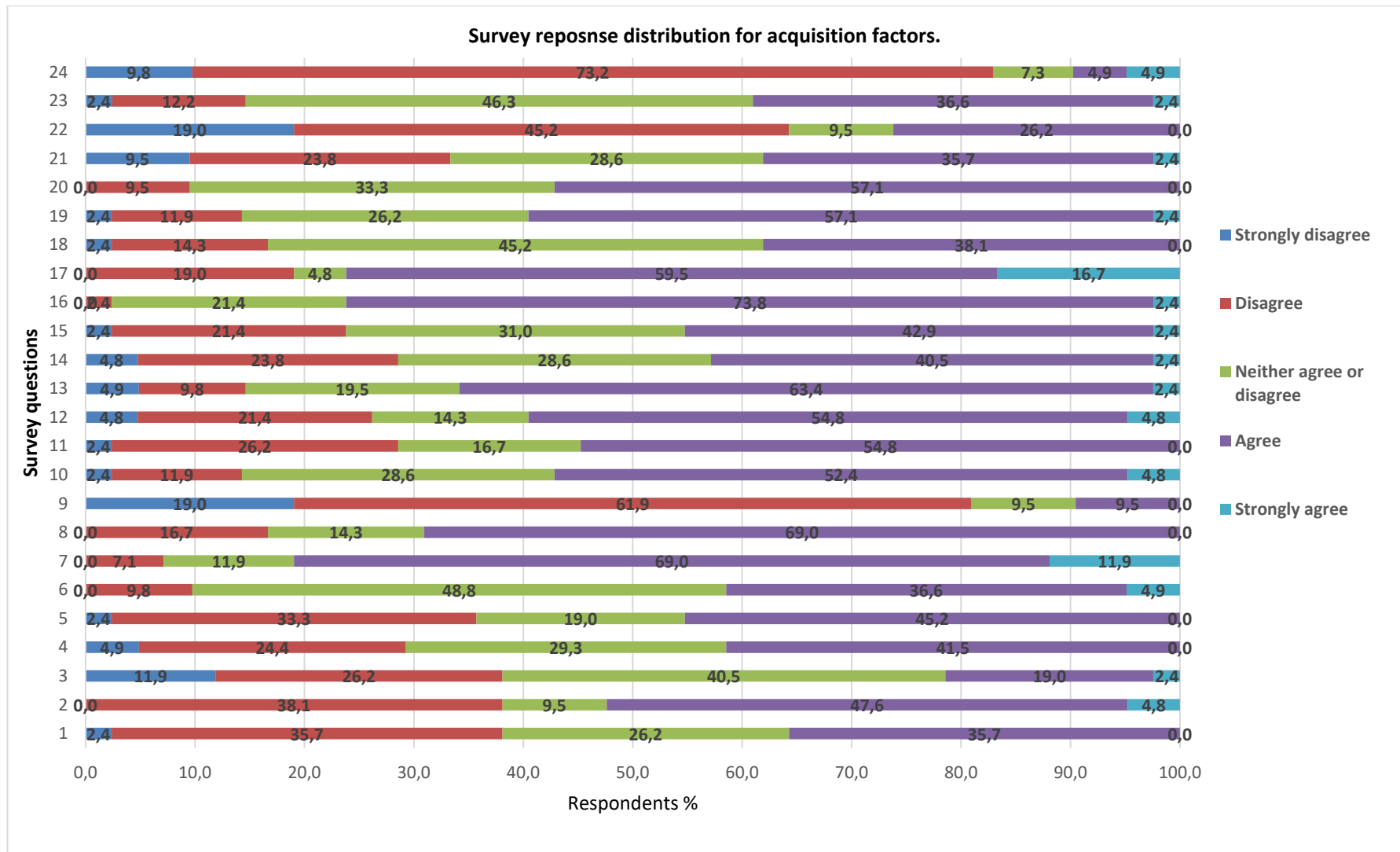


Figure 57: Survey response distribution in %

Source: Author

Table 38: Survey questions

Source: Author

#	Questions
1	Is the schedule estimation detailed enough?
2	Was the team composition suitable for the project timelines?
3	Was the project funded to completion?
4	Is the development cost estimations detailed enough?
5	Is communication with stakeholders satisfactory and maintained throughout?
6	Was the strategy (in-house, OEM partnership, COTs) used to acquire that bogie inline with the TE's vision and mission?
7	Does the team have the necessary technical skills for the acquisition strategy (in-house, MOE partnership, COTs) employed?
8	Is requirements management done in a satisfactory manner?
9	The procurement processes are suitable for all types of acquisition strategies. (in-house, MOE partnership, COTs)
10	Is the design effort adequately managed during design? Addressing the customer's needs and not over designing.
11	Is the process of identifying stakeholders satisfactory?
12	Are design changes managed adequately in a standardized manner?
13	Are design changes communicated adequately to the rest of the team?
14	Is risk (system quality, funding, legal, schedule, cost, performance, strategic, market) identification adequately done?
15	Are the risk management interventions managing the risk adequately?
16	Is there adequate identification and planning for all the work to be done to complete the project?
17	Have you experienced scope creep in your project?
18	System quality is managed in a satisfactory manner throughout the development period?
19	The project enjoyed adequate leadership support throughout.
20	Are team members allocated enough work? i.e not overworked or underworked.
21	Contract management with suppliers is satisfactory.
22	Communication with suppliers is satisfactory.
23	Is there adequate support (maintenance, retrofitting , modifications) to customers once bogies have been delivered?
24	Are there plans in place on what happens to the bogies once retired?

4.2 Archival Research Results

The approach taken for the archival research was to interrogate the current acquisition process in TE PD from the qualitative data obtained from the internal process. The process was interrogated by comparing the project documents detailing the acquisition process to the developed acquisition lifecycle and the acquisition factors identified to be important for the process. The acquisition factors were amalgamated from the literature review and survey responses. The information obtained from the two acquisition process documents is secondary information as it was not compiled by the researcher. To scrutinize the process, the latest templates referred to as ‘Template A’ and ‘Template B’ were obtained internally and studied. Template A is approved by management and details the milestones and deadlines of each project. For any changes to the project scope or priorities of the project, the management that initially approved the documents has to approve the changes and possibly re-establish the baseline of the project. Template B, however, is a short formal document that describes the project in its entirety from the project objectives, how the work is to be carried out, the stakeholders and, once signed, it initiates a project. These documents cannot be shared due to the intellectual property protection requirements. The considerations contained in both documents were compared to the acquisition factors identified in the proposed framework throughout the amalgamated lifecycles. Template A and Template B’s considerations are as follows: problem/opportunity identification, project scope, project deliverables, sub-projects, project stages (with stage description, names, and description), procurement plan, communication plan (communication matrix, meetings, reports), project organization (project management team, steering committee, other stakeholders), strategic alignment, objectives, alternative solutions, critical success factors, inclusions, exclusions, assumptions, dependencies, constraints, milestones, customer (person), sponsor (person), project management team, abbreviations and definitions, budget, risks, benefits and measures. Just as a reminder, factors deemed critical for new product development by (Dwivedi & Karim, 2021) are listed in Table 39 below, and factors that contribute to project failure most of the time, as ranked by (Stewart, 2021), are shown in Table 40 below.

Table 39: NPD process critical success factors

Source: (Dwivedi & Karim, 2021)

#	Critical Success Factors	Lester (1998)	Cengiz et al. (2005)	Floren et al. (2018)	Copper et al. (1995)	Fernandez et al. (2017)	Sun et al. (2004)	Suwannapom et al. (2010)	Holland et al. (2000)	Connell et al. (2001)	Total
1	Top management commitment	X	X	X	X	X	X	X	X	X	9
2	Presence of clear goals & milestones	X	X	X	X	X	X	X	X		8
3	User/customer involvement (i.e market research)	X	X	X		X	X	X	X		7
4	Involvement of cross-functional teams	X	X	X	X	X			X	X	7
5	Placement of structured NPD process	X	X		X		X	X	X		6
6	Talented team members with relevant experience to NPD Process &Activities			X	X		X	X	X	X	6
7	Establishment of an entrepreneurial culture	X		X	X				X	X	5
8	Effective communication amongst team members & Management	X			X			X	X	X	5
9	Alignment of NPD Process activities with strategy.			X	X				X	X	4
10	Focusing on innovation & Out-of-the-box ideas	X	X				X			X	4
11	Availability of financial requirements				X		X		X		3
12	NPD Process Speed		X				X				2

Table 40: Ranking of factors that lead to project failure

Source: Author adapted from (Stewart, 2021)

Factor ranking	Factor leading to failure
1	Scope creep
2	Overallocated Resources
3	Poor Communications
4	Bad Stakeholder management
5	Unreliable Estimates
6	No or inadequate Risk Management
7	Unsupported Project Culture
8	The accidental Project Manager
9	Lack of Team Planning Sessions
10	Monitoring and controlling

Based on the archival research, the Transnet Project Lifecycle (PLP) process, TE PD project process, and proposed bogie acquisition process lifecycle processes were compared. In going through the TE PD bogie acquisition documents for projects, it is evident that process is followed as all projects apply the current templates. Different project teams are doing things right, but the things they are doing can be improved. It is evident, when looking at Table 41, that the acquisition lifecycle process implemented by TE PD has augmented the Transnet PLP, especially in the early stages of a project to make the process better suit the risk associated with the kind of projects undertaken in TE PD. The process can still be improved, however, especially at the project and post-project phases.

Table 41: Transnet vs TE PD vs proposed framework acquisition processes though lifecycle

Source: Author adapted from (PD PMO, no date a; Transnet Capital Projects, 2008)

Bogie Acquisition Processes	Acquisition Lifecycle Phases																										
	Pre-Project Phase							Project Phase										Post-Project Phase									
	Opportunity Identification or Need	Stakeholder Identification	Stakeholder requirements	Risk Analysis	Decide on Acquisition Strategy	Acquisition Planning	Building the team	Concept Development and Selection	Develop Project Plan	Develop SEMP	Develop a ConOps	Functional Analysis	Develop System and Components	Requirements	Detailed Design	Manufacture	Subsystem Verification	System Verification	System Validation	Production and Sales	Marketing	Commissioning	Operation and maintenance (Performance monitoring)	Support (Retorfit and modifications)	Lifetime Performance Evaluation.	Decommission	Dispose
1 Suggested Bogie Acquisition Framework	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
2 Transnet Project Lifecycle Process (PLP)	Red	Red	Red	Red	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
3 TE PD Bogie acquisition	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green

Legend	
Green	Considered by process
Red	Not considered by process
Yellow	Partially considered

4.3 Semi-structured Interview Results

The purpose of the semi-structured interviews restated below is to:

- validate the bogie acquisition issues identified from the critical literature review and survey responses, and
- validate the systems framework for the acquisition of bogies through lifecycle for TE PD projects.

The interviewees were given a presentation of the bogie acquisition framework, and using their expert knowledge and experience, were asked to critique the framework. Interviewees were presented with the checklist matrix with 30+ acquisition factors identified from the critical literature review conducted, survey responses, and archival data, and asked to comment on the likelihood of the framework to address these factors. The interviews were conducted remotely and recorded using Microsoft Teams. The inputs from the interviewees were transcribed to Microsoft Excel in a table format then incorporated into Microsoft Word.

4.4 Revised Framework

Once the results from the research were considered, as well as the critique of the framework from industry experts, the framework was revised and four more viewpoints in the strategic view were added. The revised framework is shown in Figure 58 below as well as the write up from Table 47 to Table 58 in APPENDIX D.

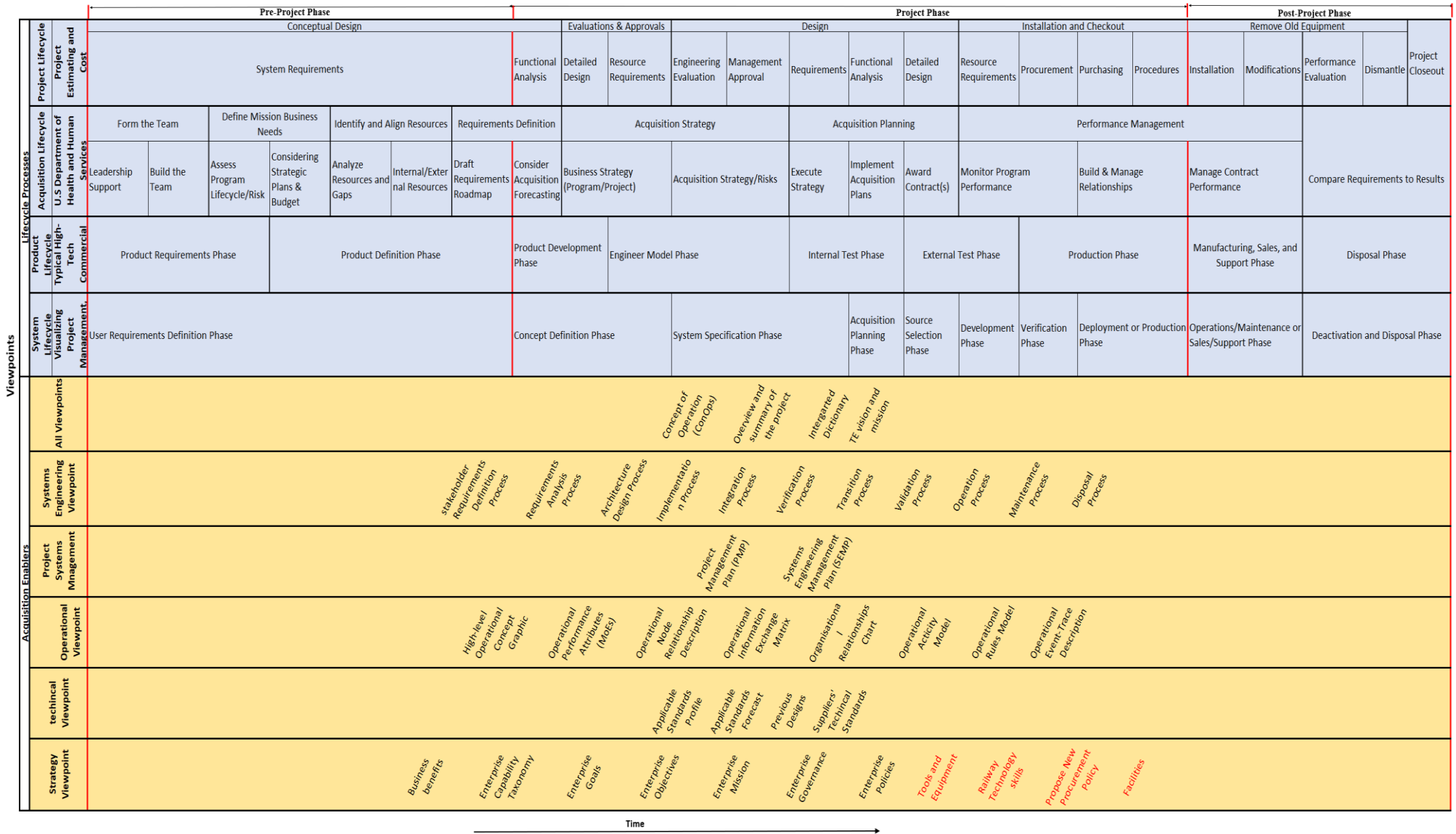


Figure 58: Revised framework

Source: Author

5. ANALYSIS AND DISCUSSION

This section compares the information gathered from critical literature from the focus areas to the research findings from surveys, archival research, and semi-structured interviews; then, it critiques the findings. The reliability and validity of the research findings were achieved through critically analyzing and comparing the findings from the surveys, archival research, and semi-structured interviews.

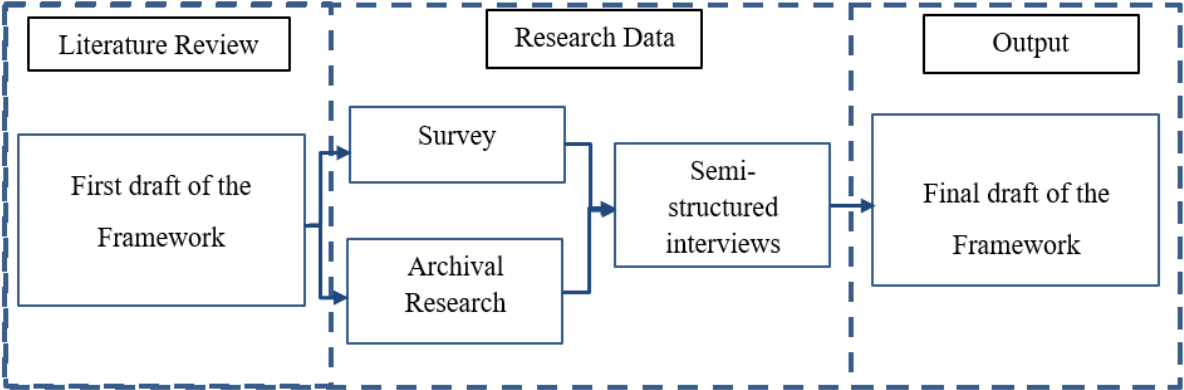


Figure 59: Process of creating final framework

Source: Author

5.1 Archival Research

The researcher found that the phases of the project lifecycle and definitions thereof are discussed after acquisition factors have been considered in Template A. This means the acquisition factors are not considered with a complete acquisition lifecycle of rolling stock in mind. A comprehensive lifecycle is crucial as it addresses the *When?* part of the acquisition factors. Schedule, budget, control, and monitoring, quality, risk, and all other important acquisition factors need to be considered not with one or a few phases of the lifecycle in mind, but the entire lifecycle in mind so as to minimize scope creep, cost overruns, and reduce risk or developing a bogie/system that does not address the needs or offer a maximized value proposition for the main stakeholders.

5.2 Surveys

The responses of the survey are based on the experiences of those involved in the projects, previous and present, and what they believe to be the issues. It is important for one to be able to see past the symptoms and provide a diagnosis of the real problem and how best to address it. Each respondent has a static view of the project and their responses. Once archival research was done on the acquisition process templates and issues experienced as reflected by the survey, responses started to make sense to the researcher. The biggest issue experienced according to respondents is scope creep, which, according to (Stewart, 2021), is the leading cause of project failure. A ranking of the causes leading to project failure is quoted once more in

Table 40 above.

According to question seventeen (17) in Figure 57 above, 59.5% and 16.7% of the respondents agreed and strongly agreed respectively to having experienced scope creep in their projects. However, the respondents believe work required to complete the project was adequately detailed, according to responses to question sixteen (16). A possible reason became clear to the researcher why there was scope creep experienced on most projects. There was no process that detailed the work to be done, using the lifecycle and breaking down the bogie and its components, to identify the work and services required to acquire all the components that made up the system. A process like a Work Breakdown Structure (WBS) would be very helpful in this case. It was evident also from the response distribution that the

acquisition process does not consider the possible impact of disposing of the bogies as 73.2% and 9.80% of the respondents disagreed and strongly disagreed respectively that there are plans in place of what is to happen to bogies once they are retired. This is question 24 of the survey. An opportunity to salvage all possible value from the bogies could be identified and used as part of value proposition to potential customers or any cost associated with disposing of the bogies could be identified so that it does not pose a risk at end of life of the bogie. Technical skills of the team members are not an issue, according to the responses to question seven (7), as over 69.0% and 11.9% of the respondents agreed and strongly agreed respectively that there are adequate technical skills internally to acquire bogies using any acquisition strategy. In question nine (9), 19.0% and 61.9% of the respondents strongly disagreed and disagreed respectively that the current procurement processes are suitable for all types of acquisition TE PD implements for its acquisition of bogies. Another issue that has been identified is communication with suppliers. Looking at responses to question 22, only 26.2% of the respondents believed there is adequate communication with suppliers but a considerable portion 45.2% disagreed while 19.0% strongly disagree. The feedback from the open questions gave some good insights into the possible causes to some issues perceived by the respondents. The researcher added some of the feedback to the checklist matrix in APPENDIX E, such as bogie pricing and identifying tasks that influence the pricing of the bogie. Most respondents believed that, should the acquisition issues identified by the research be addressed, this would significantly improve the rolling stock acquisition process in TE PD. A summary of the responses to open questions is shown in Table 44 in APPENDIX B. 54.80% of the respondents responded to question two (2), while 61.90% responded to question three (3), and 45.20% responded to question four (4).

5.3 Semi-structured Interviews

The interviews were conducted one-on-one, and each lasted no less than 1 hour. The responses from the interviews were compared to their responses on the surveys and open questions of the surveys to ensure the responses were consistent. The researcher asked interviewees for examples of situations that resulted in the feedback given, but the projects names or people involved were not disclosed. This method of ensuring data is consistent and captured in its entirety is recommended by (Leedy & Ormrod, 2018). The feedback from the semi-structured interviews was vital as the interviewees added invaluable information to the acquisition factors that are to be considered through life of the acquisition process. The factors added by the interviewees were: 1. maintenance of tools and equipment used during development, 2. technology readiness, 3. technology knowledge base in team members, 4. risk associated with policy, and 5. cost of creating the bogie system. Interviewee number two, with 35+ years in railway at TE, stressed the need for such a framework to improve the acquisition of bogies as, in his experience, bogies account for 20% of revenue generated from rolling stock.

Interviewee number two further recommended the checklist matrix be used to measure the 'health' of the project over and above being a checklist for the planning of the acquisition. This would mean the checklist would be visited during acquisition to monitor the progress and success of a project. A summary of the responses to the semi-structured interviews with subject matter experts is shown in Table 46 in APPENDIX C.

6. CONCLUSION

This section focuses on a summary of the research and provides conclusions of the findings. Limitations for the research are also discussed in this section as is future work.

6.1 Summary

The objectives of the research restated are:

- **Main Objective** (Section 1.6.1)
 - Evaluate the current processes for the acquisition of rolling stock, including bogies, within TE
- **Sub-objectives** (Section 1.6.2)
 - Identify systems engineering principles and methodologies that can be adopted in the development of a systems framework for the acquisition of bogies
 - Establish a systems framework for the acquisition of bogies in Transnet Engineering Product Development

In going through the project templates, it is clear all projects follow process as intended. From the archival research conducted, it is evident that the current process is more project management strong and is limited in application of systems engineering principles and methodologies in system design and project management. The survey responses gave insight into some of the issues as perceived by the respondents who have been involved in rolling stock projects and bogies projects in TE PD. According to survey responses, the biggest issue experienced in bogie acquisition projects is scope creep. According to (Stewart, 2021), this is the number one reason from top ten reasons why projects fail as can be seen in the literature review and Table 40 shown earlier. This further highlights the importance of improving the process of estimating and determining the work to be done and better estimation of time needed to do the work through use tools such as WBS and SEMP. It was found from the archival research that project phases are only stated and defined at the end of Template A after acquisition factors such as risk, assumptions, and budget have already been listed in the body of the document. In future, the developed checklist matrix would be useful in determining when the different acquisition factors need to be considered, and enablers of the framework will be used for application of the framework. The proposed framework from Table 47 to Table 58 makes recommendations on different systems engineering features and methodologies to apply when performing the tasks for the different viewpoints.

The research found that the project lifecycle implemented in TE PD has been adapted to include the pre-project phase, starting the project at identification of a need or an opportunity and obtaining leadership buy-in early on from the identified opportunity. The project cycle includes phases identified in the Transnet PLP as well but, as found in this research, that process is more suitable for mega projects with requirements that are fixed and unlikely to change during the project. The developed acquisition lifecycle process is suitable for high-risk projects associated with development of new innovative products that require research. Four different lifecycle processes – namely, 1. system lifecycle, 2. acquisition lifecycle, 3. product lifecycle, and 4. project lifecycle – have been amalgamated to develop an acquisition lifecycle process suitable to develop a complex system such as a bogie and can be altered accordingly to develop other rolling stock equipment.

The checklist matrix measures the health and status of a project by looking at which acquisition factors have been considered in the design phase and which phases of the acquisition lifecycle process have they been considered for.

The main contribution of this research is the development of the acquisition lifecycle that is ideal for acquiring a complex system such as a bogie and combining this lifecycle with acquisition factors. The implementation of the two ensures that the acquisition is done through life of the bogie and important factors that determine the success or failure of this acquisition are considered for the entire life of the

bogie system. The enabler identified from the literature that comes mainly from systems engineering principles and methodologies as well as project management principles will be useful in application of the framework. According to the Pareto Principle developed by Vilfredo Pareto, an Italian economist, 80% of the problems are caused by the top 20% of the issues (Laoyan, 2021). From internal research, the top issues experienced in rolling stock acquisition in TE PD are as shown in Table 42 as well as the interventions proposed by the framework. This list makes up 21.8% of the 32 acquisition issues listed on the checklist in APPENDIX E. Contributions from subject matter experts have been captured in red on the matrix.

Table 42: Top seven rolling stock acquisition issues in TE PD

Source: Author

#	Problematic acquisition factor	Rank	Interventions from the framework
1	Procurement	1	Proposed changes in policy.
2	Retirement plans for bogies	1	through lifecycle consideration of disposal requirement and early intervention in design and estimation of financial impacted related to the disposal.
3	Scope creep	2	<ul style="list-style-type: none"> • Use of a detailed WBS through lifecycle • Use of SEMP
4	Communication with suppliers	2	<ul style="list-style-type: none"> • Put in plan a standardized communication plan. • Identify and use a central place for record keeping. e.g MS Teams
5	Support during operation	2	<ul style="list-style-type: none"> • Requirements management through lifecycle • Use of a ConOps • Design For X principle on the checklist
6	Suppliers contract management	3	<ul style="list-style-type: none"> • Use of a detailed WBS through lifecycle • Contract management principles • Proposed changes to procurement policy
7	System quality	3	<ul style="list-style-type: none"> • Use of a ConOps • Use of MOE of stakeholders • Design For X principle on the checklist

6.2 Limitations

For this research, the following were identified as limitations:

- The developed framework is developed with TE in mind and is developed for the acquisition of bogies and adaptable to include all rolling stock. Should one wish to use this framework in a different organization or a different product, the background research and literature would have to be done on the product as well as the organization.
- The research from surveys and semi-structured interviews were conducted from point of view of TE PD as it was conducted with current and former employees. Further research can be done with suppliers and customers of TE PD to expand on the understanding of the actual problem to solve.
- The framework provides the different viewpoints with applicable systems engineering principles and methodologies, responsible stakeholders, but does include templates required to implement the framework. These can be developed later using industry standards.
- The framework, as presented, has not been tested through application to measure its effectiveness.

6.3 Future Research and Recommendations

Considering the summary and limitations of the research, the following future work and recommendations are made:

- The stakeholders identified to be the owners of the different viewpoints can be altered to serve the purpose per project with the names and contact information as well as organization for each stakeholder must be identified as the acquisition process will not only be a multidisciplinary exercise but a multiorganization one as well.
- It would be ideal for the framework to have a custodian who will be responsible for its application and be a common thread for all stakeholders. A lead systems engineer with all systems engineering competencies would be ideal for the position.
- Templates for the different viewpoints of the framework must be created and standardized and applied in different bogie acquisition projects.
- The framework can be adapted to include acquisition of all kinds of rolling stock and not just bogies.
- The framework can be expanded and used to acquire other products that TE needs to serve other operating divisions in Transnet, such as ports and TFR.
- It is recommended that the performance of projects using the framework be monitored for comparison to previous processes using traditional methods.

"A clever person solves a problem; a wise person avoids it."

- Albert Einstein -

LIST OF REFERENCES

- (TCSE)., W. engineering (2020) 'Systems Thinking for a Digital World SE Overview and SE Management Disclaimer & Referencing'.
- Alexander S, G. (2020) *What is Enterprise Architecture (EA)?* Available at: <https://www.techtarget.com/searchcio/definition/enterprise-architecture> (Accessed: 20 April 2022).
- Alghamdi, A.S. (2009) 'Evaluating Defense Architecture Frameworks for C4I System Using Analytic Hierarchy Process Abdullah S . Alghamdi Department of Software Engineering , College of Computer and Information Sciences ', 5(12), pp. 1075–1081.
- Allert, F. (2013) *FLEXX Compact – the most successful bogie platform for regional and commuter trains - Global Railway Review*. Available at: <https://www.globalrailwayreview.com/article/19492/flexx-compact-the-most-successful-bogie-platform-for-regional-and-commuter-trains/> (Accessed: 11 April 2022).
- Anderson, D. (2021) *How to eliminate the cost of quality by design*. Available at: http://www.halfcostproducts.com/design_for_quality.htm (Accessed: 29 April 2022).
- APSC381 (2020) *APSC 381: Fundamentals of Design Engineering – Engineering Design and Practice Sequence*. Available at: <https://edps.engineering.queensu.ca/edps-iii-iv/apsc-381-fundamentals-of-design-engineering/> (Accessed: 29 April 2022).
- Ash, P. (2021) *Exports threatened as lack of spare parts and cable theft cripple Transnet*. Available at: <https://www.timeslive.co.za/sunday-times/news/2021-12-19-exports-threatened-as-lack-of-spare-parts-and-cable-theft-cripple-transnet/>.
- AustrianDEEWR (2012) 'MEM18017C Modify mechanical systems and equipment Release: 1', pp. 1–11.
- Bellman, B. (no date) *The Department of Defense Architectural Framework (DoDAF) | EA Principals*. Available at: <https://www.eaprincipals.com/content/department-defense-architectural-framework-dodaf> (Accessed: 24 April 2022).
- Billups, A. (2015) *HHS ACQUISITION INITIATIVES - ppt download*. Available at: <https://slideplayer.com/slide/5274091/> (Accessed: 19 April 2022).
- Blanchard, B.S. and Fabrycky, W.J. (Wolter J.. (2014) *Systems engineering and analysis*. 5th edn. Pearson.
- Bombardier (2022) *Bombardier financial Report*. Available at: <https://bombardier.com/en/Bombardier-Financial-Report-2021-en.pdf?attachment>.
- Booth, D.E., Templeton, C.A. and Machine, C.A.T. (1998) *Tool And Manufacturing Engineers Handbook*. 4th edn.
- CAGW Staff (2020) *California's \$100 Billion Nightmare High-Speed Rail Project | Citizens Against Government Waste*. Available at: <https://www.cagw.org/thewastewatcher/californias-100-billion-nightmare-high-speed-rail-project> (Accessed: 11 April 2022).
- Carlo, F. Di *et al.* (2021) 'Retrofitting a process plant in an Industry 4 . 0 perspective for improving safety and maintenance performance', (January), pp. 0–17. doi:10.3390/su13020646.
- Caruso, J., Jakova, T. and Varrone, A. (2010) 'Ministry of Defence Architecture Framework', pp. 2–36.
- Cengiz, E., Ayyildiz, H. and Kirkbir, F. (2019) 'CRITICAL SUCCESS FACTORS'.
- Checkland, P. (2000) 'Soft Systems Methodology: A Thirty Year Retrospective a', *Systems Research and Behavioral Science Syst. Res*, 17, pp. 11–58.
- Cloete-Hopkins, N. (2011) *Freight Transportation and Logistics Project*. University College London.
- Cochran G, W. (1997) *Sampling Techniques*. 3rd edn. New York City: John Wiley & Sons.
- Collins Harper (2022) *Framework definition and meaning | Collins English Dictionary*. Available at:

- <https://www.collinsdictionary.com/dictionary/english/framework> (Accessed: 10 April 2022).
- Creswell, J.W. and David Creswell, J. (2018) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 5th edn. SAGE Publications Inc.
- CRRC (2016) *Direct drive bogie's experiment succeeds in Qingdao_Home-old_CRRC*. Available at: <https://www.crrcgc.cc/en/g5175/s10162/t278508.aspx> (Accessed: 23 April 2022).
- CRRC Cooperation Limited (2020) *CRRC Financial Results*. Available at: <https://www.crrcgc.cc/Portals/73/Uploads/Files/2021/9-18/637675711244375026.pdf>.
- 'Defense Acquisition Guidebook' (2010).
- Défense Acquisition University Press (2001) *Systems Engineering Fundamentals*.
- Dion, F. et al. (2015) *Connected Corridors: I-210 Pilot Integrated Corridor Management System, UNIVERSITY OF CALIFORNIA, BERKELEY*. Available at: https://connected-corridors.berkeley.edu/sites/default/files/Concept_of_Operations_I-210_Pilot_%282015-06-15%29.pdf (Accessed: 24 April 2022).
- DoD (2007) 'Volume I: Definitions and Guidelines DoD Architecture Framework Version 1.5', *DoD Architecture Framework Version 1.5* [Preprint].
- Dwivedi, R. and Karim, F.J. (2021) 'Critical Success Factors of New Product Development: Evidence from Select Cases', *Business Systems Research*, 12(1), p. 2021. doi:10.2478/bsrj-2021-0003.
- Edgett, S., Shipley, D. and Forbes, G. (1992) 'Japanese and British companies compared: Contributing factors to success and failure in NPD', *The Journal of Product Innovation Management*, 9(1), pp. 3–10. doi:10.1016/0737-6782(92)90056-I.
- Edraw, M. (2021) *The Complete Guide To Understand IDEF Diagram | EdrawMax Online*. Available at: <https://www.edrawmax.com/article/the-complete-guide-to-understand-idef-diagram.html> (Accessed: 23 April 2022).
- Elm, J.P. et al. (2008) *National Defense Industrial Association A Survey of Systems Engineering Effectiveness-Initial Results (with detailed survey response data)*. Available at: <http://www.sei.cmu.edu>.
- EPM (2019) *The 5 Whys*. Available at: <https://expertprogrammanagement.com/2019/05/the-5-whys/>.
- Fairley, D. (2021) *Procurement and Acquisition - SEBoK*. Available at: https://www.sebokwiki.org/wiki/Procurement_and_Acquisition (Accessed: 11 April 2022).
- Forsberg, K., Mooz, H. and Cotterman, H. (2005) *Visualizing Project Management Models and frameworks for mastering complex systems Third Edition*. johan Wiley & Sons Inc.
- Gaille, B. (2017) *9 SWOT Analysis Pros and Cons*. Available at: <https://brandongaille.com/9-swot-analysis-pros-and-cons/#:~:text=What Are the Pros of SWOT Analysis%3F 1,... 3 It allows for additional tool identification>.
- Gerber, A. and Roux, P. (2020) 'Enterprise Architecture as Explanatory Information Systems Theory for Understanding Small- and Medium-Sized Enterprise Growth', *Sustainability*, pp. 1–31.
- Guthrie, G. (2020) *13 software development methodologies explained - Backlog, Backlog*. Available at: <https://backlog.com/blog/13-software-development-methodologies-explained/> (Accessed: 20 April 2022).
- Halligan, R. (2012) 'www.ppi-int.com', pp. 1–8.
- Halligan, R.J. (1993) 'Requirements Quality Metrics: The Basis of Informed Requirements Engineering Management', *1993 Complex Systems Engineering Synthesis and Assessment Technology Workshop (CSESAW '93)*, (May), pp. 1–7.
- Harappa (2020) *The Iceberg Model Of Culture And Behaviour*. Available at: <https://harappa.education/harappa-diaries/iceberg-model-of-culture-and-behavior/> (Accessed: 24 May 2022).
- Hattingh, M. et al. (2020) *Responsible Design, Implementation and Use of Information and*

- Communication Technology*. Edited by Marié Hattingh et al. Cham: Springer International Publishing (Lecture Notes in Computer Science). doi:10.1007/978-3-030-44999-5.
- Hawkins, A. (2019) *Boeing 737 Max crashes: everything you need to know - The Verge*. Available at: <https://www.theverge.com/2019/3/22/18275736/boeing-737-max-plane-crashes-grounded-problems-info-details-explained-reasons> (Accessed: 3 May 2022).
- Hitchins, D.K. (1999) *PUTTING SYSTEMS TO WORK*.
- INCOSE (2015) *Systems Engineering Handbook*. 5th edn. WILEY.
- Innovative Architects (2020) *SDLC Models & Methodologies [COMPLETE GUIDE]*. Available at: <https://www.innovativearchitects.com/KnowledgeCenter/basic-IT-systems/8-SDLC-models.aspx> (Accessed: 20 April 2022).
- Irandu, E. (2020) ‘The Economic Implications of Belt and Road Initiative in the Development of Railway Transport Infrastructure in Africa: The Case of the Standard Gauge The Economic Implications of Belt and Road Initiative in the Development of Railway Transport Infrastructure in Africa: The Case of the Standard Gauge Railway in Kenya’, (December). doi:10.1163/1821889X-12340027.
- Ishikawa, K. (1976) ‘Guide to Quality Control (Kaoru Ishikawa) (z-lib.org).pdf’. TOKYO: JUSE Publishing Company, pp. 18–29.
- ISO/IEC 15288 (2007) *ISO - ISO/IEC 26702:2007 - Systems engineering — Application and management of the systems engineering process, ISO*. Available at: <https://www.iso.org/standard/43693.html> (Accessed: 11 April 2022).
- James, A. (2006) ‘BUSA5235A_PDM_Module 2_ Systems Thinking Overview_All Slides’, *Systems Engineering Management* [Preprint].
- Kenned, A. (2020) *The Advancement of Party Logistics – AK Logistics and Supply Chain*. Available at: <https://aklogisticsandsupplychain.com/2020/03/02/1pl-2pl-3pl-4pl-5pl-6pl-the-advancement-of-party-logistics/> (Accessed: 20 April 2022).
- Langford, J. (2006) ., *Reliability, Maintainability, & Supportability Volume 10, Number 1, “Reliability, Maintainability, Supportability and Logistics (RMS&L)*. Available at: http://www.rmspartnership.org/Newsletters/RMS_Newsletter_Jan06.pdf.
- Laoyan, S. (2021) *Understanding the Pareto principle (The 80/20 rule)*. Available at: <https://asana.com/resources/pareto-principle-80-20-rule>.
- Leedy, P.D. and Ormrod, J.E. (2018) *PRACTICAL PRACTICAL*. 12th edn.
- Leenders, R.T.A.J., Van Engelen, J.M.L. and Kratzer, J. (2003) ‘Virtuality, communication, and new product team creativity: A social network perspective’, *Journal of Engineering and Technology Management - JET-M*, 20(1-2 SPEC.), pp. 80–83. doi:10.1016/S0923-4748(03)00005-5.
- Leith, Paxton and Bourne, D. (1985) *Locomotives Of The South African Railways*. Struik.
- Leong (2008) ‘Positivism Paradigm’, in. Available at: <https://personal.denison.edu/~kabouf/Pub/2008-Positivist-Paradigm.pdf> (Accessed: 11 April 2022).
- Lewis, C. (1996) *Pantograph testing in South Africa*. Available at: <http://www.traintesting.com/SAR.htm> (Accessed: 11 April 2022).
- Lucidchart (no date) *What are your SWOT analysis needs?* Available at: <https://www.lucidchart.com/pages/what-is-swot-analysis#:~:text=SWOT analysis was invented in,that was executable and reasonable>.
- Mabusela, M.A. (2020) *A System Design Framework for the Transnet Product Development Business as an Original Equipment Manufacturer (OEM) of Railway Coaches*. University of the Witwatersrand.
- Madzibane, S. (2018) *Development of a Systems Front End Research Framework to inform Strategic Planning of Projects in Transnet SOC Ltd*. University of the Witwatersrand. Available at: <http://content.ebscohost.com/ContentServer.asp?EbscoContent=dGJyMNLe80Sep7Q4y9f3OLCmr1G>

ep7JSsKy4Sa6WxWXS&ContentCustomer=dGJyMPGptk%2B3rLJNuePfgeyx43zx1%2B6B&T=P&P=AN&S=R&D=buh&K=134748798%0Ahttp://amg.um.dk/~media/amg/Documents/Policies and Strategies/S.

Mo, J.P. and A. Sinha (2014) *Engineering Systems Acquisition and Support*. Elsevier Science.

Modigliani, P. and Chang, S. (2014) 'Defense Agile Acquisition Guide', *The MITRE Corporation* [Preprint]. Available at: <https://www.acqnotes.com/Attachments/MITRE-Defense-Agile-Acquisition-Guide.pdf> (Accessed: 12 April 2022).

Morgan, P. (2012) *South Africa: Heavy Going in Africa*, Clay & Co. Available at: <https://www.mondaq.com/southafrica/rail-road-cycling/212676/heavy-going-in-africa>.

Mulder, P. (2017) *CATWOE Analysis*. Available at: <https://www.toolshero.com/problem-solving/catwoe-analysis/> (Accessed: 23 April 2022).

NASA (2007) 'NASA Systems Engineering Handbook', *NASA Special Publication*, pp. 3–126. Available at: <http://adsabs.harvard.edu/full/1995NASSP6105.....S>.

Naveen (2015) *What is Incremental Model in software testing and what are advantages and disadvantages of Incremental Model*. Available at: <https://testingfreak.com/incremental-model-software-testing-advantages-disadvantages-incremental-model/> (Accessed: 20 April 2022).

NK Labs (2022) *Mechanical System Architecture | NK Labs*. Available at: <https://www.nklabs.com/me-sys-arch> (Accessed: 28 April 2022).

NPDsolutions (2015) *Design for the Life Cycle*. Available at: <https://www.npd-solutions.com/lifecycle.html> (Accessed: 29 April 2022).

Panja, S.C. and Gangopadhyaya, M. (2015) 'Human Factors Analysis for Railway Coach and Bogie Maintenance Using AHP', p. 89.

PD PMO PROJECT (no date) 'PD PMO PROJECT MANAGEMENT MASTER PLAN'.

Perell, D. (2019) *Why Did The Boeing 737 Max Crash? - David Perell*. Available at: <https://perell.com/essay/boeing-737-max/> (Accessed: 3 May 2022).

Pivnic, L. (2005a) *Soul of A Railway - Braamfontein West to Klerksdorp (home signal) (2)*, *Soul of A Railway 2*. Available at: <https://sites.google.com/site/soulorailway/soul-of-a-railway/system-7-western-transvaal/braamfontein-west-to-klersdorp-home-signal-2> (Accessed: 23 April 2022).

Pivnic, L. (2005b) *Soul of A Railway - Northwards to just short of the home signal at Pretoria by Les Pivnic ©*, *Soul of A Railway 1*. Available at: <https://sites.google.com/site/soulorailway/soul-of-a-railway/system-7-western-transvaal/northwards-to-just-short-of-the-home-signal-at-pretoria-by-les-pivnic> (Accessed: 23 April 2022).

PM_PrepCast (2012) *What is a Project Management Plan?* Available at: <https://www.project-management-prepcast.com/free/pmp-exam/tips/304-what-is-a-project-management-plan> (Accessed: 24 April 2022).

PPI (2015) 'Types of requirements', *Project Performance (Australia) Pty Ltd 2002-2015*, (June), p. 1.

Project Management Institute. (2008) *A guide to the project management body of knowledge (PMBOK Guide)*. 4th edn. Project Management Institute.

Project Management Institute (2017) *A guide to the project management body of knowledge (PMBOK guide)*. 6th edn. Project Management Institute.

Pueo, M. et al. (2020) 'Design methodology for production systems retrofit in SMEs', *International Journal of Production Research*, 58(14), pp. 4306–4324. doi:10.1080/00207543.2019.1651460.

R. Baduel, J.M. Bruel, I. Ober, E.D. (2018) 'Open Archive Toulouse Archive Ouverte OATAO is an open access repository that collects the work of Toulouse This is an author ' s version published in : to the repository administrator : tech-oatao@listes-diff.inp-toulouse.fr DEFINITION OF STATES AND MODE', 2018(June).

Retief, G.. (2019) *Table of Contents*. University of the Witwatersrand.

- Richard Puyt, Finn Birger Lie, Frank Jan De Graaf, C.P.M.W. (2020) ‘Origins of SWOT Analysis’, No 1.
- Robertson, S. and Robertson, J. (2013) *Mastering the Requirements Process Getting Requirements Right*. 3rd edn. Addison-Wesley.
- Rogers, K. (2017) *The Iceberg Model for Problem-Solving, BigThinking*. Available at: <https://bigthinking.io/the-iceberg-model-for-problem-solving/#:~:text=The Iceberg Model is a,models that trigger problematic events>.
- RSA_PublicEnterprises (2019) *Transnet - Department of Public Enterprises (DPE), RSA Government*. Available at: <https://dpe.gov.za/state-owned-companies/transnet/> (Accessed: 24 April 2022).
- Saunders, M., Lewis, P. and Thornhill, A. (2009) *for business students fi fth edition*. 5th edn. Prentice Hall.
- SEBoK (2020) *Guide to the Systems Engineering Body of Knowledge (SEBoK), version 2.3 Guide to the Systems Engineering Body of Knowledge version 2.3*. Available at: www.sebokwiki.orgpdfgeneratedusingtheopensourcemwlibtoolkit.seehttp://code.pediapress.com/form oreinformation.
- Shaw, A. *et al.* (2014) *PWC*.
- Shobhit, S. (2022) *Business Development: Basic Overview of Activities*. Available at: <https://www.investopedia.com/articles/personal-finance/090815/basics-business-development.asp> (Accessed: 28 April 2022).
- Shubhamkar (2020) *3D train bogie alstom - TurboSquid 1513256*. Available at: <https://www.turbosquid.com/3d-models/3d-train-bogie-alstom-1513256> (Accessed: 11 April 2022).
- Siemens Mobility (2020) *Siemens Annual Report*. Available at: <https://assets.new.siemens.com/siemens/assets/api/uuid:45446098-6c39-45ba-a5fc-e5f27ebfa875/siemens-ar2020.pdf>.
- Sigonyela, M. (2012) *WAGONS ORDER BOOSTS TRANSNET’S EASTERN CAPE FACTORY*. Available at: <https://www.transnet.net/Media/Press Release Office/WAGONS ORDER TO BOOST TRANSNET EASTERN CAPE FACTORY.pdf> (Accessed: 12 April 2022).
- Slater, S.F. (1994) ‘Competing in high-velocity markets’, *IEEE Engineering Management Review*, 22(2), pp. 24–29.
- Sof E (2022) *B-2 Spirit of Kansas: The most expensive crash in USAF history*. Available at: <https://special-ops.org/b-2-most-expensive-crash-in-usaf-history/> (Accessed: 12 April 2022).
- Srinivas, H. (1990) *No Title*. Available at: <https://www.gdrc.org/uem/lca/guidelines.html>.
- Stewart, J. (2021) *Project Failure: Top 10 Reasons Why Project Fail*. Available at: <https://project-management.com/top-10-reasons-why-projects-fail/> (Accessed: 4 May 2022).
- Tatravagónka (2016) *Y25Ls-K - Tatravagónka Poprad*. Available at: <http://tatravagonka.sk/bogie/y25ls-k/?lang=en> (Accessed: 23 April 2022).
- TCSE (2018) ‘Wits TCSE Transnet Centre for Systems Engineering Partnering for Systems Solutions Systems Engineering : Soft Systems Methodologies’, (April), pp. 1–65.
- TheRailwayTechnicalWebsite (2016) *Bogies | The Railway Technical Website | PRC Rail Consulting Ltd*. Available at: <http://www.railway-technical.com/trains/rolling-stock-index-l/bogies.html> (Accessed: 23 April 2022).
- Thomson, P.. (2013) *Value Proposition Canvas Template - Peter J Thomson*. Available at: <https://www.peterjthomson.com/2013/11/value-proposition-canvas/> (Accessed: 20 April 2022).
- Tortorella, M. (2015) *Reliability, maintainability, and supportability. Best practices for Systems Engineers*. Wiley.
- Transnet-4.0 (2017) *About Us Overview*. Available at: <https://www.transnet.net/AboutUs/Pages/Overview.aspx> (Accessed: 21 April 2022).

- Transnet-ir (2018) *Transnet Online Integrated Report 2018 / From MDS to Transnet 4.0*. Available at: <https://www.transnet-ir-2018.co.za/from-mds-to-transnet-4-0.php> (Accessed: 12 April 2022).
- Transnet-ir (2020) *Transnet Integrated Report*. Available at: <https://www.transnet.net/Pages/Home.aspx> (Accessed: 10 April 2022).
- Transnet Africa Strategy (2015) 'Transnet Africa Strategy Presentation', *Transnet Africa Strategy*, (August), pp. 1–33. Available at: <https://static.pmg.org.za/150812Transnet.pdf>.
- Transnet Capital Projects (2008) 'Project Lifecycle Process Overview Manual'.
- Transnet HC Portal (2021) 'Transnet HC Portal'.
- TransnetEngineering (2021) *Our Divisions Transnet Engineering*. Available at: <https://www.transnet.net/Divisions/Pages/RailEng.aspx> (Accessed: 10 April 2022).
- Transnet Engineering ir (2021) *Transnet Engineering Integrated Report*. Available at: [https://www.transnet.net/InvestorRelations/AR2021/Transnet Engineering.pdf](https://www.transnet.net/InvestorRelations/AR2021/Transnet%20Engineering.pdf).
- Vos, J.F.J. and Achterkamp, M.C. (2006) 'Stakeholder identification in innovation projects', *European Journal of Innovation Management*, 9(2), pp. 161–178. doi:10.1108/14601060610663550.
- Wheatcraft, L. (2015) *INCOSE Guide to Writing Requirements updates made at IW 2015, AR Digital*. Available at: <https://argondigital.com/blog/training/incose-guide-to-writing-requirements-updates-made-at-iw-2015/>.
- Wigmore, I. (2017) *Complex Systems*.
- Wood, M. (2013) *ProjectManagement.com - Why You're Confusing Frameworks with Methodologies*. Available at: https://www.projectmanagement.com/contentPages/article.cfm?ID=278600&thisPageURL=/articles/278600/why-you-re-confusing-frameworks-with-methodologies#_=_ (Accessed: 11 April 2022).
- Youker, R. (2017) *The Difference between Different Types of Projects 1*. Available at: www.maxwideman.com.
- Zavod, K. (2021) *Freight diesel locomotive 2TE70*. Available at: <https://www.kolomnadiesel.com/en/catalog/detail.php?ID=2215> (Accessed: 11 April 2022).

7. APPENDIX A: ETHICS CLEARANCE

Ethics clearance to conduct research within Transnet was obtained on 1 December 2021, with ethics clearance number MIAEC 104/21. A confirmation email from Dr Emwanu is shown below.

Dear Shane,

I am pleased to inform you that the School Ethics Committee completed assessing your ethics application for your MSc research project titled: "A Systems Framework for the Acquisition of Bogies for Transnet Engineering Product Development (TE PD)" and it has been ratified by the University Main Ethics Committee (non-medical). Your ethics clearance number is MIAEC 104/21.

Please use your ethics clearance number as a reference for all future correspondence on this matter.

By copy of this email your supervisor is also informed.

Regards,

Dr. Emwanu

8. APPENDIX B: LIKERT SURVEY RESPONSE RATE

Table 43: Survey response rate

Source: Author

Profession	Designation	Number of Surveys Issued	Number of Survey Responses	Desired Response Rate	Actual Response Rate
Mechanical Engineering	Principle Engineer	5	4	80%	80%
	Senior Engineer	8	5	50%	63%
	Engineer	10	6	50%	60%
	Junior Engineer	5	2	40%	40%
Electrical Engineering	Principle Engineer	1	1	100%	100%
	Senior Engineer	3	2	67%	67%
	Engineer	5	2	40%	40%
	Junior Engineer	5	0	20%	0%
Systems Engineering	Principle Engineer	2	2	100%	100%
	Senior Engineer	3	2	67%	67%
Integration Engineering	Principle Engineer	1	1	100%	100%
	Senior Engineer	2	1	50%	50%
	Engineer	2	1	50%	50%
	Junior Engineer	2	1	50%	50%
Metallurgy Engineering	Principle Engineer	1	1	100%	100%
	Senior Engineer	2	1	50%	50%
Software Engineering	Principle Engineer	1	1	100%	100%
	Senior Engineer	2	1	50%	50%
Industrial Engineering	Senior Engineer	1	1	100%	100%
	Engineer	2	1	50%	50%
Industrial Engineering	Senior Engineer	2	1	50%	50%
Project Lead	Project Manager	5	5	80%	100%
Total		70	42		

Figure 60: Survey response distribution

Source: Author

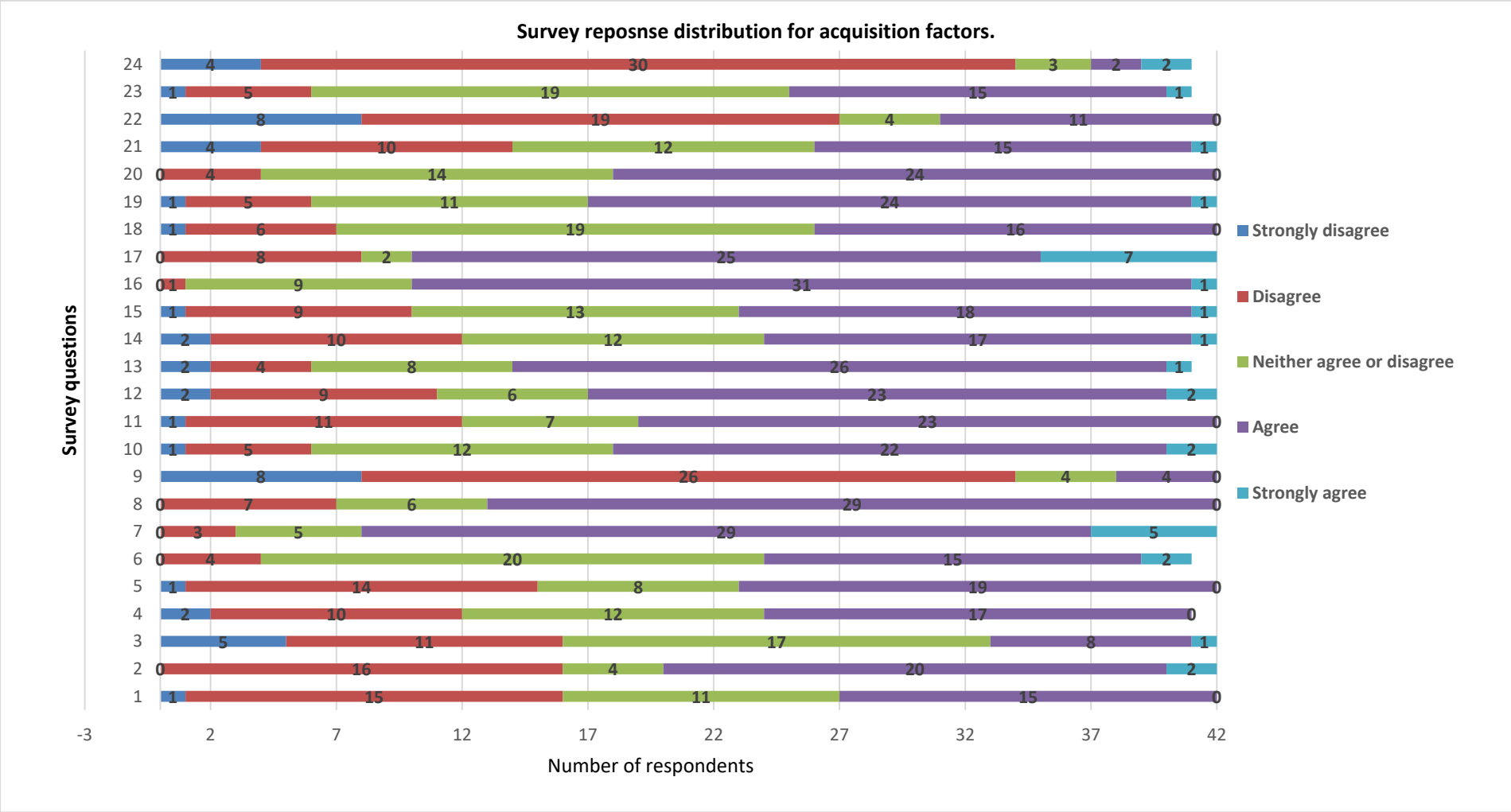


Table 44: Responses to survey open questions

Source: Author

#	Open Question	Responses
1	Are there a factors that were not mentioned in the previous questions that you feel TE PD would benefit from should they consider that factor in their process of acquiring bogies? Please elaborate	<p>A1. No, seems like everything has been thought of from the statements and questions above.</p> <p>A2. Use of system thinking and management is significant</p> <p>A3. Is enough attention given to resources in general? Like machinery, facilities (like workshops), design tools, human capital. I would have like to say "sometimes" at some of the questions above.</p> <p>A4. Looks like it could make improvements if it helps improve record keeping and communication.</p> <p>A5. I believe all 10 knowledge areas mentioned in the PMBOK standard have been raised. If there is any shortcoming - it may be ascribed to the manner in which the questions have been framed.</p> <p>A6. Organization flexibility and development</p> <p>A7. A much better business case for all project</p>
2	Do you feel that should all the above-mentioned factors be considered better when planning for bogie projects, most of the issues you experienced would be addressed? Please elaborate.	<p>A1. theoretically, yes.</p> <p>A2. It will help, but i have seen that it is close to impossible to foresee and plan for all the detailed steps in the process.</p> <p>A3. If implemented, yes.</p> <p>A4. Yes, If implemented.</p> <p>A5. Yes, it allows for overview of project life cycle</p> <p>A6. I believe that should the factors (raised) have been "better" addressed then it may have led to an improvement or "better" outcome - however "shortcomings" in organisational policies and procedures may still have prevented a more desirable outcome.</p> <p>A7. Yes. Preferably managed by a common person</p> <p>A8. No. Some important aspects will always be missed. They are missed because of lack of knowledge, when the knowledge is acquired, they need to be implemented for improvement of the process. Complete flexibility in re-organization, knowledge acquisition and implementation seem to always lack</p> <p>A9. Yes, good planning ensure risk is minimize</p> <p>A10. Definitely with stakeholder engagement and documentation of all changes made</p> <p>A11. No. Some seem to be outside TE's control such as the PFMA which determines the "procurement processes that are suitable for types of acquisition strategies" as well as satisfactory communication with potential suppliers.</p> <p>A12. Yes, many key factors will be addressed. Determining which stakeholders must be in involved in the process and in what stage is important. Having clearly established handover points are important. Having standardised change management is important. Being able to liaise with suppliers during development is important.</p> <p>A13. Possibly yes. Any acquisition requires planning and support from everyone involved so if everyone is always aware of what is happening, there should be no issues that cannot be resolved.</p> <p>A14. Yes</p>
3	Any general comments?	<p>A1. None</p> <p>A2. No</p> <p>A3. TE needs to engage more project in systems approach</p> <p>A4. I believe it would be beneficial to contact each respondent and establish how they arrived at each response. In essence what I'm saying is that many of the responses provided are heavily dependent on the precise stage of the project vis-a-vis the project timeline. Shane - I strongly recommend that you contact me at least to establish what I'm say!</p> <p>A5. The above questions were answered for general rolling stick (not just bogie).</p> <p>A6. Funding of projects can be done better. Supply management delays execution of important milestones.</p> <p>A7. Null</p>

9. APPENDIX C: SEMI-STRUCTURED INTERVIEWS RESPONSE RATE

Table 45: Semi-structured interview actual sample set

Source: Author

Experience required	Duration and date	Formal Training Required
<ul style="list-style-type: none"> - 20+ years experience - Transnet Experience 	<ul style="list-style-type: none"> - 5th May 2022 - 1 hour 25 minutes 	<ul style="list-style-type: none"> - Mechanical Engineer with Speciality structural design
<ul style="list-style-type: none"> - 30+ years - Rolling stock development - Research and Development - Transnet Experience 	<ul style="list-style-type: none"> - 5th May 2022 - 1 hour 7 minutes 	<ul style="list-style-type: none"> - Mechanical Engineer Honours level BEng degree
<ul style="list-style-type: none"> - Experience of 20+ years and 15+ project management experience preferable - Experience 	<ul style="list-style-type: none"> - 7th November 2022 - 2 hour 57 minutes 	<ul style="list-style-type: none"> - Systems Engineer Masters at least - Mechanical Engineer - PMI training

Table 46: Semi-structured interviews responses.

Source: Author

Interviewee #	Questions	
	1. Based on your experience at TE, please comment on the bogie acquisition factors identified from the critical literature review and survey responses to be addressed by the framework.	2. Please critique the bogie acquisition framework that has just been presented to you.
1	<p>Maintenance of Tools and equipment</p> <ul style="list-style-type: none"> The framework should consider the maintenance of tools and equipment used to create the bogie system for internal design. This has an impact on the quality of the created system. <p>Asset Management Lifecycle (ISO 55000)</p> <ul style="list-style-type: none"> It is worth considering the asset management life cycle standard to identify other possible acquisition factors. <p>Cost of Creating the system.</p> <ul style="list-style-type: none"> It would be beneficial to have a better way of determining how much it really costs to create a bogie. In the framework this acquisition factor is referred to as development cost. <p>Facilities</p> <ul style="list-style-type: none"> It's important to ensure that the facilities needed to acquire a bogie are available and maintained. 	<ul style="list-style-type: none"> The framework shows a well thought out process that covers a wide variety of factors. It is similar to the process that TE PD following and covers about 80% of tasks of the lifecycle process. The process can be used to identify processes that require funding and help ensure funds are available in time and when needed. It can also assist with the legal side of the acquisition and ensure that there are lawyers in the team to address the legal matters. A business plan would be a good addition to the process as well. The framework should consider Intellectual Property infringement and protection.
2	<p>Technology</p> <ul style="list-style-type: none"> Team composition and acquisition strategy opted for should be based on the members' experience in working with the different technologies. Technology such as, brakes, wheels, couplers and so on. In Transnet these are called VITs (Very Important Technology). The organisation should retain the employees with understanding of such technology and share the skills within. Technology readiness levels study should be done and a gap analysis. Then there should be a plan in place to address any deficiencies to enable Transnet to reach status of world recognised OEM of rolling stock. <p>Risk</p> <ul style="list-style-type: none"> The PFMA policy poses a different kind of risk to projects because employees are not allowed to communicate with suppliers and procurement processes are also hindered by the red tape. 	<ul style="list-style-type: none"> Bogies account for about 20% of revenue of rolling stock. It is worth while having an improved acquisition process that allows for seamless acquiring of bogies. This process can be extended to other rolling stock products as well. The checklist presented in the form of a matrix can be used as a measure to determine the health of a project during its life based on how many boxes it ticks.
3	<p>Project Management Plan</p> <p>The project management plan is missing the following two outputs.</p> <ul style="list-style-type: none"> Integration Management Plan Stakeholder Management Plan <p>Production Stage</p> <ul style="list-style-type: none"> The current system lifecycle needs to be modified on the production stage for the creation of all production tools, jigs, equipment, manufacturing processes, quality controls, etc. The time and resources needed to create the tools needs to be made available as well as the impact of the tools and equipment on the quality of the bogies produced. <p>System Engineering Technical Process Viewpoints</p> <p>The framework technical process viewpoint can be improved by the inclusion of the following:</p> <ul style="list-style-type: none"> SETPV-06: Add Safety Certification Authority – the new bogies need to be certified safe for use SETPV-10: Add “Integrated logistic Support” and “Obsolescence Management” <p>Mandatory Maintenance</p> <p>Obligated Maintenance Planning of the new bogies. This will require applying tools such as Fault Tree Analysis, FMECA, Reliability Analysis and RCM as inputs to the mandatory Maintenance Plan.</p> <p>Strategic Viewpoint</p> <p>To improve on the management of the organization's capability to develop new bogies the framework can add the consideration below.</p> <ul style="list-style-type: none"> StV-08: Applicable SE Tool is “Capability Maturity Measurement” 	<p>The framework is comprehensive and well researched with minor considerations missing.</p> <ul style="list-style-type: none"> The framework can be improved by detailing how the mandatory maintenance of the bogies will be developed and which SE methods will be used. The framework was missing an important part of and system lifecycle during the production phase which is the creation of production tools and equipment and their maintenance.

10. APPENDIX D: WRITEUP FOR REVISED FRAMEWORK

Section A: All Views

Table 47: Revised All viewpoints (AV)

Source: Author

All Viewpoints (AV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
AV-01	Overview and Summary	It provides an executive level summary information of the framework to be used to acquire a bogie or bogies for TE PD. It will provide a summary of the processes involved in acquiring the bogie/s through lifecycle.	(MOD Homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	All Systems Engineering Competencies and Principles as well as Project Management Principles.
AV-02	Integrated Dictionary	Provides terms and explanations to be used in this framework as well as description and catalogues of all elements and relationships between them.	(MOD Homedefence, 2010)	Lead Systems Engineer and relevant stakeholders.	Model Based Systems Engineering (MBSE) Tools.
AV-03	Concept of Operation (ConOps)	The ConOps serves as a foundation for the Systems Engineering Processes. It serves as the foundation to the development of the system and should be accessible to all stakeholders to ensure that everybody's needs are catered for by the bogie. The ConOps addresses the five main questions; Who?, What?, Where?, Why?, and How?.	(U.S. Department of Transportation, 2005) (MOD Homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Model Based Systems Engineering (MBSE) Tools. Functional Flow Block Diagram (FFBD), System Lifecycle, User Operational Concept Description(OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview
AV-04	TE vision and mission	TE's mission and vision which is informed by Transnet's vision and mission are considered throughout the framework in parallel with all other processes. It is covered in more detail in the Strategic Viewpoint in StV-03 and StV-05.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020)	Lead Systems Engineer	Systems Engineering Management Plan (SEMP)

Section B: Lifecycles

Table 48: Revised Lifecycle viewpoint (LCV), project lifecycle process

Source: Author

Lifecycle Viewpoint (LCV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-01	Project Lifecycle Process	<p>The Project Lifecycle Process is the overarching lifecycle process that the other lifecycles (LCV-02, LCV-03, and LCV04) form part of. This is because the project does not end when the bogie is delivered but the clients using the bogie product of TE PD has to be supported and eventually the bogie has to be retired and disposed of.</p> <p>Phase 1: Project Initiating</p> <p>This is the initiation part of the project where a Business Case is developed and stakeholders are identified. The needs of the project are identified and a Project Charter is created. The Project Charter contains details of ; Project constraints, goals, scope project manager, budget, expected timelines. A register for stakeholders is created containing their roles, designation, influence, and communication requirements. There are mainly three ways bogies projects start in TE PD. 1. Business Development (BD) identifies upcoming Railway projects and position TE PD to tender(pushing product into the market), 2. BD identifies projects already at tender stage and bit to supply bogies (Market pull). It is at this stage the Acquisition strategy to be used is identified (in-house, OEM partnership, or COTs). LCV-02 has started at this stage.</p> <p>Phase 2: Project Planning</p> <p>This is one of the most important phases of the project as the success of a project is highly influenced by how much planning was done before execution. The Project Management Plan (PMP) from SMV-01 viewpoint is created. The PMP will include; 1, Success factors (Schedule, budget, and other factors),2. The scope, 3. Deliverables, 4. Schedule, 5. Budget, 6. Human resource plan. (The nature of the project will influence the team selection between TE PD or TE PD R&D),7. Quality management Plan, 8. Risk management plan, 9. Procurement Management Plan, 10, Change Procedure. LCV-03 viewpoint starts during this phase as the user requirements are gathered.</p> <p>Phase 3: Project Execution</p> <p>Here the project manager and the project team are executing the acquisition. The team composition will depend on the acquisition strategy opted for. If it's COTs then TE PD will mostly be managing the acquisition or if it's an in-house development then team will be TE PD employees and suppliers, or if it a partnership then it's a bit of both. The project manager will be producing the project status updates and communicating with stakeholders. This phase LCV-04 execution.</p> <p>Phase 4: Monitoring and Control</p> <p>This phase exists to ensure that Phase 3 above is executed and executed as needed. So they happen concurrently. Using the viewpoints referred to in this research as the enablers, this phase monitors and control the success factors defined in Phase 1 which are, schedule, Budget, and quality.</p> <p>Phase 5: Project Closure</p> <p>This phase of the project is the most ignored maybe because the bogie system is not longer with TE PD and has been delivered to the client. The bogie systems needs support while in operation which may mean modifications or retrofitting and this is possible until the bogie system is retired. The design, development, testing, and commissioning may be done but support continues. Lessons learned and release of resources will occur gradually through the project lifecycle.</p>	<p>(PMBok, 2008)</p> <p>(Kevin Fordberg PhD et al, 2005,p 840)</p>	<p>Project Manager and Lead Systems Engineer with participation of all stakeholders.</p>	<p>All Systems Engineering Competencies and Principles as well as Project Management Principles. All other Viewpoints</p>

Table 49: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-02	Acquisition Lifecycle Process	<p>This lifecycle process starts from leadership buy-in on the project to a point where a bogie is delivered and commissioned at the client. It includes LCV-03 and LCV-04.</p> <p>Form the Team: Once a need has been identified by BD from LCV-02 Phase 1 and the nature of the project known, a team is built based on skills required.</p> <p>Identify and Align Resources: Identify the resources required internally and externally once the nature of the opportunity is identified, is it a push or pull to the market type of project and identify any gaps.</p> <p>Requirements Definition: Develop a requirements definition roadmap and acquisition forecasting. This is where viewpoint SETPV-02 on Requirements Analysis becomes useful.</p> <p>Acquisition Strategy: Then based on the timelines from an opportunity identified either by BD or the department initiating the project, the acquisition strategy is decided on and the team to bring the bogie to physical existence is built. This team will be built based on the level of risk and available technical skills.</p> <p>Acquisition Planning: The strategy will also include: Objectives of the acquisition: <ul style="list-style-type: none"> • Capabilities to be provided • Major milestones Acquisition approach taken: <ul style="list-style-type: none"> • Single step launch or incremental. • competitive or sole source • System Integration • Commercial-Off-The Shelf (COTs) Business Considerations: <ul style="list-style-type: none"> • Limiting factors (Funding, schedule) • Availability of assets and technology Risk Management: <ul style="list-style-type: none"> • Major risk associated with the bogie acquisition strategy taken. • Identify and manage risk shared with partners and suppliers </p> <p>Contract Type: The contract to be entered into with bogie OEM development partners or COTs partners needs to be decided on. <ul style="list-style-type: none"> • Incentives associated with the timelines • Performance parameters </p> <p>Products support strategy: The type of support TE PD is going to offer to offer to it's customers is planned for at this stage. From delivery to maintenance to modifications and improvements. <ul style="list-style-type: none"> • Oversight of delivery of system • Maintenance • Improvement </p> <p>Performance Management: Once the contracts have been awarded execution starts. All the plans made are implemented and performance is monitored based on the milestone agreed on in the contracts and the timelines. Contract management is a significant part of this phase. Bogie development, integration, testing, deployment, customer support, and maintenance are also monitored during this phase.</p> <p>Compare Requirements and Results: Each phase will have it's own requirements and those will be monitored throughout. Lessons learned will be recorded as well.</p>	<p>(MITRE, September 2013)</p> <p>(ISO/IEC/IEEE 15288-2002)</p> <p>(NASA, December 2007)</p>	All stakeholders lead by Lead Systems Engineer	Principle of acquisition tenders and contracts, Acquisition Process Activities, Acquisition Outcomes, bogie lifecycle

Table 50: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-03	System Lifecycle Process	<p>The system lifecycle of a bogie looks at the phases that a bogie goes through in its life. Knowing this cycle before hand is important as it informs the LCV-04 viewpoint which looks at the different phases of developing the physical system being the bogie.</p> <p>User Requirements Definition: This phase is important as it will determine the feasibility of the project and define the scope of the project as well. Requirements will be gathered from all stakeholders especially the user of the bogie to ensure they gain value in the bogie system.</p> <p>Concept Definition Phase: Here concept and concept alternatives are developed with approval from the user, the architecture, life-cycle budgetary and ownership cost estimations.</p> <p>System Definition Phase: Once concepts have been created from the previous phase, the system is defined in more detail and the context in which it operates. The interfacing requirements of the bogies with rail and vehicle body are identified. Available technology for the concept is investigated as well as risk reduction efforts. The technical feasibility is explored at this stage as well.</p> <p>Acquisition Planning Phase: Once the feasibility is concluded as well as the study phase of the project are done, the acquisition phase starts where schedule and budget are estimated. The method of acquisition is defined and if it's internal or external, at this stage as well as suppliers. The final step of this phase is approval to go ahead with the acquisition of the proposed system.</p> <p>Source Selection Phase: This phase is about the selection of a contractor through a fair and open process. The aim is to select a contractor which provides best value from the responses to the Request For Proposal (RFP). For internal (TE) development the process will not include RFP. It will start from choosing the team based on the required technical skills as well as timelines.</p> <p>Development Phase: Be it an internal development or partnership with other OEMs, this phase is concerned with the bringing to physical existence the first designed bogie. From design to development, then integration.</p> <p>Verification Phase: The verification process of the bogie is done mainly by testing. The bogie as well as standard components are tested according to EN, AAR and UIC standards as well as the URS. Some verification will be done by demonstration, visual inspection, or analysis.</p> <p>Production Phase: Once the bogie has been tested and validated, and designed capabilities agreed on by the customer, mass production of the bogie system then starts and further marketing in order to respond to market opportunities.</p> <p>Operational, Maintenance, and Support Phase: Developed training manuals and maintenance manuals are put to use in the operational and maintenance phase. Support may be offered in a form of modifications and retrofits as well during operation.</p> <p>Retirement/Disposal Phase: The final phase is to decommission the bogie and retire it safely. Plans have to be put in place to ensure all the value from the bogie is extracted and it is disposed of in a safe manner not impacting the environment negatively.</p>	<p>(ISO/IEC/IEEE 15288-2002)</p> <p>(Jones B.L., 2009)</p> <p>(INCOSE, 2015)</p>	<p>Lead systems Engineer, Client, Design Team</p>	<p>All Systems Engineering Competencies and Principles as well as bogie lifecycle.</p>

Table 51: Revised Lifecycle viewpoint (LCV), acquisition lifecycle process continued

Source: Author

Viewpoint ID	Viewpoint name		Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
LCV-04	Product/System Development Lifecycle Process	<p>Described in this process are the stages that will be followed to develop and manage an integrated bogie. This process forms part of the acquisition lifecycle process (LCV-02) which forms part of the overarching Project lifecycle process (LCV-01). This structured sequential has phases that are only complete once the requirements and milestones of each phase are met and delivered on. These are the typical phase to successfully deliver a bogie.</p> <p>Concept Stage: Product Requirements Phase: This phase is concerned with the gathering all requirements from stakeholder requirements to system requirements at system and component/element level. This will include inherent and derived requirements. This process is done with LCV-03 in mind. Product definition Phase: Once requirements have been gathered, a Concept of Operation (OCD) is developed which will share a common understanding between TE and the client of how the bogie will operate.</p> <p>Development Stage: Product development Phase: The concept is then developed further according to the design specification and integrated according the viewpoint SETPV03 to SETPV-05 below. Different kinds of engineering models are developed during this phase to analyse the design in different scenarios and tested according to EN,UIC, and AAR standards. Internal Testing: The internal testing phase will be done at a component level as well as at system level according to EN,UIC, and AAR standards depending on the type of bogie being tested. If the bogie is narrow gauge then testing will be done internally but if it's standard gauge then it will be externally. External Testing is done by partners such as TTCI and UP based on the specifications developed in SETPV-06 below. Then the bogie validated in the expected environment of operation as stated in viewpoint SETPV-08.</p> <p>Maintenance of Tools and Equipment The tools and equipment used to develop the bogie prototypes must be kept well maintained to ensure they produce the kind of quality of bogies that is expected.</p> <p>Production Stage: Production Tools: Once the design is fully tested and satisfies all the requirements or a an agreed on compromise is reached, It is time for creation of the production tools such as jigs, equipment, as we as production process and quality control.</p> <p>Production: Once production tools creation is done, it is time for mass production of the bogies and integration into to the rest of the vehicle and infrastructure.</p> <p>Maintenance of Tools and Equipment Similar to the maintenance of tools and equipment during the design development phase, tools and equipment used for mass production must be maintained to ensure the quality of the bogies produced is as expected and acceptable.</p> <p>Utilization/Support Stage: Once the bogie has been integrated to the rest of the vehicle and official hand over is done, it's time to support the clients through maintenance, modification, retrofit and any other support they may need. This phase is executed according to viewpoint SETPV-09 and SETPV-10.</p> <p>Retirement Stage: Once the bogie has served its life according to the design and agreed life expectancy, it will be decommissioned and retired in a safe manner and ensures all the value out of the bogie has been derived. Any potential retirement costs have been identified as well.</p>	<p>(Cengiz et al, 1998)</p> <p>(Leenders et al, 2003)</p> <p>Interviewee Number 1</p> <p>Interviewee Number 3</p>	<p>Lead systems Engineer, Client, Design Team, Project Team</p>	<p>LCV-03 Viewpoint, Strategic viewpoint (STV), Project Management and Systems Engineering Management (PSMV) viewpoint.</p>

Sections C: Enablers

Table 52: Revised Technical standards viewpoint (TV)

Source: Author.

Technical Standards Viewpoint (TV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
TV-01	Applicable Standards Profile	This section defines the technical and non-technical standards that apply to the acquisition of bogies for this framework. It also describes the guidance and policy applicable to acquiring bogies in TE PD and Transnet as a whole.	(MOD Homedefence, 2010)	Project Team, Lead Systems Engineer, Client, Railway Industry Regulators, Government Regulators	Context Diagram, Work Breakdown Structure (WBS), System Lifecycle.
TV-02	Applicable Standards Forecasting	Identify expected changes to technical standards identified in TV-01 above for the expected duration of the project until disposal phase of the bogie system.	(MOD Homedefence, 2010)	Project Team, Lead Systems Engineer, Client, Railway Industry Regulators, Government Regulators	Project Plan
TV-03	TE PD Previously acquired Bogies	Identify lessons learned from previous bogie acquisition project and avoid previous pitfalls going forward.		Project Team, Lead Systems Engineer	
TV-04	Suppliers Technical Standards	Compile a list of standards that will be required for materials, services, standard components for completion of the project.		Project Team, Lead Systems Engineer	

Table 53: Revised Project management and systems engineering management viewpoint (PSMV)

Source: Author.

Project Management and Systems Engineering Mmanagement Viewpoint (PSMV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
PSMV-01	Project Management Plan (PMP)	The PMP document serves as a formal document that is approved and defines how the project will be executed, monitored, and controlled through the lifecycle to acquire a bogie/s by TE PD.	(PM PrepCast, 2010) (Kevin Forberg PHD et al, 2005)	Project Manager	The Five Project Management Essentials. <ul style="list-style-type: none"> • Organisational Commitment • Project Communication • Teamwork • Project cycle • The ten Management Elements
PSMV-02	System Engineering Management Plan (SEMP)	The SEMP is the foundation document that is used for technical engineering activities conducted for the duration of a project through lifecycle. It conveys information to all personnel on the technical integration methodologies and activities for project defined by the project scope on the project plan.	(NASA, December 2007)	Lead System Engineer	Systems Engineering Principles; <ul style="list-style-type: none"> • System Design • Systems Thinking • System Lifecycle • Project Implementation • Technical Management

Table 54: Revised Strategic viewpoint (StV)

Source: Author.

Strategic Viewpoint (StV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
StV-01	Business Benefits	This viewpoint is ensures that the acquisition process objectives are inline with TE PD's vision and mission so that the project enjoys the support of top management and gets funding and all the support it needs.	(US Department of Health and Human Services,)	Lead Systems Engineer, TE Top Management	Business Case, Return on Investment, MoEs
StV-02	Enterprise Capability Taxonomy	This captures capability taxonomies in TE PD and represents them in a model of a hierarchy of capabilities. The attributes of capability required for TE PD to be able to acquire bogies successfully are; <ul style="list-style-type: none"> • People • Process • Products • Documentation • Technology • Facilities A capability audit has to be conducted within TE PD and then followed by a gap analysis. Once this is done, these attributes shall be planned out in a timeline format to ensure there shift from TE being pure manufacturing to being world recognised OEM is achieved.	(PWC report, 2014) (Transnet Integrated Report, 2020) (BUSA 7470A, 2020) (MOD Homedefence, 2010)	TE Leadership, Process Improvement (PI), Lead Systems Engineer, Human Resource (HR)	Systems thinking, System Lifecycle, Work Breakdown Structure (WBS)
StV-03	Enterprise Goals	Transnet has set a goal to be aR100billion company through its new Transnet 4,0 strategy. TE PD has to quantify in monetary terms it's contribution to the target from their bogie programs.	(TransnetIntegrated Report, 2020)	TE Leadership	
StV-04	Enterprise Objectives	In an effort to assist into achieve Transnet's goal stated in StV-03 above, TE as the Engineering division of the organisation will contribute through; <ul style="list-style-type: none"> •Innovating new products • Improving maintenance (Introducing condition monitoring through 4IR) • Growing the Manufacturing business. acquiring new products such as bogies. The above list of objectives are important inputs into the framework as they influence how bogies will be acquired in TE. In0house designs, Partnership with other OEM while growing TE's capabilities or COTs.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020) (PWC Report , 2014)	TE Leadership, Lead Systems Engineer	
StV-05	Enterprise Mission	Transnet's mission is to link economies, connect people, and grow Africa. Transnet through its ports is the main entry point into Africa through the Seas and one of the biggest economies in Africa. It has set its plans to grow its footprint in Africa not only as a logistics company but as an OEM supplier of rolling stock as well. The Acquisition of Bogies by TE PD is a big part of realizing this mission.	(Transnet Integrated Report, 2020) (PWC Report , 2014)	Minister of Enterprises, Group CEO	
StV-06	Enterprise Governance	All applicable governing legislation such as PFMA, King IV, P2,12 and 13, and the Companies Act and others relevant to the acquisition of bogies have to be identified. This includes applicable legislation required by potentials clients in which the acquired bogies will be operated.	(Transnet Integrated Report, 2020) (Transnet Engineering Report, 2020)		Rich Picture, Requirements Analysis, Stakeholder management, CATWOE

Table 55: Revised Strategic viewpoint (StV) continued

Source: Author.

Strategic Viewpoint (StV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
StV-07	Tools and Equipment	Identify all equipment necessary to acquire the bogie through lifecycle and put plans in place for? <ul style="list-style-type: none"> • Sourcing the equipment • Maintaining the equipment • Training staff to use the equipment 	Interviewee number 1	Lead systems engineer, Project team	System Lifecycle, Work Breakdown Structure (WBS)
StV-08	Railway Technology skills	<ul style="list-style-type: none"> • Team composition and acquisition strategy opted for should be based on the members' experience in working with the different technologies. Technology such as, brakes, wheels, couplers and so on. In Transnet these are called VITs (Very Important Technology). The organisation should retain the employees with understanding of such technology and share the skills within. • Technology readiness levels study should be done and a gap analysis. Then there should be a plan in place to address any deficiencies to enable Transnet to reach status of world recognised OEM of rolling stock. 	Interviewee number 2 Interviewee number 3	TE HR, Project Manager, Lead systems engineer	Work Breakdown Structure (WBS), Capability Maturity Measurement
StV-09	Facilities	Identify important facilities needed to acquire bogies and ensure that the project team has access to these facilities through lifecycle.	Interviewee number 1	Lead Systems Engineer, project team	Lifecycle , System Development Lifecycle (LCV-04)
StV-10	Propose New Procurement Policy	Identify risks to acquisition of rolling stock presented by current policy such as the PFMA and propose policy changes to government that be less of a hindrance to the acquisition of rolling stock and other projects	Interviewee number 2 Interviewee number 3	TE Leadership, Lead Systems Engineer, Minister of Enterprises, Group CEO	Systems thinking, contract management

Table 56: Final Systems engineering technical process viewpoint (SETPV)

Source: Author.

Systems Engineering Technical Process Viewpoint (SETPV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
SETPV-01	Stakeholder Requirements Definition Process	This process identifies all Stakeholders and their interest and role in the Bogie. The stakeholders are then ranked in order of importance based on their influence on the bogie's development or operation. Their needs/requirements are then identified and the measure of effectiveness (MoEs) related to the needs/requirements.	(ISO/IEC/IEEE 15288-2002) (Robert J. Halligan, 2012)	Lead Systems Engineer, Client, as well as contribution from other stakeholders.	System Lifecycle, Requirements Analysis, Rich Picture, Context Diagram, Systems thinking
SETPV-02	Requirements Analysis Process	A ConOps will need to be developed for the bogie and once this is done more requirements are likely to be identified as the ConOps is verified by the different stakeholders. These requirements will form part of the inherent requirements such as; 1. Design, 2. Physical, 3. Resource, 4. Functional, 5. States and Modes, 6.External Interfaces, 7. Performance, 8. Other Qualities. From these different types of requirements, five Requirements Specifications; 1. System Specification, 2. Item Performance Specification, 3. Item Detail Specification, 4. Process Specification, and 5. Material Specification.	(ISO/IEC/IEEE 15288-2002) (Robert J. Halligan,19930) (Robert J. Halligan, 2012) (Defense Acquisition University, January 2001)	Lead Systems Engineer, Client, as well as contribution from other stakeholders.	OCD, ConOps, System Lifecycle, Functional Analysis (RFS Loop), Rich Picture, Context Diagram, Trade-Off Analysis,
SETPV-03	Architecture Design Process	System architecture design process activities of the bogie enable the creation of a global solution based on principles, concepts, and properties logically related and consistent with each other. The solution architecture and design of the bogie system have features, properties, and characteristics that satisfy as far as possible the problem or opportunity expressed by a set of system requirements (From SEV-02 above) and are implementable through the correct use of the bogie as detailed in the output of process OV-03 viewpoint below. The Output of the SETPV-03 are; 1. Architecture Definition Strategy,2. System Architecture Description, 3. Document Tree, 4. Preliminary Interface Definition, 5. Preliminary Technical Performance Measure (TPM) needs, 6. Preliminary TPM Data, 7. Architecture Traceability, 8. Architecture Definition Records.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015) Interviewee Number 3	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Communication management Plan Project change management Plan Risk management Plan Integration management Plan Stakeholder Management Plan
SETPV-04	Implementation Process	The process of realizing the bogie standard components that satisfy the system requirements according to SETV-02, architecture SETV-03, and design. The following are the outputs of this process; 1. Implementation Strategy, 2. Implementation Enabling Systems Requirements, 3. Implementation Constraints, 4. System Elements, 5. System Elements Documentation, 6. Operator/Maintainer Training Manuals, 7. Implementation Traceability, 8. Implementation Reports and 9. Implementation Records.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Quality management Plan Resource management Plan Communication management Plan Project change management Plan Risk management Plan Procurement management Plan Stakeholder Management Plan
SETPV-05	Integration Process	The purpose of the Integration Process is to synthesize the specified standard components of the bogie to make up the complete bogie system that satisfies the system requirements, architecture, and design. The outputs of this process are; 1. Integration Strategy, 2. Integration Enabling System Requirements, 3. Implementation Constraints, 4. Integration Procedure, 5. Integration system or standards components , 6. Interface definition update identification , 7. Integration Reports, 8. Integration Records	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Quality management Plan Resource management Plan Communication management Plan Project change management Plan Risk management Plan Procurement management Plan Integration management Plan Stakeholder Management Plan

Table 57: Revised Systems engineering technical process viewpoint (SETPV) continued

Source: Author.

Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
SETPV-06	Verification Process	The purpose of this process is to provide objective evidence that the acquired bogie system or standards components making up the bogie fulfil the bogie's specified requirements (defined in SETPV-01 above) and characteristics. The outputs of this process are; 1. Verification Strategy, 2. Verification enabling system requirements , 3. Verification constraints ,4. Verification Procedure ,5. Final RVTM , 6.Verified bogie system, 7.Verification Report, and 8. Verification Records	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-07	Transition Process	This process is concerned with the establishment of the bogie's capability to provide services specified by the stakeholders (SETPV-01 and SETPV-02) in the operational environment. The outputs of this process are; 1. Transition strategy 2. Transition enabling system requirements ,3. Transition constraints 4. Installation procedure 5. Installed bogie system ,6. Trained operators and maintainers , 7. Transition report , 8. Transition record.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-08	Validation Process	The purpose of the validation process is to provide objective evidence that the bogie system when in use, fulfils its business or mission objectives and stakeholders needs/requirements, achieving its intended use in its intended operational environment. The outputs of this process are; 1. Validation Strategy, 2. Validation enabling system requirements (Validation requirements forms part of SETPV-01 andSETPV-02), 3. Validations constraints, 4. Validation Procedure, 5. Validation requirements, 6. Validated bogie system, 7. Validation report, and 8. Validation record (Note: Industry requirements standards for bogies are EN 16363, EN 16749, UIC 512 and will supplement the URS)	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Design Team, Lead Systems Engineer, Suppliers, Safety Certification Authority, relevant stakeholders.	Requirements management, Technical Standards viewpoints (TV)
SETPV-09	Operation Process	The Operation process is to use the bogie system for the purpose for which it was developed. The outputs that enable this to happen are; 1.Operational strategy , 2. Operational enabling system requirements , 3. Operational constrained , 4. Operational report, and 5. Operational record.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Operator, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Model Based Systems Engineering (MBSE) Tools, FFBD, System Lifecycle, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview.
SETPV-10	Maintenance Process	In order to sustain the capability of the bogie system to provide its service as intended, maintenance has to be carried out regularly. This process enables this and the following are the outputs of this process; 1. Maintenance strategy, 2. Maintenance enabling system requirements, 3. Maintenance constraints, 4. Maintenance procedure, 5. Maintenance report	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015) Interviewee Number 3	Maintainer, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Maintenance theory, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Reference Documents, Integrated Logistic Support, Obsolescence Management, FMECA, Reliability Analysis, RCM
SETPV-11	Disposal Process	This process is concerned with the ending of the existence of the bogie system and it's standard components for its specified intended use. During this appropriate handling of the retirement process of the bogie is identified and any potential disposal needs are identified.	(ISO/IEC/IEEE 15288-2002) (INCOSE, 2015)	Owner, Design Team, Lead Systems Engineer, Suppliers, relevant stakeholders.	Reference Documents, Regulatory Requirements

Table 58: Revised Operational viewpoint (OV)

Source: Author.

Operational Viewpoint Viewpoint (OV)					
Viewpoint ID	Viewpoint name	Viewpoint description	Reference/Source	Responsible Stakeholder/s	Applicable Systems Tools
OV-01	high-Level Operational Concept Graphic	<ul style="list-style-type: none"> A graphical illustration of different operational scenarios has to be developed based through lifecycle of the bogie. The graphical illustration will serve as a tool for discussion of the expected operation of the bogie. It can be used to provide a common way to more detailed information in published architectures. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Model Based Systems Engineering (MBSE) Tools, FFBD, System Lifecycle, User Operational Concept Description (OCD), Operational Scenarios, Operational Needs, Scope, Reference Documents, System Overview.
OV-02	Operational Performance Attributes. (MoEs)	<ul style="list-style-type: none"> Performance characteristics of the bogies have to be defined during this process. The extent to which the bogie performs during operation has to be measured using Measure of Effectiveness (MoEs) and they are defined during this process. They also assist in determining the required design effort to meet the needs of the stakeholders. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	MoEs, Requirements Analysis
OV-03	Operational Node Relationship Description	<ul style="list-style-type: none"> A description of the bogies operational behaviour is defined using a User Operation Concept Description (OCD) and provides common understanding between client and TE PD on how the bogie is expected to operate. It is during this process that the capabilities of the bogies are defined and agreed on by stakeholders. Different documents for Standard Operating Procedure for different stakeholders (Maintainer, Operator, Manufacturer, Integrator, Transporter, Tester) are eventually compiled and provided to the relevant stakeholders. 	(MOD homedefence, 2010)	Lead Systems Engineer with participation of all stakeholders.	Scenarios, States and Modes, FFBD,
OV-04	Operational Information Exchange Matrix	Any interoperability of the bogie is defined during this process and the requirements to this effect defined and managed.	(MOD homedefence, 2010)	Client/Customer, Design Team, Lead Systems Engineer	Definition of Interoperability Requirements
OV-05	Operational Rules Model	<ul style="list-style-type: none"> Doctrinal operational procedures from the client are defined during this process and their rationale captured. Business Rules for the major stakeholders as well as those within TE are defined at this stage. Operational constraints within TE and for the major stakeholders as well as those within TE are defined at this stage. 	(MOD homedefence, 2010)	Client/Customer, Design Team, Lead Systems Engineer, Support service (Procurement, HR, Finance), Infrastructure Owner, Operator	Systems Thinking
OV-06	Operational Event-Trade Description	<ul style="list-style-type: none"> Identification of non-operational requirements related to the bogie occurs during this process. The captured expected behaviour is analysed during this process and trade-offs made and agreed on by all stakeholders. Scenarios for testing during operation are defined during this process as well as methods of testing, tools for testing, data recording and presentation, as well as evidence that requirements have been met and allowable variances. <p>(Note: The trade-off shall consider the cost and schedule impact of testing that results from the Work Breakdown Structure (WBS))</p>	(MOD homedefence, 2010)	Client/Customer, Lead Systems Engineer	Scenarios, States and Modes, FFBD, MoEs, Requirements Analysis, Verification Requirements

11. APPENDIX E: ACQUISITION AND DESIGN FACTORS CHECK LIST

Acquisition and Design Factors		Acquisition Lifecycle Phases																									
		Pre-Project Phase							Project Phase													Post-Project Phase					
		Opportunity identification or Need identification	Stakeholder identification	Stakeholder requirements	Risk Analysis	Decide on Acquisition Strategy	Acquisition Planning	Building the team	Concept Development and Selection	Develop Project Plan	Develop SEMP	Develop a ConOps	Functional Analysis	Develop System and Components Requirements	Detailed Design	Manufacture	Subsystem Verification	Subsystem Verification	System Validation	Production and Sales	Marketing	Commissioning	Operation and maintenance (Performance monitoring)	Support (Retrofit and modifications)	Lifetime Performance Evaluation.	Decommission	Dispose
1	Requirements management	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
2	Contract Management					X		X					X	X	X	X	X	X	X	X					X		
3	Quality			X		X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	Risk		X	X	X	X						X	X	X	X	X	X	X	X	X		X	X	X			
5	Reliability					X		X					X	X	X	X				X		X	X	X			
6	Availability												X	X	X	X	X	X	X			X	X	X	X		
7	Maintainability										X	X	X	X									X	X	X		
8	Safety		X	X	X			X		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
9	Performance											X			X	X	X	X	X	X		X	X	X			
10	Ergonomics/Human Factors		X	X	X			X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
11	Environment		X	X	X			X				X	X		X									X	X	X	X
12	Misuse or damage			X	X							X	X										X	X	X	X	X
13	Time-to-Market		X	X	X														X	X							
14	Operability			X							X	X	X	X	X							X	X	X	X		
15	Durability			X	X								X	X	X	X		X					X	X	X		
16	Ownership cost		X	X									X	X	X	X	X		X				X	X	X	X	X
17	Development cost			X		X	X		X						X	X	X	X						X			
18	Competitiveness	X	X	X	X	X									X	X				X	X		X	X			
19	Stakeholder Management		X	X	X																				X		
20	Manufacture & Assembly/Disassembly			X	X	X	X		X	X					X	X				X			X	X	X	X	
21	Architecture Design			X	X	X									X		X	X	X					X			
22	Business development	X	X																X	X							
23	Customer value proposition			X									X	X	X	X	X	X	X	X	X	X	X	X	X		
24	Communication management	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
25	Team staffing management		X		X	X	X								X	X								X			
26	Control and Monitoring				X										X	X							X				
27	Scope control	X	X		X										X				X					X			
28	leadership support	X	X	X		X																					
29	Funding/Budget														X	X	X	X	X	X		X		X	X		
30	Pricing	X		X																							
31	Resource Management			X	X	X	X								X	X	X	X	X	X	X	X	X	X	X	X	X
32	Logistics		X	X	X	X												X	X		X	X		X	X	X	X

Requirements management

(Halligan, 2012) attributes poor requirements management as the single biggest cause of failure – up to 80% of the total project cost. This unexpected cost is a result of scope creep, cost overruns, and loss of capability. It is important to identify all requirements through life of the bogie and consider them during design phase.

Quality

In a broad sense, quality is said to include a combination of measures of ‘goodness’, of the attributes of the product, of the performance to specifications in manufacturing, of value in terms of product cost, and of the satisfaction that is perceived by the customer. (Tortorella, 2015). According to (Booth, Templeton & Machine, 1998), the overall objectives of designing for quality are:

1. Design product that meets the requirements (both spoken and unspoken needs) of the customer.
2. Design a robust product that can counter or minimize the effects of potential variations in manufacturing of the product, the product’s environment, and the use or misuse of the product.
3. To continuously improve the product’s reliability performance, and technology to exceed customer’s expectations and offer supreme value.

In order to support the effort to design for quality, (Anderson, 2021) states that designers need to avoid costly defects, errors, rework, scrap, procurement of replacement materials, factory/machine capacity degradation, re-qualifications/re-certification costs, and overhead demands to sort out quality problems, which increase the overall cost.

Reliability

If defined as the probability a system or component will successfully performance as expected for a specified period of time, or accomplish a mission scenario if used under specified conditions (Langford, 2006). (Langford, 2006) and (NPDsolutions, 2015) recommend: reliability predictions be done regularly, testing and evaluations be conducted, analysis for Reliability-Centered Maintenance (RCM) and Failure Mode, Effects, and Criticality (FMECA) analysis be done, use parts proven in service, reduce parts count and interconnections. Reliability engineers need to be involved in the design process from the beginning and the use of Computer Aided Design (CAD) as well as Finite Element Modelling (FEA) can be used to improve the reliability of the product with reduced time and cost (Booth, Templeton & Machine, 1998).

Availability

(Langford, 2006) defines the inherent availability of a system as the probability for readiness for commitment to operate a system when used under specified conditions and ideal support environment at any point in time. This excludes preventive maintenance and logistics delay times.

Maintainability

Is the characteristic of design that pertains to the economy, ease, safety, accuracy in the performance of maintenance function (Langford, 2006). Service and support policies and procedures need to be in place, service training need to be developed and conducted, maintenance manuals written, and spare parts levels established (Booth, Templeton & Machine, 1998). Basic design rules, which need to be established in parallel with the design process to reduce time-to-market, must be there to increase maintainability according to (Booth, Templeton & Machine, 1998). They are:

1. easy access to serviceable items location,

2. reduce adjustments,
3. mistake-proofing fasteners, connections, and re-assembly,
4. built-in test and indicators for maintenance diagnosis,
5. common hand tools and minimum number,
6. simple service procedure and few serviceable parts,
7. quick access, common fasteners and attachments, and
8. easily replaced modules and parts.

Safety Performance

To maximize safety, the design process needs to incorporate features that will enable operation and maintenance of the system to be undertaken without causing damage to equipment, software, facilities and/or injury to personnel (Langford, 2006). This must be considered during the development phase as well.

Ergonomics/Human Factors

This means things that relate to the interface of the system with humans. During design, the objective is to design for compatibility between the functional and human elements of the system in operation, maintenance, support, and use of the system (Langford, 2006).

Environment

The system has to be designed with the environment in mind and the design effort to eliminate the negative impact to the environment by the system and vice versa. (APSC381, 2020) and (Srinivas, 1990) recommend the following guidelines when designing for the environment: avoid or minimize use of hazardous materials, avoid material with high energy content, minimum number of materials used, optimize efficiency of transport modes, design for easier maintenance, design for re-use, design for possible manufacturing/refurbishing, and use recyclable materials.

Misuse or damage

The design phase has to design with possible misuse and damage in mind and create different scenarios as a result of such actions and design for them.

Time to Market

Taking a product to market is one of the most important phases of the project and phases in the project that affect this milestone. The most important factor that needs to be identified and accounted for in the time it takes to market a product. Controlling this process effectively allows a company to be competitive and keep up with or lead the market.

Operability

The longest lasting phase in the system lifecycle is the operation phase and is also the one where, in most cases, the owner of the system extracts value from owning the system. The design process needs to ensure all possible scenarios of operation are accounted for and designed for.

Ownership cost

One of the most important factors customers take into account when buying a product is cost of owning this product. Thus, this must be considered during the phases of the acquisition that impact ownership cost such as maintenance cost, energy consumption cost, and consumables.

Development cost

A good understanding of the development cost is needed so that the budget for developing the bogie is as accurate as possible and funding is sourced and made available when needed. A model to develop the bogie needs to be established either based on current organization capability or future organization capability created by investment (Booth, Templeton & Machine, 1998). A basic development cost model is shown in the Figure 61 below.

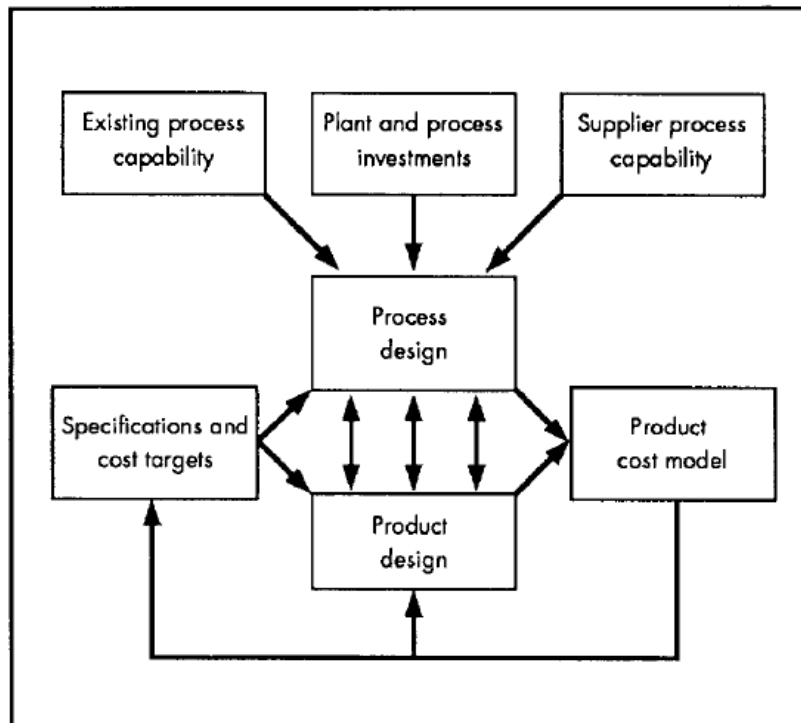


Figure 61: Bogie development cost model

Source: (Booth, Templeton & Machine, 1998)

Competitiveness

In order to be market leaders, an organization must keep up with the trends in terms of tools and technology, processes, and pricing so as to remain relevant.

Stakeholder Management

Stakeholder management is the process of identifying people, groups, or organizations that impact or be impacted by the project (Forsberg *et al*, 2005). This process needs to be centred around the bogie and be considered throughout the lifecycle.

Manufacture and Assembly/Disassembly

(APSC381, 2020) identified a common failure of product development not to be building product that don't work but making products that are difficult to build. This results in driving up the price and cost of ownership of the system as manufacturing challenges increase, systems are unreliable, difficult to maintain, and time consuming (APSC381, 2020). (Booth, Templeton & Machine, 1998) states that the best way to design for manufacturing is to use the concurrent engineering framework. Concurrent engineering framework is made up of: 1. enabling technology, 2. continuous process improvement, 3. organization and teams, and 4. design-for-X principles. The important principles for designing for manufacturing and assembly according to (Booth, Templeton & Machine, 1998) are:

1. reduce number of parts,
2. standardize and use common parts,
3. design for ease of fabrication,
4. mistake-proof product design and assembly,
5. design for parts orientation and handling,
6. minimize flexible parts and interconnections,
7. use simple patterns for ease of assembly,
8. design for efficient joining and fastening, and
9. design for modular products.

Architecture Design

NK Labs define architecture as a conceptual model that defines the structure and behaviour of a system. It allows a group of engineers to collaborate efficiently towards archiving a common goal. The system architecture design begins during requirement definition as designers need to know who will use the system and how will they use it. The functional requirements need to address the need. Basic technologies that will be used need to be established as well. Industry standards need to be considered when establishing the technologies (NK Labs, 2022).

Business Development

Business development is defined in its simplest forms as the ideas, initiatives, and activities that help a business be better. This results in the increasing of profitability, business expansion, revenue as well as building strategic partnerships and making strategic business decisions (Shobhit, 2022).

Communication Management

Project communications is the root cause of many project failures and can create conflict in project teams. Techniques of communication and a common vocabulary are prerequisites for teamwork, project cycle, for project management elements (Forsberg *et al*, 2005).

Team Staffing Management

The staffing of a project team will correspond with the project phases and funding of a project. The core team has to be developed first and the rest will be based on milestones at each phase (Forsberg *et al*, 2005).

Control and Monitoring

Monitoring is defined as the collection of project performance data, producing performance measures, and reporting and disseminating the performance information to the stakeholders. Control is defined as comparing actual performance with planned performance, analyzing variances, assessing trends to in order to implement process improvements, evaluating possible alternatives, and making recommendations as and when needed for corrective action (Forsberg *et al*, 2005).

Scope Control

Monitoring the process of the project and product scope and managing changes to the scope baseline is referred to as control of a project scope. (Forsberg *et al*, 2005). The outputs of this process are: 1. work performance information, 2. change requests, 3. project management plan updates, and 4. project documents updates (Forsberg *et al*, 2005).

Funding

Phases that require funding for execution need to be identified and accounted for beforehand and funding made available in time so as not to delay projects.

Pricing

In order for a company to survive and be self-sustaining, the development cost needs to be less than the selling price (Booth, Templeton & Machine, 1998). Factors that influence pricing need to be considered through the lifecycle in order to keep the price under control and make the bogie affordable for the customers. Development cost is determined internally in the organization and influenced by design, procedures, wage rates, and manufacturing processes. Traditionally, an organization sets a target development cost that must not be exceeded for the organization to make a profit and be competitive. A competitive selling price is informed by perceived quality as well as desired attributes of the bogie (Booth, Templeton & Machine, 1998).

Resource Management

Project resource management changes processes include: 1. resource management plan, 2. estimation of activity resources, 3. acquire resources, 4. develop team, 5. manage team, and 6. control resources (Forsberg *et al*, 2005).

Logistics

The management of the flow and management of materials is crucial to the completion of a project based on the number of organizations involved (Forsberg *et al*, 2005). Logistics of storing, transporting of the bogie system itself during design and testing phases until accepted at customer's operating site needs to be considered as well as the cost and risk of the logistics process.