A Business Process Reengineering Framework Using the Analytic Hierarchy Process to Select a Traceability Technology for Spare Parts Management in Capital-Intensive Industries

by

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Thesis presented in partial fulfilment of the requirements for
the degree of Master of Engineering Management in the
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March 2016

Declaration

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Date: ....March 2016........

Abstract

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Thesis: MEng (Engineering Management)

March 2016

Spare parts are essential for the effective operation of a capital-intensive organisation and, together with material consumption, form approximately 50% of a typical maintenance budget. However, few companies actually adopt proper structural, factual and quantitative Spare Parts Management (SPM) approaches despite the relatively vast body of literature on spare parts. Integrated approaches to manage spare parts as well as to supplement theoretical models with practical guidelines are required in order to bridge the gap between research and practice. This study derives from an opportunity identified for improving processes within SPM, particularly through the utilisation of asset traceability technology. A framework is proposed that (i) guides the Business Process Reengineering (BPR) of processes within SPM while considering elements of Change Management, and (ii) guides the selection [through use of the Analytic Hierarchy Process (AHP)] of traceability technology for integration within SPM at capital-intensive organisations.

The research comprises a discussion of *Asset Management (AM)*, including PAS 55 and ISO 55000 (two important AM series of documents), and *Change Management*, which is an essential aspect for implementations. *SPM*, a subset of AM related to spare parts and the focal point of the study, is also addressed, including characteristics of spare parts and how spare parts differ from general inventory; classification criteria and classification techniques;

demand forecasting for spare parts; and inventory warehousing management. Various aspects (including 29 best practices) of *BPR* are described in order to support the proposed framework. These include criteria for selecting processes to redesign, the role of Information Technology in BPR and typical barriers to effective implementation of BPR. The *AHP* (a multi-criteria decision-making method) is explained in detail, as it facilitates the selection of asset traceability technology. An overview of *asset traceability technologies* (specifically barcode technology, Radio Frequency Identification (RFID) technology and Global Positioning System (GPS) technology) is also provided, including the description of certain characteristics of each technology.

The proposed framework, based on the literature review, serves as a structured guide and consists of two primary parallel elements (referred to as streams), namely the *BPR stream* and the *Change Management stream.* The BPR stream encompasses six phases of BPR (Contextualise SPM, Business Process Redesign, Asset Traceability Technology, Decision-Making, Implement, and Monitor and Evaluate) while the Change Management stream consists of three stages (Unfreeze State, Change State and Refreeze State).

The framework is validated through face validation via semi-structured interviews with participants forming a panel of experts involved in and familiar with SPM and asset traceability technology. According to the expert panel, the proposed framework satisfies achievement of the desired framework attributes, namely (i) *Generic and adaptable*, (ii) *Holistic and comprehensive*, (iii) *Structured and objective- or outcome-oriented* and (iv) *Practical.* In addition, the expert panel perceived the framework to be *useful*, *easy to use* and *understandable.* However, recommendations were proposed to further improve the framework, including the addition of a "scoping and objectives" section and the expansion of the Change Management element.

Uittreksel

’n Besigheidsproses Hersieningsraamwerk wat die Analitiese Hiërargie Proses gebruik om ’n Opspoorbaarheidstegnologie te kies vir Onderdelebestuur in Kapitaal-Intensiewe Industrieë

(“A Business Process Reengineering Framework Using the Analytic Hierarchy Process to Select a Traceability Technology for Spare Parts Management in Capital-Intensive Industries”)

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Onderdele is noodsaaklik vir die effektiewe bedryf van ’n kapitaal-intensiewe organisasie en maak, tesame met materiaalverbruik, ongeveer 50% uit van ’n tipiese instandhoudingsbegroting. Ten spyte van die relatief groot hoeveelheid literatuur beskikbaar oor onderdele, pas min maatskappye egter ordentlike strukturele, feitlike en kwantitatiewe Onderdelebestuur toe. Geïntegreerde benaderings om onderdele te bestuur, sowel as om teoretiese modelle te ondersteun met praktiese riglyne, word benodig ten einde die gaping tussen navorsing en praktyk te oorbrug. Die studie het voortgevloei uit ’n geleentheid geïdentifiseer om prosesse binne Onderdelebestuur te verbeter, spesifiek deur die gebruik van bate opspoorbaarheidstegnologie. ’n Raamwerk word voorgestel wat (i) die Besigheidsproses Hersiening lei deur prosesse binne Onderdelebestuur, met die inagneming van elemente van Veranderingsbestuur, en (ii) die keuse van opspoorbaarheidstegnologie lei vir integrasie binne Onderdelebestuur by kapitaal-intensiewe organisasies (deur die gebruik van die Analitiese Hiërargie Proses).

Die navorsing bestaan uit ’n bespreking van *Batebestuur*, insluitend PAS 55 en ISO 55000 (twee belangrike Batebestuur dokumentreekse) en *Veranderings-*

bestuur, wat 'n noodsaaklike aspek vir implementering is. Vervolgens word *Onderdelebestuur*, 'n onderafdeling van Batebestuur wat verband hou met onderdele en die fokuspunt van die studie is, aangespreek. Die volgende Onderdelebestuur aspekte word onder andere aangespreek: eienskappe van onderdele en hoe onderdele van ander algemene voorraad verskil; klassifiseringskriteria en klassifiseringstegnieke; vooruitskatting van die vraag na onderdele; en die bestuur van voorraadvlakke. Verskeie aspekte (insluitend 29 beste praktyke) van *Besigheidsproses Hersiening* word beskryf ten einde die voorgestelde raamwerk te ondersteun. Dit sluit kriteria in vir die keuse van herontwerpsprosesse, die rol van Inligtingstegnologie in Besigheidsproses Hersiening en tipiese struikelblokke vir die effektiewe implementering van Besigheidsproses Hersiening. Die *Analitiese Hiërargie Proses* ('n multi-kriteria besluitnemingsmetode) word in detail verduidelik, aangesien dit die keuse van 'n bate opspoorbaarheidstegnolgie moet fasiliteer. 'n Oorsig van *bate opspoorbaarheidstegnolgieë* (spesifiek strepieskode tegnologie, Radiofrekwensie Identifikasie (RFID) tegnologie en Globale Posisioneringstelsel (GPS) tegnologie) word ook verskaf, insluitend die beskrywing van sekere eienskappe van elke tegnolgie.

Die voorgestelde raamwerk, gebasseer op die literatuurstudie, dien as 'n gestruktureerde gids en bestaan uit twee primêre parallele elemente (wat na verwys word as strome), naamlik die *Besigheidsproses Hersiening stroom* en die *Veranderingsbestuur stroom*. Die Besigheidsproses Hersiening stroom vervat ses fases van Besigheidsproses Hersiening (Kontekstualiseer Onderdelebestuur, Besigheidsproses Hersiening, Bate Opspoorbaarheidstegnolgie, Besluitneming, Implementeer, en Monitor en Evalueer) terwyl die Veranderingsbestuur stroom bestaan uit drie stadiums (Ontvries Stadium, Verander Stadium en Hervries Stadium).

Die voorgestelde raamwerk word bekragtig deur sigwaarde bekragtiging via semi-gestruktureerde onderhoude met deelnemers wat 'n paneel van deskundiges vorm wat betrokke en vertroud is met Onderdelebestuur en Bate Opspoorbaarheidstegnolgie. Volgens die paneel van deskundiges slaag die voorgestelde raamwerk daarin om die vereiste raamwerk kenmerke te bereik, naamlik (i) *Generies en aanpasbaar*, (ii) *Holisties en omvattend*, (iii) *Gestruktureerd en doel-of uitkomsgeöriënteerd* en (iv) *Prakties*. Boonop het die paneel van deskundiges die raamwerk gesien as *nuttig*, *maklik om te gebruik* en *verstaanbaar*. Aanbevelings was egter voorgestel om die raamwerk verder te verbeter, insluitend die byvoeging van 'n "bestek en doelwitte" afdeling en die uitbreiding van die Veranderingsbestuur element.

Acknowledgements

I would like to express my sincere gratitude to the following people and organisations for their roles in the completion of this study:

- Prof. P.J. Vlok and Dr J.L. Jooste, my research supervisors, for their guidance and advice throughout the duration of my Master's programme.
- Anglo American (especially Alan O'Keeffe) for providing financial support and information, without which the completion of this thesis would have been impossible, as well as the employees of Anglo American that participated in the validation of this study.
- Tronox and ArcelorMittal South Africa (especially the relevant employees) for participating in the validation of the study.
- Imke de Kock, Hugo van der Merwe and Celeste de Vries for the roles they played in providing feedback and translations.
- Dr Nyaga, as well as my aunts, Colleen and Kim, for helping me with proofreading in the last stretch.
- My family, namely Rob, Janelle and Byron, for their unwavering support and faith in me.
- My fellow colleagues and dear friends who made the office a pleasant and entertaining environment.
- My heavenly Father who strengthens me (Philippians 4:13).

The Author
February 2016

Dedications

This thesis is dedicated to
Rob, ***Janelle*** *and* ***Byron Flynn***
for their unfaltering support,
unconditional love and
faith in me.

Contents

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Acronyms

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
A-GPS	Assisted Global Positioning System
ACRG	Asset Care Research Group
AHP	Analytic Hierarchy Process
AIDC	Automatic Identification and Data Capture
AIM	Asset Information Management
AIMS	Asset Information Management System
AM	Asset Management
ASCII	American Standard Code for Information Interchange
BAM	Business Activity Monitoring
BPI	Business Process Improvement
BPM	Business Process Management
BPMN	Business Process Modelling Notation
BPR	Business Process Redesign or Reengineering (collective)
BPRD	Business Process Redesign
BPRE	Business Process Reengineering
BT-based	Binary-Tree-based
CI	Consistency Index
CIMFR	Central Institute of Mining and Fuel Research
CMMS	Computerised Maintenance Management System
CPN	Coloured Petri Nets
CR	Consistency Ratio
D-GPS	Differential Global Positioning System
EAM	Enterprise Asset Management
EAN	International Article Number (previously: *European Article Number*)

ECI	Extended Channel Interpretation
ELECTRE	Elimination Et Choix Traduisant la Realité (Elimination and Choice Expressing Reality)
EOQ(s)	Economic Order Quantity/Quantities
EPC	Electronic Product Code
ERP	Enterprise Resource Planning
EVA	Earned Value Analysis
FIFO	First-In-First-Out
FNC1	Function Code One
FSA-based	Framed-Slotted-ALOHA-based
GFMAM	Global Forum on Maintenance and Asset Management
GPS	Global Positioning System
HF	High Frequency
IAM	Institute of Asset Management
IDEF	Integrated Definition
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organisation for Standardisation
IS	Information System
IT	Information Technology
JIT	Just-In-Time
KPI(s)	Key Performance Indicator(s)
LF	Low Frequency
MCDM	Multi-criteria Decision-Making
MES	Manufacturing Execution System
MRO	Maintenance, Repair and Operations (or Overhauls)
NAVSTAR	Navigational Satellite Timing and Ranging System
NFC	Near Field Communication
NPO(s)	Not-for-Profit Organisation(s)
OCR	Optical Character Recognition
OEE	Overall Equipment Effectiveness
OEM(s)	Original Equipment Manufacturer(s)
PAM	Physical Asset Management
PAS	Publicly Available Specification
PDA	Personal Digital Assistant
PDCA	Plan-Do-Check-Act
PIN	Personal Identification Number

PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluation
PSM	Project Scope Management
QR Code	Quick Response Code
RFID	Radio Frequency Identification
RI	Random Consistency Index
ROI	Return on Investment
ROP(s)	Reorder Point(s)
RTLS	Real-Time Location System
RTSS	Real-Time Sensing System
SES	Simple Exponential Smoothing
SHF	Super-High Frequency
SKU(s)	Stock Keeping Unit(s)
SLAP	Storage Location Assignment Problem
SPM	Spare Parts Management
TAM	Technology Acceptance Model
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TTFF	Time-To-First-Fix
TQM	Total Quality Management
UHF	Ultra-High Frequency
UPC	Universal Product Code
UWB	Ultra-Wideband
VIN	Vehicle Identification Number
WBS	Work Breakdown Structure
WCS	Warehouse Control System
WIP	Work-In-Process
WMS	Warehouse Management System
WPS	Wireless Positioning System

Nomenclature

Variables

E_n	Priority value for the n^{th} criterion	[ ]
n	Order (dimension) of square matrix (comparison matrix)	[ ]
r_{jn}	j^{th} element in column n of comparison matrix	[ ]
x_{ij}	Element in row i, column j of comparison matrix	[ ]
λ	Eigenvalue	[ ]
λ_{max}	Maximum eigenvalue of decision matrix	[ ]
CI	Consistency Index	[ ]
CR	Consistency Ratio	[ ]
RI	Random Consistency Index	[ ]

Vectors and Tensors

A_D	Alternatives comparison matrix according to *Complexity*
A_M	Alternatives comparison matrix according to *Cost*
A_U	Alternatives comparison matrix according to *Usefulness*
C	Comparison matrix

Chapter 1

Introduction

This chapter introduces the study to the reader. A background to the study is provided after which the problem statement is defined. The delimitations and the research objectives of the study are also defined. Thereafter, the research design and research methodology are briefly described. The chapter concludes with the outline of the thesis, which is also illustrated in Figure 1.1. The figure is provided at the beginning of each chapter to guide the reader through the study with the darker shading in the graphical outline indicating the current position within the document structure.

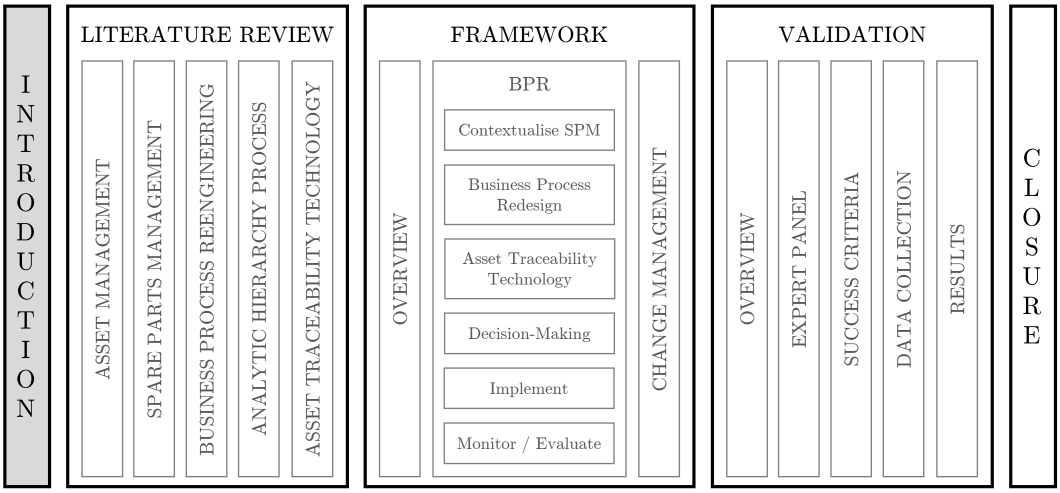


Figure 1.1: Thesis outline (from left to right)

1.1 Background

In the modern era, companies have a greater need to maximise competitive advantages due to globalisation and more prevalent information or asset sharing. In support of this, Flynn and Vlok (2015) acknowledge the increased strategic focus of organisations on increasing efficiency, improving quality and generating larger profits in the present global and highly competitive economy. As a result, industries are under pressure to reduce costs, attain higher performance targets, comply with regulatory requirements and maximise the return on assets (Ouertani, Parlikad and McFarlane, 2008). Specifically in a South African context, Lane, Guzek and Van Antwerpen (2015) highlight the challenges that local mining organisations experience while operating under global pressures. These challenges include, among others, social unrest, strikes, declining ore grades at current depths, increasing unit costs of production, increasing energy costs and skills shortages. These pressures have recently resulted in a stronger emphasis on improved management within organisations, particularly regarding Asset Management (AM).

The recent International Organisation for Standardisation (ISO) 55000 series of standards (BSI, 2014a), which was developed upon the foundation of the previous Publicly Available Specification (PAS) 55, defines AM as the "coordinated activity of an organization to realize value from assets". AM is essential for capital-intensive industries, especially within the mining industry. Mining organisations typically own millions (often billions) of assets which they operate and manage. In this regard, O'Brien (2011) states that the mining industry requires more capital (particularly regarding assets) than the majority of other industries and, as a result, AM is essential in the mining industry. The assets utilised in the mining industry typically operate in harsher environments than assets within the majority of other industries, and the critical or important assets are often operated to their operational limits.

Fogel and Terblanche (2013) indicate that there is evidence that effective AM results in improved capital productivity, enhanced decision-making, optimised life cycle costs, improved labour productivity and greater recovery rates, among others. Nevertheless, the responsibility of AM is often assigned to a disempowered function within the organisation which lacks the budget, sway and/or authority to have any substantial impact on management of assets and performance (Fogel and Terblanche, 2013). Ouertani *et al.* (2008) observe that a 2004 survey (performed by the Aberdeen Group) of 233 companies in a broad variety of industries indicated that 50% of the companies have manual AM processes. This suggests that the potential may exist to minimise errors and improve productivity through the automation of AM processes.

An important subset of AM is Spare Parts Management (SPM) which concerns the management of spare parts (a specific kind of asset). A spare part is a duplicate or replacement item used, or planned to be used, to replace either a damaged component or a component that is not functioning at a satisfactory level of performance. The replacement is sometimes performed for preventative maintenance reasons. Barry and Olson (2010) state that the purpose of spare parts is to "support the sustainability and life cycle of the expected functions of valued assets". The need for a spare part arises when a component fails to operate at the designed or expected performance levels. In this case, the component is either replaced with a spare part, allowed to run-to-failure and then replaced with a spare part, or repaired if possible. Terms referring to spare parts include *spares*, *service parts*, *repair parts* and *replacement parts* (Du Toit, 2014). SPM includes, among others, the forecasting of spare parts, the policies that dictate the ordering, receiving, storage and issue of spare parts, as well as the tracking and tracing of spare parts (although, at the moment, the majority of organisations do not perform the tracking of spare parts).

For centuries, spare parts have been an important part of organisations allowing the organisations to strive towards continuous production (by reducing overall downtime in production). Cavalieri, Garetti, Macchi and Pinto (2008) highlight that successful management of *Maintenance, Repair and Operations/Overhauls (MRO)* materials, which include spare parts, is vital in capital-intensive organisations. In the same vein, Du Toit (2014) states that capital-intensive industries, in particular, are confronted with significant challenges in SPM. As aforementioned, these industries require substantial investments in order to operate. There is always a trade-off in SPM within any industry between inventory costs and risk, but capital-intensive industries generally manage a larger number of spare parts, especially the significantly expensive ones. Typically, these industries (such as the mining industry) heavily rely on continuous production; otherwise, significant costs are incurred. In this regard, Ghodrati and Kumar (2005) find that effective SPM reduces idle time and increases resource utilisation; thereby, enhancing productivity. These issues indicate the importance of SPM within capital-intensive industries.

Suomala, Sievänen and Paranko (2002) observe that the purchasing, warehousing, selling and delivering of spare parts can impact significantly on company profits. They find that approximately one-third of net sales and two-thirds of profits are derived from spare parts. Similarly, Wagner and Lindemann (2008) find that studies from the early 2000s indicate that after-sales services and sales of spare parts account for approximately 25% of the revenues and 40% to 50% of the profits in manufacturing and engineering-driven organisations. According to Wagner and Lindemann (2008), the aftermarket for spare parts and services forms 8% of the annual gross domestic product of the USA.

Wireman (2005) highlights that approximately 50% of a typical maintenance budget is expended on spare parts and material consumption and that, for reactive organisations, up to 20% of costs related to spare parts may be waste. This is a substantial amount considering that maintenance accounts for 30% to 50% of total operating expenses (forming the largest cost) in mining organisations (Lyndon, 2014). Flynn and Vlok (2015) point out that organisations that implement *lean thinking* (the elimination of waste) should reduce excess inventory. In so doing, these organisations should attempt to ensure that no unnecessary spare parts are stored without compromising the availability of spares to meet the demand. Excess inventory may result in increased storage costs, transport costs, risk of damage and length of lead times. Therefore, considering the costs associated with ineffective SPM, it is evident that spare parts should be managed as effectively as possible. Wireman (2005) highlights the following areas of waste that are typically present in the inventory and purchasing function within organisations:

- excess stock of spare parts;
- expediting spare parts delivery;
- shelf life expiry;
- single line item purchase orders; and
- loss or lack of record of spare parts.

The loss or lack of record of spare parts, as highlighted by Wireman (2005), is an important issue. Organisations have become increasingly cooperative with each other and within their own structures; sharing equipment, resources and having spare parts (such as rotable spare parts) repaired. Hence, it is difficult to manage the exact location of spare parts, tools and people, especially in large organisations. *Squirrel stores* form one prevalent example of an issue in SPM that results in the loss or the lack of record of spare parts. According to Du Toit and Houston (2013), these squirrel stores are unofficial storage locations of spare parts used by users in engineering, maintenance and plant operations at their specific sites of work. These storage locations are established by end-users and not the official inventory staff.

Squirrel stores do not appear on inventory management systems. Although stock-outs of critical spare parts pose significant risk and cost to the organisation, there are hidden costs related to squirrel stores, which are typically overlooked. These squirrel stores can increase obsolescence of stock, theft (or, at least, the possibility of theft) and downtime as well as impact working capital (Du Toit and Houston, 2013). Although increased downtime may seem counter-intuitive since a squirrel stock is essentially an extra "safety" store, the lack of visibility typically results in teams wasting time searching for parts.

Du Toit and Houston (2013) provide the following reasons for the existence of squirrel stores: *lack of trust*; *ineffective supply chain practices*; *policy and control*; *risk of increased obsolescence and theft*; *risk of increased downtime*; *working capital*; *impeded planning cycles*; *demand variability*; *increased uninsured stock on hand*; *increased costs and spending*; and *limitations on cross-use*. Du Toit and Houston (2013) argue that it is vital to know what inventory is owned at any given time before inventory levels can be reduced. This includes knowledge of the location and quantity of all spare parts.

Similarly, Ouertani *et al.* (2008) argue that it is critical to know the location of assets in order to effectively manage them. They assert that providing *relevant, timely and useful location information* to the persons and systems responsible for managing asset-intensive business processes results in a number of significant benefits. Among these benefits are the timely and informed decision-making based on real-time information, the decrease in information-related errors, the reduction in costs associated with searching for misplaced or lost assets, and the improvement of overall productivity and throughput. Barry and Olson (2010) also claim that MRO materials are not always available at the right locations or at the right times as required by organisations. This occurs despite the significant costs and efforts by inventory managers to be able to issue the materials so as to satisfy unpredictable demand.

Most research and industrial practice regarding SPM involves the forecasting of demand and the attempt to optimise stock levels to achieve a desired service level at a minimum cost (Wagner and Lindemann, 2008; Du Toit, 2014). Huiskonen (2001) states that spare part inventories are usually managed through the use of general inventory management principles instead of principles applicable specifically for spare parts. Moreover, Cavalieri *et al.* (2008) report that few companies actually adopt proper structural, factual and quantitative approaches to manage spare parts despite the relatively vast body of literature on spare parts. Thus, Bacchetti and Saccani (2012) emphasise that integrated approaches to manage spare parts and to supplement theoretical models with practical guidelines are required in order to bridge the gap between research and practice.

1.2 Problem Statement

As highlighted in Section 1.1, there is a need for improved business processes regarding SPM within capital-intensive industries. It was also mentioned that a significant percentage of companies have manual processes for the majority of their AM (which includes SPM) activities. Furthermore, Wireman (2005) indicates that an area of waste typically found within organisations is the loss or lack of record of spare parts. Therefore, SPM requires more effective processes which may require or benefit from the utilisation of traceability technology.

Business Process Reengineering (BPRE) and Business Process Redesign (BPRD) are two concepts focused on improving business processes within organisations. Both BPRD and BPRE are used interchangeably in practice (and in some academic papers) and are often considered to be the same concept referred to using the term *BPR* (which may represent either *Business Process Redesign* or *Reengineering*). Ramirez, Melville and Lawler (2010), however, find that BPRD is an approach focused on business processes and their efficiency in order to improve organisational performance. Mansar and Reijers (2007) assume BPRE to have a much broader scope than BPRD. According to them, BPRD focuses on streamlining a specific business process in terms of its interdependent tasks and resources while BPRE involves all aspects of restructuring an organisation's processes (from change management to project management). Based on this distinction, BPRE (which includes drastic change programmes) encompasses BPRD.

Reijers and Mansar (2005) consider BPRD as an initiative which consists of two challenges in addition to the challenge of managing a BPRD project, namely:

1. a technical challenge owing to the difficulty of developing a solution, which is a significant improvement of the current design; and
2. a socio-cultural challenge originating from the organisational impact on the people involved who may react against any changes.

Various authors express that BPR generally lacks a systematic approach to guide a redesigner from Point A to Point B (Gerrits, 1994; Valiris and Glykas, 1999; Sharp and McDermott, 2001; Reijers and Mansar, 2005). There is, therefore, an opportunity to create a guide for the Business Process Reengineering (henceforth referred to as BPR unless otherwise stated) of processes within SPM.

According to Grové (2007), the three primary drivers of business performance are people, information (and processes) and technology, with information being the "centre point" among these drivers. Specifically regarding BPR, Greasley (2005, p. 437) reports that the three primary enablers or levers of change are information, Information Technology (IT) and organisational or human resources. Similarly, Barry, Helstrom and Potter (2010) assert that the typical business transformation triangle of any implementation strategy consists of people, processes (including information) and technology. Therefore, the primary focus of any business improvement initiative should be on these three factors. Organisations can use asset information (which is captured throughout the lifecycles of the assets) to collect, reposition and redeploy their assets in the most effective manner (Burkett, Kemmeter and O'Marah, 2002).

Technology integration allows for real-time information and integrates various fields, processes and applications into one manageable package. However, Fogel and Terblanche (2013) report that there is no evident correlation between *further investment* in Information Technology (IT) and computer systems, and asset performance. However, IT and computer systems are merely tools assisting with the management of information and activities. The onus is on the organisation to have the necessary AM principles already in place for these tools to be effective. Similarly, Heber (2014) states that mining organisations cannot simply layer new technologies over existing operating models, but should assess whether the operating models may require revision or overhauls. This requires the evaluation of processes and improvement of these processes (perhaps through BPR) before new technology (such as asset traceability technology) is considered.

Additionally, Barry *et al.* (2010) state that the implementation of a Computerised Maintenance Management System (CMMS), or other technology solution, requires that the business process provides the software-managed tasks to relevant people while aligning these people with the enabling technology and its ability to execute desired tasks. This implies that the process should educate and train people to use the technology as well as to act in a different manner as appropriate for the new system. Changing people's behaviour requires consideration of the work culture and the impact that the planned changes will have on this culture. It is important to ensure that the people involved will adapt or that the changes will be adopted into the work culture. This requires *Change Management*.

Following the points discussed, the study investigates the relevant areas highlighted and proposes a framework that guides the BPR of processes within SPM, and that supports the selection of asset traceability technology in an attempt to improve current practices within SPM. A variety of Multi-criteria Decision-Making (MCDM) methods are available for decision-making. However, this study utilises the Analytic Hierarchy Process (AHP), without significant evaluation of other methods, as the method to support the selection of asset traceability technology for the SPM environment. This is based on the AHP's simplicity while remaining powerful enough to aid quality complex decision-making, in addition to its popularity, ease of understanding, ease of implementation and ability to handle subjective data.

In view of this, the central research question arises as:

> *Is it possible to develop a framework that (i) guides the BPR of processes within SPM while considering elements of Change Management, and (ii) supports the selection (through use of the AHP) of traceability technology for integration within SPM, to improve current practices within the SPM environment at organisations within capital-intensive industries?*

The central research question translates into the following null hypothesis:

$\boldsymbol{H_0}$ **:** *It is not possible to develop a framework that guides the BPR of processes within SPM while considering elements of Change Management, and that supports the selection (through use of the AHP) of traceability technology for integration within SPM, to improve current practices within the SPM environment at organisations within capital-intensive industries.*

1.3 Research Aim and Objectives

The background and problem statement serve as a prelude to the research aim and objectives that need to be achieved through the execution of the study. The aim of the study is

> *to develop a framework that guides the BPR of processes within SPM while considering elements of Change Management, and that supports the selection (through use of the AHP) of traceability technology for integration within SPM, to improve current practices within the SPM environment at organisations within capital-intensive industries.*

The research objectives are aimed at addressing the needs identified in the problem statement. In order to achieve the stated aim, this study seeks to address the following objectives:

1. To master the fundamental principles of AM and SPM, a subset of AM.
2. To acquire sufficient knowledge of the fundamental principles of Change Management necessary to facilitate an implementation project or BPR initiative.
3. To master the fields of BPR and asset traceability technologies, as well as the AHP which will support decision-making.

4. To develop a framework that (i) guides the BPR of spare parts processes while considering elements of Change Management, and (ii) supports the selection (through use of the AHP) of traceability technology for integration within SPM at capital-intensive organisations.

5. To validate the developed framework through the method of face validation.

The Cambridge Dictionaries Online (2015) defines the term *framework* as “a supporting structure around which something can be built” or “a system of rules, ideas, or beliefs that is used to plan or decide something”. Similarly, the BusinessDictionary (2015) defines the term *framework* as a “broad overview, outline, or skeleton of interlinked items which supports a particular approach to a specific objective, and serves as a guide that can be modified as required by adding or deleting items”. In terms of this study, the proposed framework follows these definitions by serving as a broad, logical, stepwise guide that establishes the relationship between various interlinked concepts while referring to relevant information or sections required within the guide to achieve certain outcomes.

The proposed framework should have the following attributes:

- *Generic and adaptable*: the framework should be applicable to various environments in different organisations (within capital-intensive industries) and should not be restricted to a specific site only.

- *Holistic and comprehensive*: the framework should be a multi-discipline-integrated, holistic approach that considers all, or at least the majority, of the relevant aspects concerned with the problem studied.

- *Objective-* or *outcome-oriented*: the framework and the steps therein should be structured in such a way that outcomes or objectives are the focus and are clearly stated.

- *Practical*: the framework should be applicable to industrial practice.

- *Structured*: the framework should be logical, organised and sequential. Its steps should guide the user towards an appropriate solution.

The study attempts to achieve the aforementioned objectives and framework attributes. The delimitations of the study, derived from the objectives, are discussed in the subsequent section.

1.4 Delimitations of the Study

The scope or boundaries of a study need to be defined clearly in order to focus effectively on the relevant research and to attain the research objectives of the study. The research objectives of this study are discussed in Section 1.3. The following boundaries are applicable to this study:

1. The study is concerned with improving SPM through the BPR of processes (including traceability technology integration) relating to spare parts in capital-intensive organisations, particularly mining organisations. It does not provide a guideline with regard to spare parts forecasting or specific stock control policies. In addition, it does not discuss every possible aspect of SPM or provide extensive detail on each aspect considered as these issues vary significantly among organisations whereas the study is limited in duration.

2. The AHP is utilised, without significant evaluation of other methods, to aid decision-making relating to technology selection in the study. As previously mentioned, the AHP is simple yet powerful enough to aid quality complex decision-making, in addition to being popular, easy to understand, easy to implement and able to handle subjective data. This, however, is neither the only decision-making method available nor claimed to be the optimal decision-making solution for technology selection.

3. The proposed framework serves as a stepwise guide. It attempts to provide a comprehensive decision-making guideline with various aids and relevant considerations to support the BPR initiative. However, it is not prescriptive in nature and does not attempt to describe the finest details of every aspect that may be relevant to a BPR initiative.

4. The proposed framework is intended for the SPM environment, although it is applicable to other areas when slightly modified. Careful consideration of the structure and aspects of the framework is required should the framework be applied in a different environment.

5. The research has a focus on capital-intensive industries (particularly mining), although the proposed framework is not necessarily limited to these industries.

These delimitations were considered throughout the execution of this study. The following section discusses the research design and methodology employed in the execution of the study.

1.5 Research Design and Methodology

Mouton (2001) describes the *Three Worlds* framework which is based on three *frames* or *contexts* referred to as *worlds*. The first world is *World 1* which concerns everyday life (including real-life problems) and lay knowledge (pragmatic interest). *World 2* is concerned with science and scientific research (epistemic interest) and, finally, *World 3* relates to meta-science (critical interest). This study attempts to address a problem or need in *World 1* and make it an object of inquiry in *World 2* [as highlighted by Mouton (2001)]. The study is then validated using the knowledge and experience of people in *World 1* (those actively involved within industry). *World 3* is entered through the reflection of decisions made or responses obtained from participants as well as the methodology employed in executing the research.

Creswell (2014) describes four philosophical worldviews (or paradigms) that relate to research, namely *postpositivist*, *constructivist*, *transformative* and *pragmatic*. The postpositivist worldview is deterministic (causes determine effects or outcomes), reductionistic (ideas are reduced to a small, discrete set to test) and relates more to quantitative research. The constructivist worldview relies as much as possible on participants' views of the situation studied and, based on these views, patterns, theories or generalisations are derived. The transformative worldview focuses on power structures and an action agenda for reform to help change lives or institutions. This worldview often relates to issues such as inequality and involves collaboration with participants. The final worldview is pragmatism which is concerned with applications (what works) and solutions to problems. This worldview is focused on a problem and using all approaches available to understand the problem. The pragmatic worldview is most applicable to the study. A problem or need drives the research and the focus is on a solution that can be applied to address the specific problem or need identified.

Creswell (2014) defines the research approach as the "plan or proposal to conduct research". According to Creswell (2014), there are three primary categories of research approaches, namely the *quantitative approach*, the *qualitative approach* and the *mixed methods approach*. Leedy and Ormrod (2010) find that the quantitative approach to research involves one or more variables that can be measured in a numerical manner. The qualitative approach, however, considers characteristics or qualities that cannot be reduced to numerical values. Creswell (2014) further indicates that the qualitative and the quantitative approaches are not as discrete or rigid as they appear to be; rather they represent different ends on a continuum. Any given study tends to be more qualitative than quantitative or vice versa. The distinction is often based on the predominate use of words (qualitative) versus numerical values (quantitative), or open-ended questions (qualitative) versus closed-ended questions (quantitative). Mixed methods research includes aspects of both qualitative methods and quantitative methods and, in this way, resides between these two ends. This study follows a qualitative research approach.

Creswell (2014) also states that "research designs are types of inquiry within qualitative, quantitative, and mixed methods approaches that provide specific direction for procedures in a research design". They are also referred to as strategies of inquiry. Examples of research designs include experimental designs and surveys for quantitative research, as well as case studies, narrative research and face validation interviews for qualitative research. The research method for this study includes semi-structured interviews containing both open-ended questions and closed-ended questions (although open-ended questions are predominant). The study relies on both primary and secondary research data obtained through qualitative methods. The primary research data collection consists of semi-structured interviews during face validation (to obtain qualitative data). The secondary research data collection includes books, academic journals, articles, standards, white papers and websites.

The study comprises of five primary sections, namely: (i) the introduction to the problem and the study, (ii) the literature review, (iii) the framework development, (iv) the validation of the proposed framework and (v) the final conclusions of the study. The problem is first identified and contextualised, and the study defined. Then the literature review begins with a top-down approach by first discussing AM, after which SPM (a subset of AM) is investigated. Thereafter, other necessary elements are discussed to address the problem, including BPR, the AHP (which is used to aid decision-making) and asset traceability technology. The proposed framework is constructed by integrating the various concepts that have been studied in the literature review.

The validation of a study such as this one should ideally attempt to quantify the success of following the proposed framework through actual implementation. However, the scope and duration of the study, in addition to the costs involved and the unavailability of suitable sites to perform such an implementation, deter such validation. This explains why this study follows a qualitative research approach for validation, whereby the framework is evaluated according to certain success criteria (*Perceived Usefulness*, *Perceived Ease of Use*, *Understandability* and the achievement of various framework attributes, including *adaptability* and *comprehensiveness*, among others) through face validation (involving semi-structured interviews) with an expert panel.

As it were, Borenstein (1998) finds that the primary objective of face validation is to ensure, in a timely and cost-effective manner, that the perception of a problem held by the framework developer is consistent with the perception held by the potential user of the framework. In this study, the expert panel consisted of seven participants actively involved in SPM at three mining organisations (and that have varying degrees of experience related to BPR and traceability technology).

1.6 Thesis Outline

This section describes the structure of this thesis (illustrated in Figure 1.1 at the beginning of the chapter) which follows a logical progression where each chapter provides the context for the subsequent chapter. Additionally, there exists a continuous flow of key concepts within each chapter. The research objectives of this study, listed in Section 1.3, are addressed sequentially with the exception of Change Management which is discussed within the section of AM.

Chapter 1: Introduction
Chapter 1 introduces the study to the reader. A background to the study is provided after which the problem statement and null hypothesis are stated. The research objectives and the delimitations of the study are also defined. Thereafter, the research design and research methodology are described. Finally, Chapter 1 concludes with the outline of this thesis.

Chapter 2: Literature Review
Chapter 2 presents the first part of the literature review. The chapter begins with a thorough discussion of *AM* followed by *SPM* which is a subset of AM. Various aspects and principles of *BPR* are described in order to support the proposed framework. The *AHP* is also explained in this chapter since it is serves as an aid for decision-making.

Chapter 3: Overview of Asset Traceability Technology
Chapter 3 continues the review of literature by providing an overview of *asset traceability technology*. This is addressed in a separate chapter due to the importance and size of the content. The technology aspects described in this chapter are utilised in the proposed framework and the *AHP* supports the selection of technology based on some of these aspects. The chapter focuses on *barcode technology*, *RFID technology* and *GPS technology*. Performance metrics, operational characteristics and current asset tracking applications of each technology are considered.

Chapter 4: Proposed Framework
Chapter 4 deals with the development of the proposed framework that guides the user stepwise through a *BPR* initiative, which includes consideration for asset traceability technology aspects and *Change Management*. The framework incorporates the *AHP* to support decision-making regarding the selection of traceability technology to be integrated into the redesigned processes.

The framework is designed taking into account the specified features and is strongly based on the literature review (Chapter 2 and Chapter 3).

Chapter 5: Validation of Framework
Chapter 5 addresses the validation of the proposed framework through face validation using semi-structured interviews. The methodology of the validation, particularly concerning the expert panel, the defined success criteria and the data collection, is described after which the review of the proposed framework by expert panel is discussed. The review includes mention of the *strengths* and *weaknesses* of the framework and suggested improvements. A description of changes made to the framework based on improvements proposed during the review is also provided.

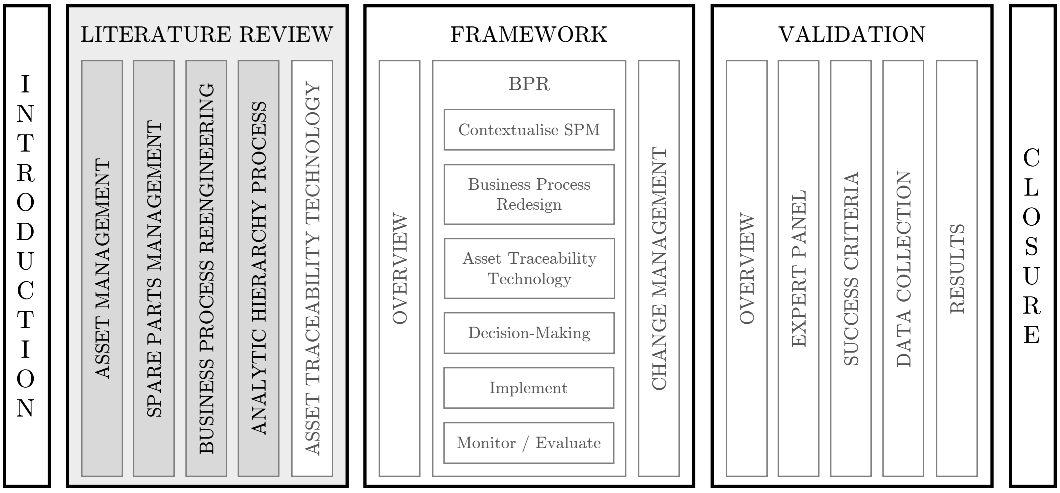
Chapter 6: Closure
Chapter 6 concludes the study by presenting a concise summary of the research and providing a possible answer to the central research question stated in Chapter 1. Limitations and recommendations for future research are also provided.

The thesis outline is depicted graphically at the beginning of each chapter to guide the reader through the study. Figure 1.1 illustrates the first instance of the described thesis outline. Darker shading in the graphical outline indicates the current position within the document structure.

Chapter 2

Literature Review

This chapter presents the first part of the literature review. The chapter begins with a thorough discussion of *Asset Management (AM)* followed by *Spare Parts Management (SPM)*, which is a subset of AM. Change Management is also discussed within the AM section. Various aspects and principles of *Business Process Reengineering and Redesign* are described in order to support the proposed framework. The *Analytic Hierarchy Process (AHP)* is explained since it serves as an aid for decision-making, specifically for the selection of asset traceability technology.



2.1 Asset Management

As aforementioned in Section 1.1, companies have a greater need to maximise competitive advantages. This places a strong emphasis on the field of *AM*, also commonly referred to as Physical Asset Management (PAM). PAM includes more than physical assets, and this thesis henceforth adopts the term *Asset Management (AM)* when referring to the management of assets within organisations (as defined by ISO 55000 (BSI, 2014a) in Section 2.1.4.2). However, before *AM* can be discussed, it is necessary to define the term *asset*.

2.1.1 Definition of an Asset

The definition of an *asset* depends on the field in which it is assessed. For instance, the financial realm, or more specifically the International Accounting Standards Board (2014), has formalised the definition of an asset to be

> *"a resource controlled by the entity as a result of past events and from which future economic benefits are expected to flow to the entity".*

According to the International Organisation for Standardisation (ISO) 55000 standard (BSI, 2014a, p. 2), whose aim is to standardise *AM* practice internationally, an asset is an

> *"item, thing or entity that has potential or actual value to an organization. [The] value may be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities".*

The general consensus among the various fields and industries, however, is that an asset is a resource (be it physical or otherwise) that realises value in some form (Nonaka, Toyama and Konno, 2000; BSI, 2008a, 2014a; International Accounting Standards Board, 2014; IAM, 2014). Du Toit (2014) acknowledges that assets form a core group of elements within any business through their function in providing products or services. There are five broad categories within AM and these categories are discussed in Section 2.1.4.1.

2.1.2 Definition of Asset Management and AM Systems

The term *AM* is often used ambiguously. Hastings (2009) confirms this by stating that AM has not been a well-defined activity. The term *AM* is used in a range of diverse fields and industries in which it implies different meanings. Woodhouse (2003) highlights six of the most common applications of the term as follows:

1. Within the financial services sector, AM refers to the management of securities (such as stocks and bonds) in an investment portfolio.

2. Board directors and some city analysts often use AM with reference to the acquisition, sale or merger of companies.

3. Equipment maintainers adopted the term AM as a more sophisticated name for better, business-focused maintenance in an attempt to gain greater credibility for their activities.

4. Desiring greater corporate sway by using the term *AM*, software vendors selling Computerised Maintenance Management Systems (CMMS) relabelled their products as *Enterprise Asset Management Systems*.

5. Within the information systems environment, AM can be interpreted as the barcode labelling of computers and peripherals as well as the tracking of their locations and/or statuses.

6. Infrastructure or plant owners and operators adopted AM to describe the care and best sustained use of physical plant, infrastructure, machinery and associated facilities to realise value. Woodhouse (2003) emphasises that AM consists of a trade-off between *Asset Care* (maintaining assets for future use through maintenance and risk management) and *Asset Exploitation* (current use of the assets to achieve objectives and derive further value). This is the interpretation upon which Publicly Available Specification (PAS) 55 (BSI, 2008a) and the more recent International Organisation for Standardisation (ISO) 55000 (BSI, 2014a) focus.

This study is primarily concerned with the 5th and 6th applications of AM as categorised by Woodhouse (2003). The focus is on the 6th definition (especially concerning spare parts), but integration of information technology results in the 5th definition also being relevant. However, the current and most relevant definition of AM is provided by the recent ISO 55000 (BSI, 2014a) series of standards based on the PAS 55 (BSI, 2008a) document.

The PAS 55 (BSI, 2008a, p. v) document defines *AM* as the

> *"systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan".*

The ISO 55000 (BSI, 2014a) series of standards defines *AM* as the "coordinated activity of an organization to realize value from assets" where realisation of value typically involves a trade-off between costs, risks opportunities and performance benefits. *Activity* may include, but is not limited to, the application of the elements of the *Asset Management System*. This also refers to the approach, the planning, the plans and their implementation. BSI (2014a) defines an *Asset Management System* as a "set of interrelated and interacting elements of an organisation, whose function is to establish the AM policy and AM objectives, and the processes needed to achieve those objectives".

2.1.3 Scope of Asset Management

Baum (2012) observes that physical assets have been managed for years, but that there has been a considerable shift in scope of the management of these assets. Hastings (2009) argues that educational and professional specialisations form a general pattern that results in a silo effect in the areas surrounding AM. This promotes departments or people responsible for each area to operate in their own self-interest (in terms of their responsibilities for the organisation) and often results in conflicting policies or actions with other departments in other areas. Additionally, most industries considered (and many still consider) Physical Asset Management (PAM), also referred to as AM, to be solely maintenance-oriented. However, PAM actually involves a broad range of activities covering many diverse aspects such as maintenance, finance, scheduling, management and strategy.

Baum (2012) states that a more holistic approach has been strongly advocated recently. Mitchell and Carlson (2001), as cited by Baum (2012), consider AM to be a "*strategic, integrated set of comprehensive processes to gain the greatest lifetime effectiveness, utilisation and return from physical assets*". Furthermore, Schuman and Brent (2005) refer to various sources that support a broader scope of AM while Amadi-Echendu, Brown, Willett and Mathew (2010) highlight that AM has been supported as an interdisciplinary approach since the 1990s. Amadi-Echendu *et al.* (2010) highlight five key characteristics of a broader conceptualisation of AM (*spatial generality, time generality, measurement generality, statistical generality* and *organisational generality*), which are depicted in Table 2.1.

This generality aims to prevent both the occurrence of the previously mentioned silo effect and the limited application of AM. The Institute of Asset Management (IAM, 2014) believes that there is no ideal model of AM, but has developed a conceptual model (illustrated in Figure 2.1), which it currently uses. All of the 39 subjects and six subject groups on AM (which have been identified by the Global Forum on Maintenance and Asset Management (GFMAM) to define the scope of AM) are aligned to this model. These subjects and subject groups form the core of the AM Landscape.

Table 2.1: Key generality characteristics of AM

Key Characteristic	**Description**
Spatial generality	AM incorporates all types of assets, including financial and human assets, in any industry
Time generality	AM includes short-term and long-term aspects of assets
Measurement generality	Measurement data relates to the economic (financial) value, the social value and the physical attributes of assets
Statistical generality	Various statistical measures are important in AM, from risk measurements to the return on asset performance
Organisational generality	AM affects all levels of the organisation, from direct contact with the specific assets to the strategic discussions among top-level managers

Adapted from Amadi-Echendu et al. *(2010) and Baum (2012)*

Ultimately, AM stretches further than mere maintenance, but rather the objective of AM is to maximise value derived from assets.

2.1.4 Standardisation of Asset Management

Collaboration among the Institute of Asset Management (IAM), the British Standards Institute (BSI) and various organisations resulted in a publicly available specification, referred to as PAS 55 (BSI, 2008a,b), being published in 2004. PAS 55 was an attempt to provide guidelines on AM to industry and the general public as a response to the demand from industry for a standard on AM. However, there was some disagreement on certain aspects of the specification and it is not to be considered a standard. Rather, PAS 55 consists of key requirements for implementation of an AM system with the criterion that a system would be considered deficient without these requirements. It also aims to assist with the life cycle management of assets. The ISO 55000 series (BSI, 2014a,b,c) was later developed through cooperation of various representative members as a standard for AM. This is the most recent official effort towards improved and standardised AM.

2.1.4.1 PAS 55

PAS 55 consists of two parts, PAS 55-1 and PAS 55-2. PAS 55-1 provides a specification for the optimised management of physical assets while PAS 55-2

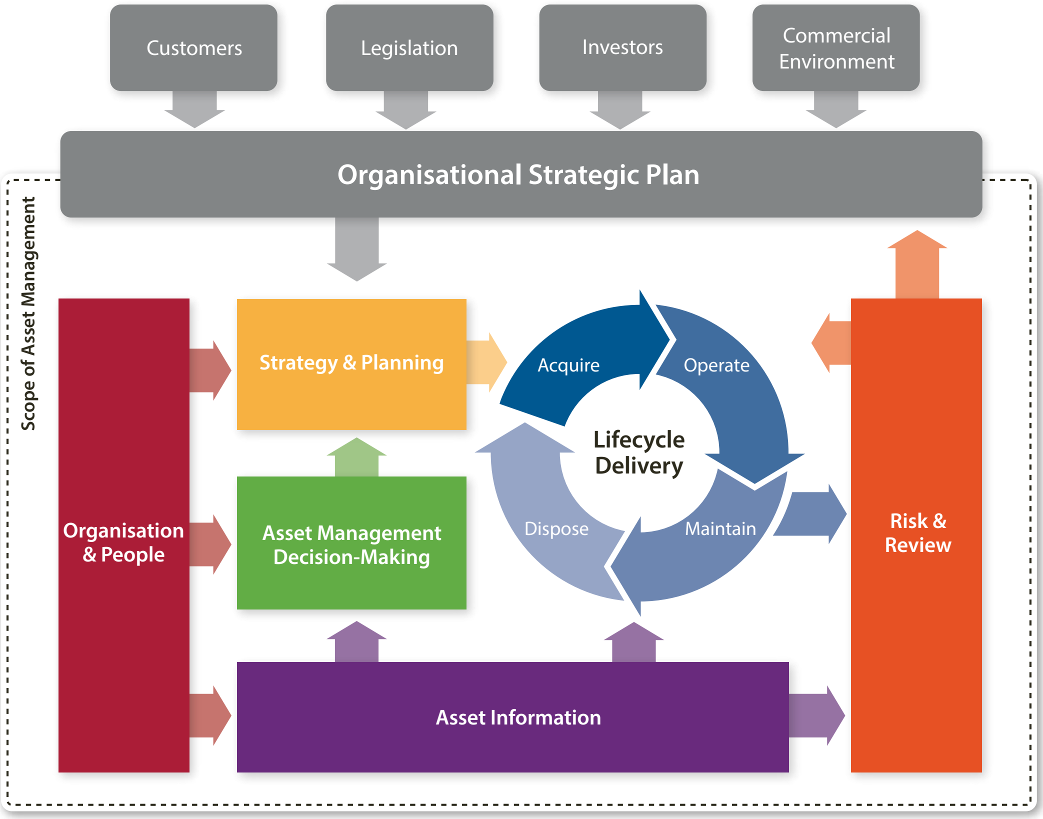


Figure 2.1: Current conceptual model of AM used by IAM
Adopted from IAM (2014)

contains guidelines for the application of PAS 55-1. The BSI (2008a) emphasises that "AM is an inherently integrated approach" and that the PAS 55 requirements and guidelines should not be partially implemented. Instead, a holistic approach is required concerning the adoption of AM within an organisation.

Figure 2.2 illustrates the scope of PAS 55 within the five broad asset categories, namely *Human Assets*, *Financial Assets*, *Information Assets*, *Intangible Assets* and *Physical Assets*. Physical assets are central to PAS 55 (as illustrated in the Figure 2.2), and this is indicative of PAS 55 focussing on the management of physical assets. Other asset categories, such as financial assets or information assets, are considered only when they have a direct impact on physical assets (Baum, 2012). PAS 55 suggests that the different asset types should be managed together in a holistic manner.

Van den Honert, Schoeman and Vlok (2013) highlight that PAS 55 is developed around the Plan-Do-Check-Act (PDCA) cycle (often referred to as the Deming cycle or circle). According to Moen and Norman (2006), the PDCA cycle was

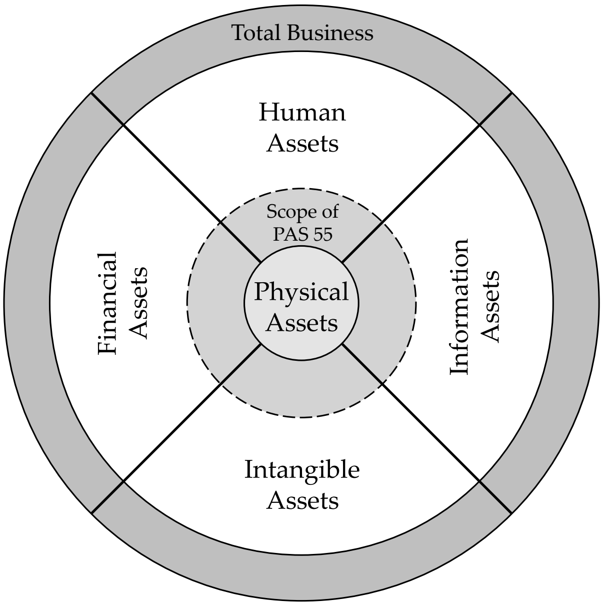


Figure 2.2: Scope of PAS 55 within the five broad asset categories

Adapted from BSI (2008a)

developed from the famous Deming wheel (Design-Production-Sales-Research cycle) by Japanese executives after Dr W. Edwards Deming presented the Deming wheel at the Union of Japanese Scientists and Engineers (JUSE) seminar in 1950. Sokovic, Pavletic and Pipan (2010) describe the PDCA cycle as a concept of continuous improvement processes embedded within the culture of an organisation and they classify it as a quality improvement methodology. Van den Honert *et al.* (2013) support this viewpoint by stating that the PDCA framework ensures quality in the AM environment.

Table 2.2 depicts how the requirements and structure of PAS 55 are arranged within the PDCA framework. The cycle begins with the planning of the task, process or framework to be executed or implemented. Regarding AM, this *Plan* phase consists of the establishment of the AM strategy, objectives and plans required to deliver results as determined by the AM policy and the organisational strategic plan. Thereafter, the planned task, process or framework is executed in the next phase, the *Do* phase. In terms of PAS 55, this phase involves the establishment of all enablers and requirements required for implementation and, thereafter, the execution of the AM plans. The third phase, the *Check* phase, is when the results of implementation are determined and measured against the AM policy, strategic objectives and legal requirements. Finally, the *Act* phase is where action is taken, if required, to ensure that objectives are achieved, as well as to improve continually the AM System. Once the *Act* phase is complete, the cycle begins from the *Plan* phase again.

Table 2.2: Plan-Do-Check-Act (PDCA) framework incorporating PAS 55

Phase	Description
Plan	Establish the AM strategy, objectives and plans required to achieve objectives aligned to organisation's AM policy and the organisational strategic plan
Do	Establish the enablers for implementing AM and other necessary requirements (such as legal requirements); implement the AM plans
Check	Monitor and evaluate results against AM policy, strategy objectives, legal and other requirements; record and report the results
Act	Ensure that the AM objectives are attained by taking action when necessary; continually improve the AM System and AM performance

Adapted from BSI (2008a)

2.1.4.2 ISO 55000

The ISO 55000 series of standards, released in 2014, was developed upon the foundation of PAS 55 through collaboration among 31 countries. The series consists of three parts, namely:

- ISO 55000:2014 — Asset management — Overview, principles and terminology;
- ISO 55001:2014 — Asset management — Management systems — Requirements; and
- ISO 55002:2014 — Asset management — Management systems — Guidelines for the application of ISO 55001.

The first part of the ISO 55000 series, ISO 55000, explains the important terms and definitions relating to AM while ISO 55001 provides the requirement specifications. Both ISO 55000 and ISO 55001 correspond to the previous PAS 55-1. ISO 55002, which provides information regarding the interpretation and application of ISO 55001, corresponds to the former PAS 55-2. Van den Honert *et al.* (2013) recognise that the ISO 55000 series is a more comprehensive and detailed framework than PAS 55 and, therefore, provides a better indication of the path towards AM implementation within an organisation.

Differences between PAS 55 and ISO 55000 Van den Honert *et al.* (2013) highlight the primary differences between PAS 55 and the ISO 55000 series as follows:

- PAS 55 mentions activities to be performed, but it does not always state the minimum criteria required to be satisfied in order to achieve the outcomes of the activities. ISO 55001, however, provides the minimum criteria for the activities proposed while ISO 55002 provides interpretation and implementation guidelines for the system's activities. Additionally, many of the PAS 55 subsections have been expanded in the ISO 55000 series as entire sections.

- PAS 55 merely informs that the context of the organisation needs to be understood and that risks should be fully assessed. The ISO 55000 series states that the context of the organisation for the AM System should be comprehended and describes what can be done in order to determine that context. ISO 55002 also offers methods to determine the risks involved as opposed to only stating that they should be assessed.

- Procedures for continual improvement are available in the ISO 55000 series of standards, but not in PAS 55. PAS 55 merely informs the reader of the different improvement actions possible and what they should achieve.

- ISO 55002 also proposes that predictive actions are to be used in conjunction with corrective, preventative and continuous improvement actions. PAS 55, on the other hand, only suggests the use of corrective, preventative and continuous improvement actions.

- Both the ISO 55000 series and PAS 55 mention the use of proactive monitoring, but only ISO 55002 includes examples of when it would be applicable. PAS 55 merely states that it should be performed, but fails to describe how it should be performed.

- ISO 55002 explains how to determine and to document the scope of an AM System. PAS 55 does not explain how to do either of these.

- ISO 55002, in comparison to PAS 55, provides more detail on effective information management of an AM System: describing fundamentals of effective information management and discussing how to control the documented information.

- Internal audits of the performance of the AM System are necessary. PAS 55 mentions the expected outcomes of the audits, but not how to conduct the audit. ISO 55002 refers the reader to ISO 19011 regarding auditing systems to ensure that the audit is performed according to a recognised standard.

The IAM (2014) recognises that the ISO 55000 series essentially describes what is necessary to be set up for a "management system for assets". It does not, however, explain how this should be done and some interpretation and knowledge of AM is a prerequisite for effective use of ISO 55000. This lack of detail is intentional, as it allows the standard to be applied across many types of organisations without constraining the solutions developed per organisation (more generic as opposed to detailed, but specific). It provides a very powerful framework which forms a checklist for good practice in the AM sphere.

Fundamental Elements of AM The BSI (2014a) considers AM to be based on four fundamental elements, namely:

- *Value:* assets are employed to provide value to the organisation and its stakeholders. The focus is not on the assets themselves, but rather on the value (tangible or intangible; financial or non-financial) that the assets can create. The value is assessed with regard to organisational objectives by the organisation and its stakeholders.
- *Alignment:* AM translates the organisational objectives into technical and financial decisions, plans and activities. These decisions together result in the achievement of the organisational objectives.
- *Leadership:* realisation of value depends on leadership and workplace culture. Leadership and commitment from all managerial levels are imperative for the successful establishment, operation and continuous improvement of AM.
- *Assurance:* AM provides assurance that assets will achieve the required outcomes. The need to effectively govern an organisation results in the assurance required by that organisation. Assurance is applicable to assets, AM and the AM System.

These four elements should always be kept in mind regarding any AM policy development and implementation. They form the foundation upon which AM provides value to organisations. However, having a few principles of AM within organisations is not sufficient; the organisations should always strive towards effective AM and best practices within the AM field.

ISO 55000 towards Effective Asset Management Woodhouse (2014) asserts that AM is to be considered a necessity in industry and, as such, the decision of ISO to recognise what is required in terms of AM, including the identification of requirements of management systems to coordinate and sustain good practices, was timely. Essentially, ISO 55000 provides a guideline or basic framework of generic (yet necessary) definitions, activities and methods that can be used by a broad range of industries to ensure that effective AM is in place within organisations. The IAM (2014) shares its opinion of effective AM, listing that it should be:

- strategic (aligned with the organisational strategy);

- enterprise-wide (avoiding silos);
- apply to asset owners, managers and those with delegated management responsibilities (as in the case of outsourced asset responsibilities);
- able to balance costs, risks and performance on different timescales;
- apply to both tangible and intangible assets; and
- apply to public, private and Not-for-Profit Organisations (NPOs).

Furthermore, the IAM (2014) emphasises the importance of understanding the 39 AM Subjects established by GFMAM which describe the body of AM knowledge in its entirety. ISO 55001 (and PAS 55 as well) is more focused on the specification of the requirements for a typical organisation's management system in order to guide, control and continuously improve AM. Familiarity only with a management system standard, such as the ISO 55000 series, does not constitute knowledge and competence across the entire discipline of AM. Therefore, the IAM (2014) urges those who wish to master the discipline to comprehend the whole discipline as represented by the 39 Subjects to the extent required by the area of responsibility or operational environment.

2.1.5 Characteristics and Benefits of Asset Management

Figure 2.3 displays the relationship and roles between key terms in AM. AM forms part of the overall management of the organisation. Within AM, is the Asset Management System which in itself contains the *Asset Portfolio*: the group of assets that are within the scope of the Asset Management System. The Asset Management System should not be confused with AM which includes a broader scope. The Asset Management System is the set of interrelated elements that define the AM policy, AM objectives and all the processes necessary to achieve those objectives. AM, on the other hand, is the "coordinated activity of an organisation to realise value from the assets" (IAM, 2014).

Stewart, Kennedy, Norton, Byrne and Rose (2003) consider the management of physical assets to be affected by six primary elements, namely: processes, practices, information systems, data and knowledge, commercial tactics, and organisational and human issues. Additionally, Hastings (2009) observes that the most difficult areas to manage in AM involve software and systems, particularly systems integration. This implies that Asset Information Management (AIM), discussed in Section 2.1.6, is an important aspect to consider regarding AM.

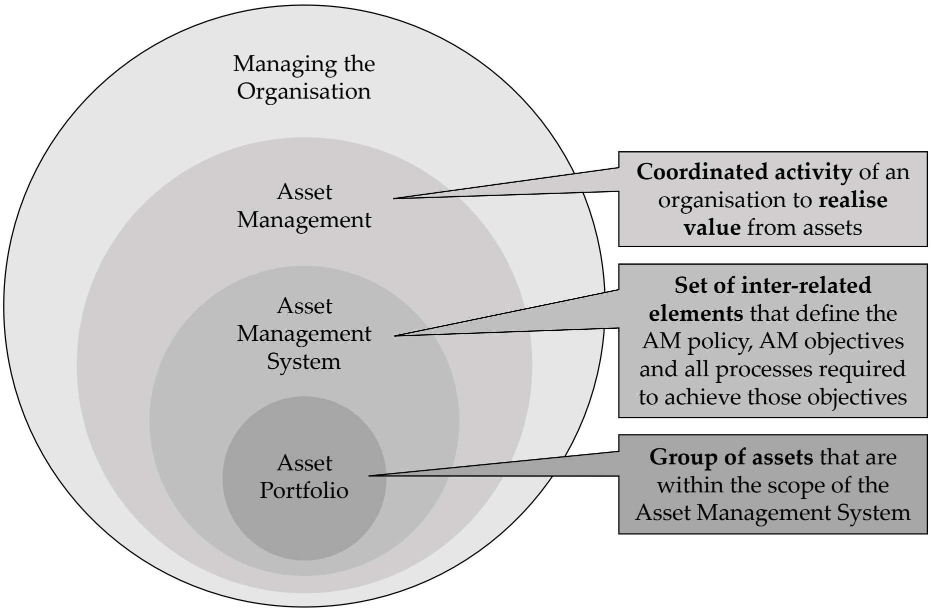


Figure 2.3: Relationships between key terms in Asset Management
Adapted from IAM (2014)

Woodhouse (2014) asserts that the benefits derived from the successful implementation of AM cannot be ignored. The major benefits of optimised AM, according to the BSI (2008a, 2014a), include (but are not limited to):

- improved financial performance;
- informed asset investment decisions;
- managed risk;
- improved services and outputs;
- demonstrated social responsibility;
- demonstrated compliance;
- enhanced reputation;
- improved organisational sustainability; and
- improved efficiency and effectiveness.

The benefits of well-planned and effective AM are worth the expense of implementing such activities. By initiating effective AM, organisations will be aligning themselves with operational best practices. Additionally, as mentioned, AIM is one of the most important yet complex aspects in AM of which to be aware.

2.1.6 Asset Information Management

According to Grové (2007), the three primary drivers of business performance are people, information and technology. Grové (2007) further states that information is the "centre point" among these drivers. Grové (2007) reports that managers require a tool that provides the exact positioning of the company "with respect to what can or cannot be delivered, where, when and if expansion is possible". Companies have plenty of data available and can capture almost any data desired. However, information (processed data that has value) is less readily available and companies need to review what can and should be monitored in order to generate most value from the data captured.

For organisations to obtain a sustainable competitive advantage through information management, the organisations need to value the information in a new manner (Grové, 2007). Although this usually refers to the competitive advantage of the entire supply chain, accurate and useful information generated from processes within companies can aid the organisations in achieving greater operational efficiency and effectiveness. This ultimately can increase the competitive advantage of the entire supply chain. As companies mature, it becomes more difficult for them to sustain a competitive advantage without making changes to infrastructure. This new infrastructure should support real-time information since timely and accurate information can aid management to make the right decisions at the appropriate times.

Furthermore, asset information is an important area of information management used by various departments within organisations. Reliability Engineers use the condition data of equipment to determine the required maintenance programs and tactics while the storeroom staff use asset identification and location data to determine stock ordering actions. Financial departments can also use asset information to determine depreciation, impairments values and other costs relating to each asset. Each department or functional unit has its own unique concerns and requirements, which an Asset Information Management System (AIMS) needs to address.

2.1.6.1 Monitoring of Asset Location

Organisations have become increasingly cooperative with each other and within their own structures; sharing equipment, resources and having spare parts (such as rotable spare parts) repaired. Hence, it is difficult, especially in large organisations, to manage the exact location of spares, tools and people. Ouertani *et al.* (2008) argue that it is critical to know the location of assets in order to effectively manage the assets. They assert that providing *relevant, timely and useful location information* to the persons and systems responsible for managing asset-intensive business processes provides a number of significant benefits. Among these benefits are: timely and informed decision-making based on real-time information, decrease in information-related errors, reduction in costs associated with searching for misplaced or lost assets, and the improvement of overall productivity and throughput.

Often the value of an asset itself is not as important as the costs involved with the misplacement or loss of the asset. It is, therefore, important as advocated by Ouertani *et al.* (2008), to know:

1. Where assets are at any given moment in time;
2. Where assets were last identified; and
3. How many of the particular assets are present in the given location.

Organisations can use this information to collect, reposition and redeploy their assets in the most effective manner. However, an AIM strategy needs to be instituted in order to derive value from managing asset information. This will eventually lead to an AIMS being developed.

2.1.6.2 AIM Strategy

Ouertani *et al.* (2008) believe that a strategy for AIM consists of two major phases, namely the identification of information required and the assessment of the most appropriate manner to effectively manage the information. This manner includes the entire process of the capture of asset information, the storage of the captured information and the retrieval of the stored information. Therefore, a strategy is required to identify the technology and system suitable for effective AM.

The approach to develop an appropriate strategy for effective management of information and assets consists of three stages, namely:

1. Design of possible strategies for AIM.
2. Evaluation of the designed strategies.
3. Selection of the most suitable strategy.

Figure 2.4 depicts this approach which is described in the following sections in detail.

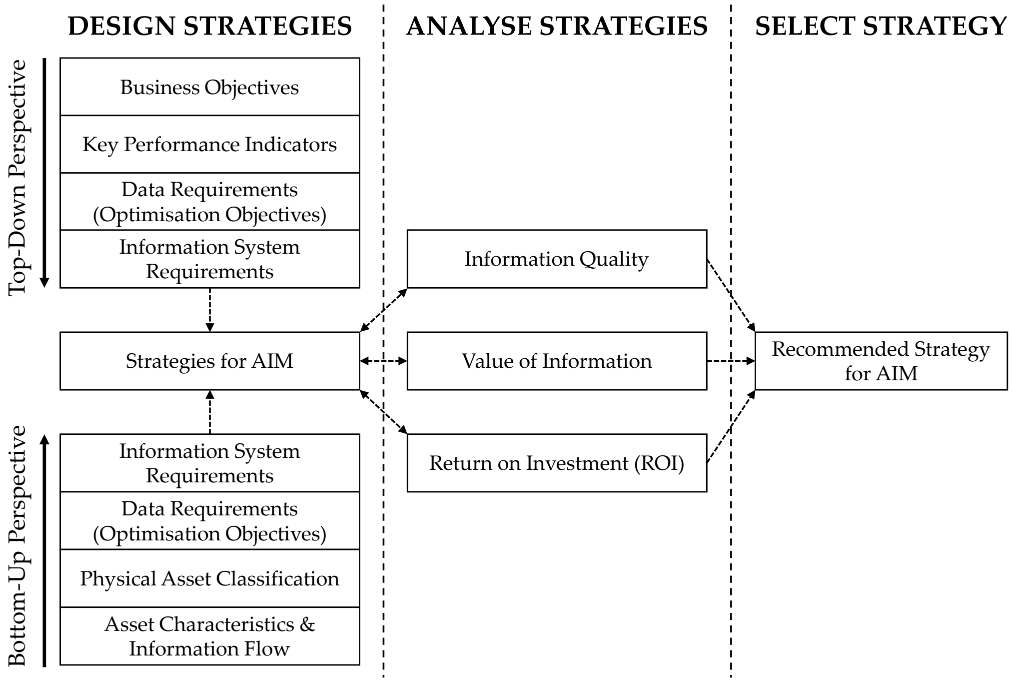


Figure 2.4: AIM strategy design, evaluation and selection process
Adapted from Ouertani et al. *(2008)*

Design Strategies There are two perspectives in viewing and designing strategies: a top-down approach and a bottom-up approach. The top-down approach involves determining the objectives or requirements from higher levels (top level) and then designing the system to meet those objectives. The bottom-up approach involves designing around the system capabilities, and then realistic top level objectives are determined based on the system capabilities. Figure 2.4 displays the flow for both of these perspectives in the *Design Strategies* stage. Well-designed strategies are essential, as Ouertani *et al.* (2008) assert. According to them, a poorly designed AIMS may produce large amounts of data that decision-makers will not use despite not having the appropriate information which they require to make decisions. Furthermore, they claim that a successful AIM strategy must be based on determining the:

- type of data to capture;
- method of capturing the data;
- method to measure the data;
- method to evaluate the data against other data; and
- manner in which to interpret and respond to the results to ensure best practice.

Analyse Strategies Once the various strategies have been designed, the decision-maker needs to evaluate them. Ouertani *et al.* (2008) emphasise that there are two important factors to consider when assessing the success of a given AIM strategy, namely the:

- value of information generated by the information technology; and
- Return on Investment (ROI) obtained from acquisition, deployment and disposal.

Techniques used in assessments should be dynamic and take into account risks, uncertainties, behaviours and complexity within an extended planning horizon. Decisions to maximise the value of information and ROI can be formulated as portfolio optimisation (Bardhan, Sougstad and Sougstad, 2004), dynamic programming (Lee and Kim, 2000) or utility maximisation problems (Lee and Chiang, 2006). Value of information is often determined on a cost-benefit basis using principles from *Supply Chain Management* and/or *Risk Analysis*.

Select Strategies After the analysis stage, the Asset Manager is capable of selecting the appropriate strategy based on the strategies assessed. The evaluations of strategies are dependent on the quality of information generated by each system, the value of the information and the overall returns derived from implementing the specific strategy by means of a cost-benefit analysis. After selecting and implementing the appropriate AIM strategy, the Asset Manager needs to monitor the overall system and compare its effectiveness against the expected performance. For this reason, the quality of information obtained from the newly implemented system should be re-evaluated and the system altered as required resulting in an effective and efficient AIMS.

2.1.6.3 Asset Information Management System

An AIMS comprises of data capture systems (hardware, middleware and software) and data management systems with the objective of managing and deriving value from information relating to assets. The system aims to allow organisations to manage assets as effectively and efficiently as possible. Figure 2.5 illustrates the typical layout of an AIMS incorporating barcode technology, RFID technology and sensors. The system addresses AIM through *data capture* (involving barcode technology, RFID technology, sensors and other relevant systems) and *data management* (which may utilise and integrate product-embedded information, networked information and information from a hybrid location). The networked information includes centralised data on a primary server and/or distributed data at various locations.

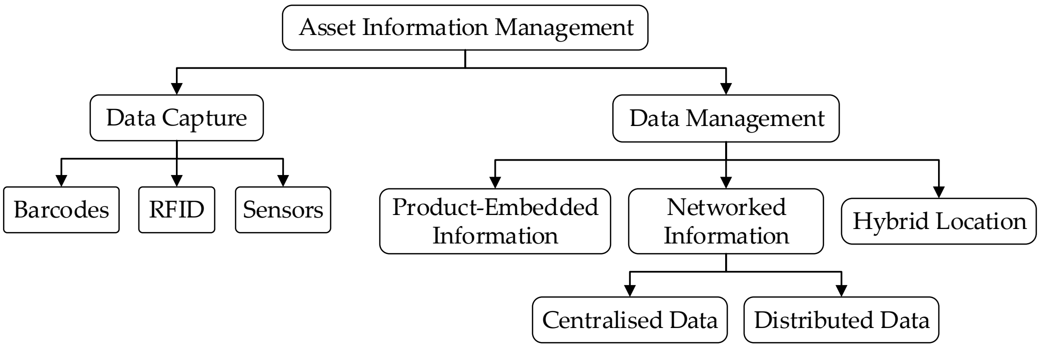


Figure 2.5: Asset Information Management layout
Adapted from Ouertani et al. *(2008)*

Technology integration allows for real-time information and integrates various fields, processes and applications into one manageable package. Figure 2.6 displays the potential integration of barcode technology or RFID technology into an AIMS, and the typical areas or components of an organisation that may benefit from the implementation of such technologies. These components include, among others, Enterprise Asset Management (EAM), Computerised Maintenance Management Systems (CMMS), Enterprise Resource Planning (ERP), Finance, Supply Chain and Customer Relationship Management (CRM).

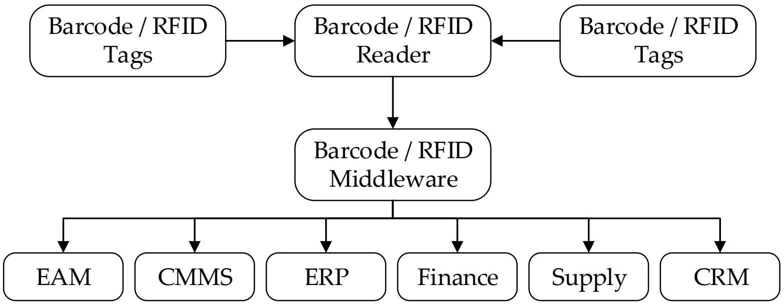


Figure 2.6: Typical organisational components integrated into an AIMS

One concern is whether an investment in automating processes and developing a more advanced AIMS at a particular organisation would be beneficial. Fogel and Terblanche (2013) report that there is no evident correlation between further investment in IT and computer systems, and asset performance. However, it is important to realise that this applies only to *further investment* in already existing IT and computer systems. IT and computer systems are merely tools assisting with the management of information and activities. The onus is on the organisation to have necessary AM principles already in place for these tools to be effective.

In addition, Burkett *et al.* (2002) highlight the importance of collecting useful information about assets throughout their lifecycle for the efficient management and control of assets. In this regard, Banker and Kauffman (2004) state that information value arises as the difference between a decision-maker's payoff in the absence of information and what can be obtained in its presence. An AIMS can store large amounts of various asset data, but the primary focus for this research is the monitoring of asset location.

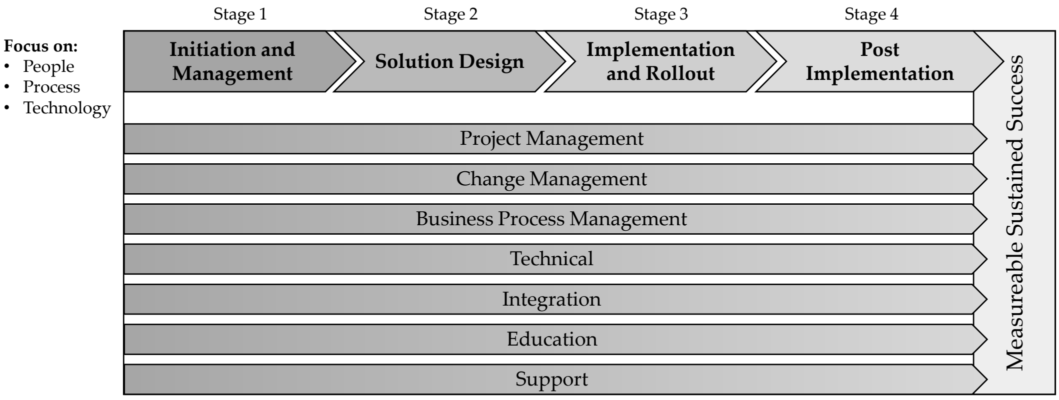


Figure 2.7: Work streams concerning technology (CMMS) implementation
Adapted from Barry et al. *(2010)*

Implementation of a new AIMS always has certain impacts on the organisation which need to be assessed. Figure 2.7 displays the phases and work streams involved with technology implementation. Any project being implemented requires *Project Management*, but Barry *et al.* (2010) explain that other work streams should also be considered regarding the management of the technology and its integration into the organisation. These other work streams typically include, among others, *Business Process Improvement, Design, Redesign or Reengineering*, *Change Management*, *Technical*, *Integration*, *Education* and *Support*. A Computerised Maintenance Management System (CMMS), for instance, cannot act alone if it is to be considered successfully implemented. The various work streams should be considered holistically and flow concurrently regarding the implementation of a technology. Similarly, Heber (2014) states that mining organisations cannot simply layer new technologies over existing operating models, but should assess whether the operating models may require revision or overhauls. Barry *et al.* (2010) illustrate the process and corresponding impacts through use of the example in Section 2.1.6.4.

2.1.6.4 Need for Change Management

Regarding the implementation of a CMMS, the business process that provides the software-managed tasks to the people involved should align the people with the enabling technology and its ability to execute desired tasks. This implies that the process should educate and train people to use the technology, and to act in a manner appropriate to the new system. Changing people's behaviour requires consideration of the work culture and the impact that the planned changes will have on this culture. It is important to ensure that the people involved will adapt or that the changes will be adopted into the work culture. This requires *Change Management* (discussed in Section 2.1.7) which is one of the most important work streams since it relates to changing people's perceptions and attitudes towards change. The final work stream is *Support* which, together with *Change Management*, aims to ensure continuance of the project and allow people to recognise the benefits.

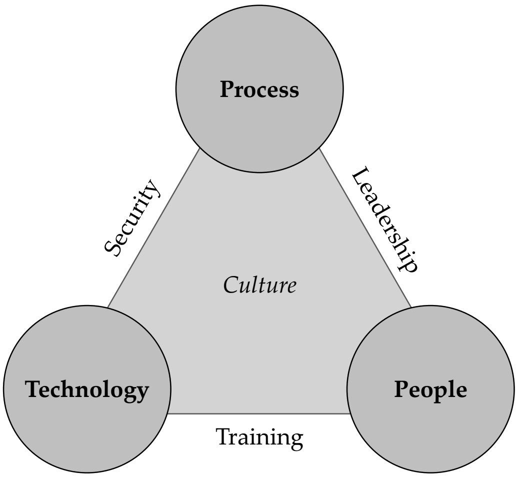


Figure 2.8: Primary elements involved in AIMS implementation
Adapted from Barry et al. *(2010)*

As can be seen from the example and Figure 2.8, there are three primary elements in the transformation: *People*, *Process* and *Technology*. A fourth element, *Culture*, is the cohesive force joining the three primary elements. In addition to these elements, there are supporting functions such as *Training* (linking *People* and *Technology*), *Leadership* (linking *Process* and *People*) and *Security* (linking *Process* and *Technology*). According to Barry *et al.* (2010), it is quite common for a completely successful CMMS implementation to be 60% people-orientated, 25% business process-orientated and 15% technology-orientated.

2.1.7 Change Management

Taking cognisance of people having such a large impact on the success of a technology implementation [a CMMS implementation is typically 60% people-orientated (Barry *et al.*, 2010)], the manner in which change is brought about within an organisation needs to be carefully managed. According to the IAM (2014), there are various forms of changes that an Asset Manager needs to consider: new technology, new approaches, ageing assets, the workforce retiring or becoming more skilled, new legislation, new knowledge and different data collection processes.

Schein (2002) distinguishes three basic kinds of change that take place in every group or organisation: *natural evolutionary change*, *planned and managed change* and *unplanned revolutionary change*. The first kind refers to the gradual adaptations necessary for organisations and people within those organisations to adjust to various environmental conditions. As something changes, people naturally adapt to the new environment. Planned and managed change, however, is a more active approach to controlling the direction of change. A new technology implemented within a company by decision of the executives is an example of this kind of change. This inherently includes natural evolutionary change, as people will need to adapt to the new technology. Finally, the last kind of change is unforeseen and often dramatic. Disasters are a good example of this type of change.

Asset Managers focus mostly on planned and managed change. However, they are expected to manage ably unplanned change and react accordingly when necessary. The Asset Manager has to be able to determine the impact that a certain significant change can have on the organisation's assets, as well as to manage all the changes such that risks to the operation of assets are minimised. According to the IAM (2014), *Risk Assessment & Management* is essential to determining which changes are significant (have the greatest risks). However, the Asset Manager should be aware that changes implemented can adapt as time passes, eventually raising or lowering the criticality of assets or systems relative to when the changes were first implemented. Furthermore, any change is always met with a certain amount of resistance and the Asset Manager needs to both understand why this resistance exists and how to deal with it.

2.1.7.1 Resistance to Change

According to Pardo del Val and Fuentes (2003), resistance (in terms of change) is the persistence to avoid change. This refers to any conduct that attempts to maintain the status quo. People react differently to different kinds of change as well as change in different contexts. Coetsee (1999) has listed the primary categories of responses to change initiatives ranging from *Commitment* to *Aggressive resistance* (displayed in Table 2.3). The most favourable response is commitment where employees align to the objectives underlying the change implementation. In contrast, aggressive resistance is the least favourable response as employees actively sabotage any initiatives relating to the change.

Identifying the responses to change and knowing how to manage them can help managers convince individuals of the value behind the changes and result in the success of the specific change effort.

Table 2.3: Individual responses to change

Response	**Description**
Commitment	Strong emotional attachment to the objectives of the change effort and the organisation in general
Involvement	Eagerness to participate in the behaviours expected or required by the change effort
Support	Endorsement of change effort through speech rather than explicit actions
Apathy	Neutral attitude towards change effort involving knowledge of the effort without engagement (either verbal or physical) to support or to oppose it
Passive resistance	Willingness to voice reservation or even threaten resignation if the change effort proceeds (mild form of opposition)
Active resistance	Behaviour that disrupts or impedes change effort, usually by doing opposite of desired actions
Aggressive resistance	Conduct or administration involving purposeful sabotage and subversion of the change effort

Adapted from Spector (2007) and Coetsee (1999)

Why Employees Resist Change It is important to understand why employees do not accept a certain change open-heartedly before managing their resistance. Hultman (1995) has suggested a number of potential contributing factors to individual resistance as follows:

- Individuals may feel that “things are fine as they are”; in other words, they feel satisfied with the status quo. In this regard, they will presume that any changes to the current system would have unnecessary adverse effects.
- Individuals may fear that change will personally affect them in an undesirable way. In this case, change is viewed as a threat to them.

- Individuals may perceive the costs of change as far outweighing its benefits despite the fact that change may potentially result in more benefits than costs.
- Individuals may consider change as potentially beneficial, but have the opinion that management will mishandle the change process.
- Individuals may agree that the change effort has substantial merit, but believe that the initiative for change is not likely going to succeed.

However, often the true cause for resistance, although being aired by employees, lies with management (Spector, 2007). Therefore, management needs to consider how it can create resistance.

How Managers Create Resistance Managers forfeit the ability to learn from resistance when they consider it a negative force. According to Spector (2007), one major cause for resistance is when managers do not allow employees to engage in an open and comprehensive diagnostic process to discuss why the status quo is unfavourable, what needs to be changed and how it needs to be changed. Should employees not envision the potential benefits of a proposed change, they will not have nor appreciate the foresight of management regarding the future of the organisation concerning the proposed change. Furthermore, the employees may simply believe that management does not possess the competence, skill or commitment required to be successful with the change initiative. Lack of input from employees may result in the oversight of valuable information during diagnostic and planning phases. Additionally, managers can obtain valuable insight by understanding hesitations or concerns raised by employees.

2.1.7.2 Stages of the Change Process

Schein (2002) supports the famous Lewin 3-stage Model of Change where any change process consists of the following consecutive stages: *Unfreezing*, *Changing* and *Refreezing*. Table 2.4 displays the characteristics or tasks associated with each stage in the Lewin model. The *Unfreezing* stage is essential to create an understanding as to why there should be change as well as to enforce the idea that change is inevitable. However, it is important to make employees feel as though their opinions and concerns have been considered. The *Refreezing* stage is also very important in order to sustain the changes made. It is important for the changes to become part of “business as usual”. Schein (2002) argues that most change theories focus only on the *Changing* phase and, as a result, they fail to bring about change or to maintain the changes that have been implemented.

Table 2.4: Stages of the change process

Stage	**Characteristics or Tasks**
Unfreezing	Willingness to change; disbelief; survival anxiety, guilt and then sense of ability to overcome learning anxiety
Changing	Learning new concepts, meanings and standards; identification with role models; searching for solutions and undergoing trial-and-error experiences
Refreezing	Internalising the new concepts, meanings and standards; incorporating changes into self-concept, identity, ongoing relationships and groups

Adapted from Schein (2002)

2.1.7.3 Approaches to Change Management

The IAM (2014) provides brief guidelines regarding *Change Management*, emphasising the importance of not over-reacting or being too subjective regarding changes. Previous risk assessments should be used to identify critical change. In addition, risk assessment and analysis should be used to evaluate the new changes to ensure that the new element or implementation (asset, technology, process or person) does not result in new, unforeseen risks. This is essential since new risks may result in a setup that is unfavourable relative to the previous setup (before changes were implemented). Spector (2007) discusses different theories of effective implementation of change. A summary of the theories and their implementations is provided in Table 2.5.

2.1.8 Asset Management in Mining

AM is essential within a mining environment and mining organisations typically own millions (often billions) of assets which they operate and manage. O'Brien (2011) supports this view by stating that the mining industry requires more capital (particularly regarding assets) than the majority of other industries and, as a result, AM is essential in the mining industry. Furthermore, Lane *et al.* (2015) assert that South African mining organisations require a step change in performance. There is also a fairly new drive for positions relating to AM to have a more significant role within the organisations, and *Asset Manager* titles are becoming more common within mining organisations.

Despite all of this, academic literature on AM (as has been defined) within the mining industry is not as extensive as one would have expected. Most sources discussing AM specifically within the mining industry (and not merely a plant

Table 2.5: Key theoretical approaches to *Change Management* implementation

Theoretical Approach	**Theoretical Contribution**	**Tasks to Facilitate Change**
Lewin's Field Theory in Social Science	Context and unfreezing of existing social habits should be the initial focus of an attempt to change behaviour	Establish the perception of dissatisfaction with the status quo among employees; provide operational models indicating new behavioural patterns; reinforce new behaviour with appropriate modifications to existing systems and structures
Organisational development	Organisations are dynamic, open systems	Consider entire organisational system for change; create an atmosphere of open discussion and constructive feedback regarding the efficacy of change implementation; process consultants should facilitate interventions
Task alignment	Desired, new behaviours should be linked to requirements of performing key tasks of the organisation	Analyse and identify Key Performance Indicators (KPIs) and behaviour patterns required for outstanding performance; link requirements for new behaviour to new strategic objectives of organisation; establish line-management support for change effort
Change resistance	Employee resistance is typically a result of the actions of change leaders	Involve employees in diagnostic and learning process; understand and learn from reasons behind employee resistance; address any residual resistance from individual employees in a timely manner

Adapted from Spector (2007)

or industrial environment) involve online forums, company websites, magazines and electronic mining journals such as the *Canadian Mining Journal* instead of peer-reviewed journals. This subsection aims to discuss briefly the current role of AM within the mining industry.

2.1.8.1 Importance of Effective Asset Management within Mining

Fogel and Terblanche (2013) conducted a study where AM maturity and the corresponding improvements in asset performance were surveyed at 57 mines internationally. The analysis focused on 17 key performance areas. Their results indicate a strong correlation between increased investment in improved process capability and the performance in 5 of the 17 key performance areas, namely *Strategy Management, Asset Care Plans, Work Planning and Control, Operator Asset Care* and *Focused Improvement.*

There is evidence that effective AM results in, among others: improved capital productivity, enhanced decision-making, optimised life cycle costs, improved labour productivity and greater recovery rates (Fogel and Terblanche, 2013). However, the responsibility of AM is often assigned to a disempowered function within the organisation which lacks the budget, sway and/or authority to have any substantial impact on management of assets and performance (Fogel and Terblanche, 2013).

Furthermore, having a partially managed AM function can result in adverse effects in performance and costs, as noted by Fogel and Terblanche (2013). These include, *inter alia*, increasing annual costs, high asset related risk exposure, attending to symptoms rather than actual causes of problems (focused on repair instead of performance improvement) and unnecessary expenditure or inefficient allocation of budgets.

Fogel and Terblanche (2013) assert that operational management within the mining industry may be reluctant to address challenges of optimising asset performance when it requires departure from the usual habits. This is based on the notion that operational management within the mining industry is generally satisfied with the asset performance (often sub-optimal) achieved in the past. Nevertheless, there is much scope for the improvement in AM maturity and performance at mining organisations to the standards achieved by other asset intensive industries.

2.1.8.2 AM Applications in Mining

Mining organisations are implementing various AM aspects and tools within their operations. One example is the tagging of RFID tags or similar systems on their assets. In this regard, D'Oliveira (2013) states that mining organisations are using AM to remain profitable.

Qic-Fleet Qic-Fleet, as a specific example, is a vehicle-mounted product that sends data of vehicles (including earthmoving vehicles) to a computer installed with QCIC Asset Management Solutions' software. The Qic-Fleet system, according to D'Oliveira (2013), has an onboard GPS that tracks vehicles and manages on-site productivity by allowing the rerouting of assets to areas in greater need. The system also monitors engine revolutions per minute, oil pressure and water temperature (forms of condition monitoring) and schedules maintenance to minimise breakdowns and downtimes. Furthermore, the system increases safety and productivity by alerting of vehicles exceeding speed limits, overloading, over-revving and excessive idling, as well as identifying operator fatigue.

Qic-Fleet has been and is currently being used in South Africa at companies such as Murray & Roberts, CAT Rental Store and Eskom (D'Oliveira, 2013). Nevertheless, applications are not limited to vehicles as the system has been applied to light-duty equipment such as generators, compressors, cranes, materials handling and plant equipment, and elevated work platforms (at Eskom's Kusile and Medupi power plants).

EAM/CMMS O'Brien (2011) highlights the value of an Electronic Asset Management (EAM) system or Computerised Maintenance Management System (CMMS) for the mining industry. A CMMS can, among other things,

- keep track of documents and allow vendors access to documents;
- track the entire lifecycles of assets (of which mining organisations have many). This is valuable from not only a cost and maintenance aspect, but also a safety perspective as the large equipment (as well as smaller equipment) used in mining can be well maintained; and
- schedule work tasks, shutdowns and closures of mines.

Maintenance vs Production According to Koro (2013), maintenance has generally always been secondary to mining operations (production), regardless of cost. This results in the condition of assets deteriorating over time, as they are not being maintained enough and are being placed under too much strain to produce or operate as much as possible. He suggests that an AM plan should be one of the primary drivers for the mining operation. This is based on his belief that, if proper AM systems and processes are in place, planned maintenance activities can be performed mostly according to the planned schedule. This is dependent on continual improvement and updating of the AM plan as operations progress. However, once this is in place, other shortfalls or problem areas in the organisation will be highlighted and the mining organisation can implement changes accordingly. It is important though to implement changes and do maintenance when business is going well. This prepares organisations for unexpected events instead of carrying out an approach of "fire-fighting".

Koro (2013) reports that PAS 55 has had influence within the mining industry, but not to the extent that is necessary for long-term sustainability of mining organisations. Despite this, there are a number of companies who are endorsed trainers and auditors of PAS 55 by the IAM. ISO 55000 is soon to be the adopted AM standard by mining organisations and certifiers for ISO 55000 are already in training. Many tools that help with the implementation of AM systems exist, such as *Rylson8*.

Risk-informed Performance-based AM in Mining Komljenovic (2008) investigated the possibility of developing a holistic Risk-informed Performance-based Asset Management in Mining (RIPBAMM) model which is derived from Risk-informed Asset Management (RIAM). The RIPBAMM approach aims to integrate various existing main mine activities such as, *inter alia*, exploration, ore body modelling, mine design, planning and scheduling, mineral treatment, operational safety and health, environmental issues and mining equipment reliability. It is primarily based on an adaptation of research already investigated in this area in the mining industry, as well as in other industries, which is concerned with the risks and uncertainties involved in normal business operations. According to Komljenovic (2008), RIPBAMM is supposed to "involve an integrated assessment of dominant influence factors and performance measures related to mining operations". This it does using probabilistic and deterministic methods.

2.1.8.3 Case Study of Asset Management Problem within Mining

Dutra and Hupp (2013) describe a case study of applying AM to increase the Return on Assets (ROA) and to obtain reliable performance. The case study was performed at Samarco, a mining company that supplies iron ore pellets to the steel-producing markets.

According to Dutra and Hupp (2013), it is compulsory to map and manage the lifecycle processes of assets when implementing an AM System. The *Maintain* phase is one of the primary phases in an asset's lifecycle. It is in this phase that maintenance plans are executed and asset data is recorded. In the case study, it was discovered that the existing performance measurement process had the following monitoring issues:

- asset Key Performance Indicators (KPIs) were not measured at asset level, but rather asset system level. This made identification of asset-specific problems more difficult;
- failure modes, completed job orders, maintenance costs and asset locations were poorly recorded; and
- there was a lack of proactive approach regarding asset performance (reactive in nature).

In addition to traditional metrics such as Mean Time Between Failures (MTBF) and asset availability, accurate cost and risk measurements are essential for identifying whether an asset is achieving the service level necessary to fulfil the business strategy (Dutra and Hupp, 2013). This is important in order to obtain reliable asset performance measurements. As a result, Samarco required a new asset performance measurement process which identifies assets that perform poorly and that supports continuous improvement. Dutra and Hupp (2013) further describe in detail the process undertaken to develop this new process. The data accuracy increased from 55% to 90% after implementing an improved process.

2.2 Spare Parts Management

A spare part is a duplicate or replacement item used, or planned to be used, to replace either a damaged component or a component that is not functioning at a satisfactory level of performance. The replacement is sometimes performed for preventative maintenance reasons. According to Barry and Olson (2010), the purpose of spare parts is to “support the sustainability and life cycle of the expected functions of valued assets”. In view of this, the need for a spare part arises when a component fails to operate at the designed or expected performance levels. It is said that the component has experienced functional failure. In this case, the component is either replaced with a spare part, allowed to run-to-failure and then replaced with a spare part, or repaired if possible. Terms referring to spare parts include *spares*, *service parts*, *repair parts* and *replacement parts* (Du Toit, 2014).

Cavalieri *et al.* (2008) highlight that the successful management of *Maintenance, Repair and Operations (MRO)* materials, which include spare parts, is vital in capital-intensive organisations. Ghodrati and Kumar (2005) explain that effective SPM reduces idle time and increases resource utilisation, thereby enhancing productivity. Additionally, Wireman (2005) highlights that approximately 50% of a typical maintenance budget is expended on spare parts and material consumption, and that, for reactive organisations, up to 20% of costs related to spare parts may be waste. This is a substantial amount considering that, according to Lyndon (2014), maintenance accounts for 30% to 50% of total operating expenses in mining organisations. Wireman (2005) reports that the following areas of waste are typically present in the inventory and purchasing function:

- excess stock of spare parts;
- expediting spare parts delivery;
- shelf life expiry;
- single line item purchase orders; and
- loss or lack of record of spare parts.

According to Cavalieri *et al.* (2008), MRO materials can be classified as:

- *Consumables and auxiliary materials:* parts that have a steady and continuous consumption in addition to having a vast supplier network. These parts include auxiliary resources for equipment operations (such as oil, filters and grease) and for maintenance activities (wiping rags and cleaning supplies).
- *Generic spare parts:* parts used to replace damaged general purpose parts within or on equipment. They are widely available on the market and catalogues for these parts are easily obtainable. These parts include mechanical components such as bearings and chains, hydraulic accessories such as valves and cylinders, and electronic components such as switches, light bulbs and fuses.
- *Specific spare parts:* parts that are only available for a particular item of equipment and provided only through a specific supplier. They are non-generic.
- *Strategic spare parts:* parts that have unforeseeable wear-out times. They often have long lead times, sporadic demand and are expensive.

Barry and Olson (2010) claim that MRO materials are not always available at the right locations or at the right times as required by organisations. This occurs despite the significant costs and efforts by inventory managers to be able to issue the materials so as to satisfy unpredictable demand. The availability of critical spare parts is an important factor in achieving organisational and production targets. This is supported by Barry and Olson (2010) as they recognise the dependency of a successfully executed maintenance plan on the availability of spare parts on a timely basis. They argue that Overall Equipment Effectiveness (OEE), a measure indicating the percentage of planned production time that is truly productive (Flynn and Vlok, 2015), will be adversely affected if critical spare parts are not available for either planned or unplanned maintenance. Therefore, it is important to understand the unpredictable demand for spare parts, as well as the policies and procedures that dictate the manner in which spare parts are procured and issued.

According to the IAM (2014), there are various tools and techniques for optimising spare parts management (regarding stock level policies). Figure 2.9 illustrates the typical trade-off between the holding cost of storing spare parts versus the risk involved with stock-outs if there is a lack of spare parts available to meet the demand for them. As seen in Figure 2.9, there is an optimal number of spare parts for each type of spare part that an organisation is expected to store. This is performed in order to minimise the holding cost without exposure to extreme risk of spare part unavailability. It is important to be cognisant of obsolescence and shelf life when considering the holding of spare parts. The opportunity to use modular and standardised spares which can replace a variety of assets is another important factor (IAM, 2014).

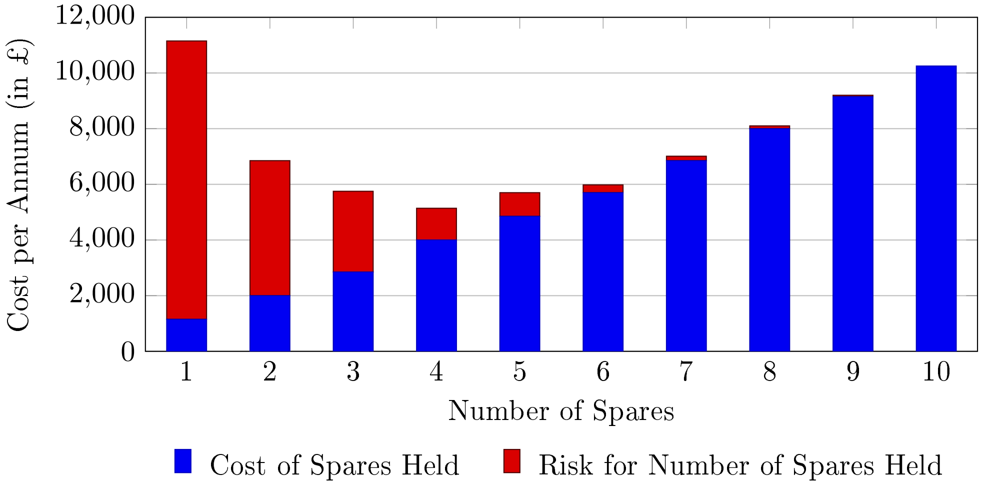


Figure 2.9: Typical spare parts trade-off between holding cost and risk
Adapted from IAM (2014) and Cavalieri et al. *(2008)*

Although the need to manage spare parts has existed since the beginning of the industrial manufacturing era, it is only in recent decades that the literature concerning spare parts has expanded substantially (Meggs, 2014). The IAM (2014) reports that there is an extensive amount of literature on SPM in terms of tools and techniques used regarding capital, critical and strategic spare parts holdings, as well as the theory and formulae for optimising stock levels and Economic Order Quantities (EOQs). The majority of this literature focuses on demand forecasting (especially intermittent demand), the classification of spare parts and various inventory stock policies (Du Toit, 2014). Important contributors towards the consolidation of recent spare parts literature include Kennedy, Patterson and Fredendall (2002).

2.2.1 SPM Literature Overview

Molenaers, Baets, Pintelon and Waeyenbergh (2012) state that SPM has become, over the past few decades, increasingly popular in literature. According to Du Toit (2014), the literature regarding SPM consists primarily of studies concerning the characteristics and classification of spare parts, the demand patterns and forecasting of intermittent demand for spare parts, the maintenance aspects of spare parts, and the various inventory models and policies.

A number of authors have attempted to improve the various literature on spare parts. Kennedy *et al.* (2002), for instance, reviewed literature on maintenance strategies where they highlight typical issues in inventory management such as age-based replacement and obsolescence. Alternatively, Van Horenbeek, Buré, Cattrysse, Pintelon and Vansteenwegen (2013) reviewed joint maintenance and inventory optimisation systems. Their review is focused on optimisation studies that consider both maintenance and inventory policies. Basten and Van Houtum (2014) surveyed the literature on models using system-oriented service measures for spare parts inventory control. Moncrief, Schroder and Reynolds (2006) present a comprehensive overview on theories and practices, and they provide various case studies relating to spare parts in *Production Spare Parts: Optimizing the MRO Inventory Asset*.

Literature regarding SPM includes both technical studies and non-technical or general studies (Du Toit, 2014). The technical studies are detailed and narrow in scope, often involving specific case studies. Technical studies attempt to improve existing systems and, therefore, involve the design and testing of parts of specific cases or models. The study performed by Vaughan (2005) is a technical study. In his paper, an inventory policy for spare parts handling demand from both a preventative maintenance perspective as well as a random failure perspective is addressed through a stochastic dynamic programming model. The non-technical studies are broader in scope and typically include generic guidelines concerning the management of spare parts. Examples of such studies include the research performed by Huiskonen (2001), Cavalieri *et al.* (2008) and Porras and Dekker (2008).

Classification of spare parts is important to categorise them according to needs and manage them appropriately. Molenaers *et al.* (2012) approach spare part classification based on criticality. Bacchetti, Plebani, Saccani and Syntetos (2010), however, suggest a hierarchical multi-criteria spare part classification approach. Gajpal, Ganesh and Rajendran (1994) discuss the evaluation of the criticality of spares through use of the Analytic Hierarchy Process (AHP) which is described in Section 2.4. The classification of spare parts is an important concept; its details are discussed in Section 2.2.3.

Spare parts are typically characterised by intermittent demand. This increases complexity regarding the forecasting of the demand of spare parts, which ultimately determines (at least partly) the stock levels required. Various authors have investigated and reviewed literature relating to forecasting in their respective papers. For instance, Boylan and Syntetos (2010) reviewed different forecasting methods and extensions used for SPM. Wang and Syntetos (2011) develop a novel concept to forecast demand that depends on the very sources of the (intermittent) demand generation process and they compare it to a well-known time-series method. In their paper, they conclude that maintenance-driven models, such as their concept, are associated with better performance under certain conditions. Additionally, an environment-based forecasting model was developed by Ghodrati and Kumar (2005) based upon the premise that environmental factors play a significant role in forecasting. The focus of this study is not on forecasting demand of spare parts, but forecasting, in general, is an important area of research regarding SPM. Therefore, Section 2.2.4 discusses spare parts demand forecasting in further detail.

Forecasting demand for spare parts is only one part of SPM. The information from forecasting needs to be used with inventory models and policies that assist with the management of spare parts. The inventory models and policies define sets of rules that determine the quantities of inventory to be ordered and when orders are to be placed. Gelders and Van Looy (1978) performed an ABC analysis in a case study at a large petrochemical organisation and developed inventory models for different classes of inventory items (including both fast- and slow-moving items). Similarly, Haneveld and Teunter (1997) developed an optimal ordering strategy for slow-moving spare parts that have short lead times. Shtub and Simon (1994) discuss the determination of Reorder Points (ROPs) in a two-echelon spare parts inventory system. Furthermore, Porras and Dekker (2008) empirically compare different Reorder Point (ROP) methods for effective spare parts inventory control at a refinery.

Other issues relating to SPM include age-based replacement, multi-echelon problems, obsolescence and repairable items (Du Toit, 2014). Although there is not much literature available regarding warehousing and facility design of spare parts, there is a substantial amount of literature regarding warehousing in general. Inventory warehousing is described in Section 2.2.5. Contributors in this area include Barry and Olson (2010), Blomqvist (2010) and Gould (2013).

Cavalieri *et al.* (2008) report that few companies actually adopt proper structural, factual and quantitative approaches to manage spare parts despite the relatively vast body of literature on spare parts. Wagner and Lindemann (2008) assert that there is a substantial discrepancy between theory and application concerning inventory concepts in manufacturing organisations. Du Toit (2014) also mentions that the practical applications of SPM in general lag behind theoretical solutions. Bacchetti and Saccani (2012) state that integrated approaches to manage spare parts and to supplement theoretical models with practical guidelines are required in order to bridge the gap between research and practice. Driessen, Arts, Van Houtum, Rustenburg and Huisman (2014) attempt to bridge this gap by developing a framework for the planning and control of the spare parts supply chain in organisations that use high-value capital assets. They also identify open research topics for future research.

Driessen *et al.* (2014) believe that the only other paper in which a framework for spare parts control has been proposed is the one by Cavalieri *et al.* (2008). Cavalieri *et al.* (2008) provide a decision-making framework for managing maintenance spare parts which is focused exclusively on the inventory control of spare parts and provides guidelines regarding decisions in the framework. In contrast, Driessen *et al.* (2014) adopt a broader perspective by including a repair shop and its control, as well as providing references to state-of-the-art techniques for decision-making.

2.2.2 Characteristics of Spare Parts

In a manufacturing environment, inventory is typically categorised as one of the following: finished goods, Work-In-Process (WIP), raw materials, or operating supplies and replacement parts (Moncrief *et al.*, 2006). Spare parts form part of the last category and can be considered a special kind of inventory. Du Toit (2014) states that spare parts have unique attributes that differentiate them from finished goods, WIP or raw materials. Additionally, Kennedy *et al.* (2002) highlight the two primary differences between spare parts inventory and other types of inventory:

- The function of spare parts differs from that for other kinds of inventory. For instance, WIP inventory may function as a buffer against irregularities (such as breakdowns and differences in production rates) in the production process. Finished goods are kept to be able to provide goods to customers as required and to protect against uncertainty and variability in lead times, quality and other supply chain factors. The primary purpose for spare parts inventory, however, is to ensure that all equipment is maintained to a proper operating condition by maintenance staff.

- The policies that govern spare parts inventories differ to those for other inventory types. WIP and finished goods depend on production rates, scheduling, lead time and quality. As such, they can be governed by changing these factors. Spare parts inventory, however, is a function of the utilisation and maintenance of equipment. Therefore, maintenance policies have a direct impact on spare parts inventories.

Furthermore, Kennedy *et al.* (2002) highlight the following unique aspects of spare parts that differentiate them from general inventory:

- Maintenance policies determine the need for spare parts whereas other inventory types typically depend solely on customer usage. Furthermore, decisions such as whether to replace or repair damaged parts or whether to have greater redundancy in order to lengthen required lead times for parts determine spare parts levels.

- Predictions of failures of parts are not accurate enough to allow organisations to order spare parts to arrive exactly when failures will occur. Additionally, more accurate options, such as *Condition Monitoring*, are often too expensive and laborious to be performed on all equipment. This results in substantial equipment downtime should spare parts not be available or easily and quickly obtainable.

- Part failures are often dependent on and related to each other. The inability to distinguish failure dependencies adds to the difficulty of knowing the right type of spare parts required in the right quantities.

- It is often possible to cannibalise other parts in order to meet the demand for spare parts.

- Quantifying costs related to quality, “lost production” and increased risk (safety- and production-oriented) as a result of spare part stock-outs (not having enough spare parts on hand) is a difficult process.

- Equipment for which spare parts were designed may become obsolete and discontinued. In this case, it becomes difficult to determine the quantity of spare parts to stock for the obsolete product and the spare parts of discontinued products often become difficult to obtain.

- Components of equipment are usually stocked instead of the whole equipment units, especially when the whole unit of equipment is expensive. Repair of equipment (replacing only components) may be preferred to replacement of the whole unit.

It is evident that spare parts are uniquely different from other types of inventory and, therefore, should be handled somewhat differently. However, within the group of spare parts are differences among items which require the classification and different treatment of spare parts. This classification is discussed in Section 2.2.3.

2.2.3 Classification of Spare Parts

Boylan and Syntetos (2010), as cited by Bacchetti and Saccani (2012), indicate that spare parts for consumer products are diverse with different costs, service requirements and demand patterns. Therefore, a classification of spare parts is useful to determine service requirements for various spare parts classes and for forecasting and inventory control decisions. According to Syntetos, Keyes and Babai (2009), categorisation of Stock Keeping Units (SKUs) is critical to facilitate the decision-making process which may affect areas such as forecasting and inventory policies. In addition, Syntetos *et al.* (2009) highlight that classification enables time-constrained management teams to focus their efforts on the parts which matter most.

2.2.3.1 Classification Criteria

Several classification criteria for spare parts are considered in literature by researchers. However, Bacchetti and Saccani (2012) observe that not much emphasise has been placed on identifying in which context one criterion is preferred to another criterion or criteria. According to Wagner and Lindemann (2008), the most important characteristic of spare parts is the criticality factor (the importance of spare parts in the production process). However, Boylan and Syntetos (2010) believe that part criticality (as a criterion) is more suitable for technical systems than products used by private customers.

Bacchetti and Saccani (2012) summarise the classification criteria used in 25 published studies attempting to classify spare parts. The criteria included *Part Cost/Value*, *Part Criticality*, *Supply Characteristics/Uncertainty* (such as replenishment lead time, supplier availability or risk of non-supply), *Demand Volume/Value*, *Demand Variability*, *Part Reliability*, *Life Cycle Phase*, *Part Weight*, *Repair Efficiency* and *Part Specificity*. Figure 2.10 displays the criteria in terms of number of studies that used each criterion. It is evident from Figure 2.10 that *Part Cost/Value* and *Part Criticality* were most commonly used for classification after which *Demand Volume/Value*, *Supply Characteristics/Uncertainty* and *Demand Variability* were relatively frequent. Each of the remaining criteria was not used in the majority of the studies investigated. Bacchetti and Saccani (2012) provide a table displaying the list of publications used in their review, and which criteria were used in each publication.

The most commonly used criteria to classify spare parts are *Part Criticality*, *Part Cost/Value* and *Demand Volume/Value*. Once the classification criteria

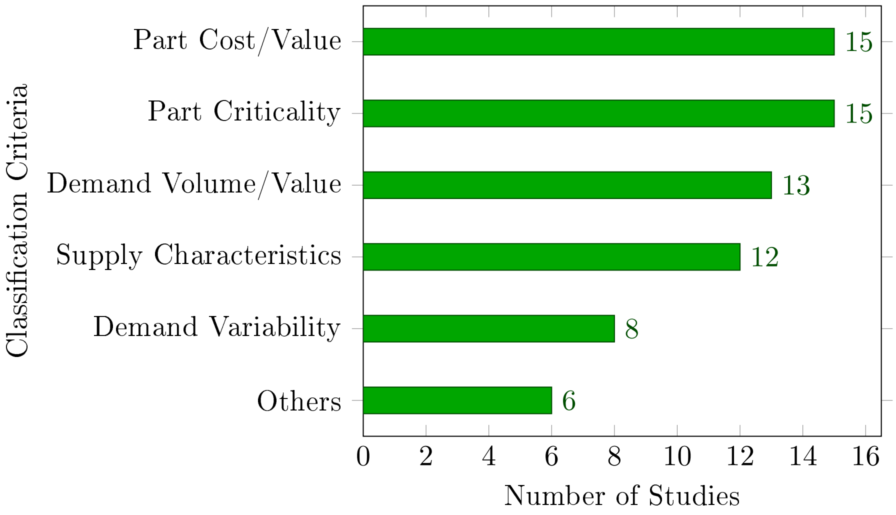


Figure 2.10: Number of studies (out of 25 studies) using each classification criterion *Adapted from Bacchetti and Saccani (2012)*

have been defined, a classification technique (discussed in Section 2.2.3.2) is required.

2.2.3.2 Classification Techniques

A classification technique refers to the manner in which spare parts are classified. Classification techniques can be qualitative or quantitative in nature. Most papers adopt quantitative classification techniques. Ramanathan (2006) mentions that the most common technique to classify inventory items is the ABC approach which is proposed in ten of the publications reviewed by Bacchetti and Saccani (2012). The ABC approach is based on the Pareto principle (which is also referred to as the 80:20 rule).

The Pareto principle refers to the general observation that a few items have large importance (80% of effects are as a result of 20% of the causes), and that many items have little importance (20% of effects are as a result of 80% of the causes). According to Syntetos *et al.* (2009), the ABC approach involves a Pareto report that lists all Stock Keeping Units (SKUs) in a descending order according to the specific criterion. These SKUs are then placed into the relevant categories that are typically labelled A, B and C. A indicates the items with the highest values for the specified criterion, C the items with lowest values and B represents all intermediate items. Silver, Pyke and Peterson (1998) state that one of the benefits of the ABC approach is the identification of the large group of C items which consume a large amount of managerial time without contributing significant value. These items can be managed appropriately once identified.

The ABC technique is used for both the single criterion, typically demand volume (Gelders and Van Looy, 1978; Syntetos *et al.*, 2009), and the multi-criteria classifications. The ABC approach is easy to use and implement, and it is widely adopted in practice to classify spare parts. Du Toit (2014) claims that the ABC approach is successful when the assortment of spare parts differs primarily in terms of a single criterion only. In practice, however, there is often a need to classify inventory items according to more than one criterion. Bacchetti and Saccani (2012) highlight different methods proposed for implementation of multi-criteria ABC classifications, namely matrix models, weighted linear optimisation, artificial neural networks, weighted Euclidean distances with quadratic optimisation and fuzzy logic.

Syntetos, Boylan and Croston (2005) and Boylan, Syntetos and Karakostas (2008) propose a two-dimensional matrix classification based on demand variability and order frequency while Williams (1984) and Eaves and Kingsman (2004) suggest the partitioning of the variance of demand during lead time. Alternatively, Yamashina (1989) considers the definition of product-still-in-use quantity curves and service part demand curves as inputs for spare parts classification. Nagarur, Hu and Baid (1994) and Porras and Dekker (2008) suggest a hierarchical two- or three-dimensional quali-quantitative classification. Petrović, Petrović, Senborn and Vujosević (1990) and Petrović and Petrović (1992) consider an expert system involving the determination of failure rates and fuzzy logic. Finally, Ernst and Cohen (1990) developed the *Operations Related Groups* methodology that is based on a statistical clustering technique.

Conversely, qualitative methods attempt to evaluate the importance of holding spare parts according to information on the specific usages of spare parts, costs, downtime and storage considerations. One of the most popular qualitative methods is the Vital, Essential, Desirable (VED) approach. The VED method is based on consultation with experts (Mukhopadhyay, Pathak and Guddu, 2003). Structuring a VED analysis, despite VED's apparent simplicity, is often a difficult task as it may be biased towards subject judgements of users (Bacchetti and Saccani, 2012). To prevent, or at least limit, the potential for bias, VED can be combined with a systematic procedure for classifying spare parts. Gajpal *et al.* (1994) recommend a VED classification model based on the use of the AHP (Saaty, 1987, 1990; Saaty and Vargas, 2012) which defines three groups of spare parts (vital, essential and desirable). The AHP is discussed in Section 2.4. Similarly, Braglia, Grassi and Montanari (2004) used a decision tree of multiple attributes integrated with AHP models to solve the various multi-attribute decision sub-problems at different nodes in the decision tree.

2.2.4 Spare Parts Demand Forecasting

According to Du Toit (2014), intermittent demand is characterised by "sequences of zero demand observations interspersed by occasional non-zero [demand observations]". Erratic demand is characterised by demand observations that vary greatly in size in a seemingly unpredictable manner. If demand is both intermittent and erratic, it is termed *lumpy demand* (Cavalieri *et al.*, 2008). Conversely, slow-moving demand is more regular in nature, but less frequent and in smaller quantities. Demand for spare parts is generally intermittent and erratic (lumpy) and, therefore, forecasting the demand of spare parts presents a serious challenge (Boylan and Syntetos, 2010). Additionally, Driessen *et al.* (2014) assert that most spare parts inventory models assume Poisson demand, which is not a tenable assumption when forecasts evolve in real-time based on sensor information. The difference between slow-moving demand and lumpy demand patterns is shown in Figure 2.11.

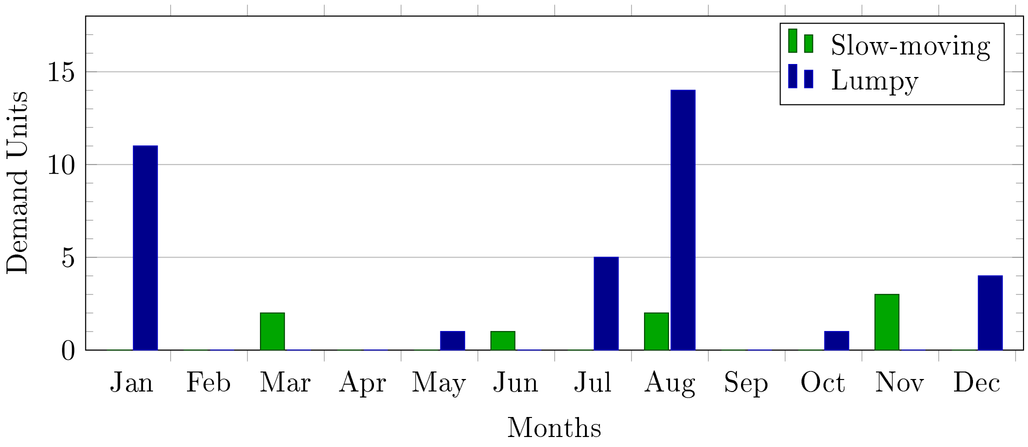


Figure 2.11: Comparison of slow-moving and lumpy demand patterns
Adapted from Du Toit (2014)

Research concerning the forecasting of intermittent demand has developed significantly over recent years. According to Wang and Syntetos (2011), insights derived from research are useful for the theoretical development of inventory policies and some of the results are incorporated into inventory management software. However, the practical implementation of such policies still trails behind.

2.2.4.1 Demand Forecasting Techniques

Demand forecasting techniques for spare parts are typically classified either as reliability-based forecasting or time-series-based forecasting. The decision of the class of forecasting technique to use is strongly dependent on data availability. Wang and Syntetos (2011) and Cavalieri *et al.* (2008) claim that time-series analysis is more commonly used in practice, as opposed to reliability-based forecasting that is used when historical data on explanatory variables is available. However, various studies have displayed the significant benefits of using reliability-based forecasting techniques (Kennedy *et al.*, 2002; Wang and Syntetos, 2011). Kalchschmidt, Zotteri and Verganti (2003) state that models based on information relating to demand generation perform better than the traditional time-series models when demand uncertainty increases.

Time-series-based forecasting techniques applied to spare parts include Croston method (Croston, 1972), Simple Exponential Smoothing (SES) and Moving Average (Du Toit, 2014). Moving Average and SES are simple and well-known time-series-based forecasting methods. SES involves assigning different weights to historic observations whereas the Moving Average method involves assigning equal weights to historic observations. The Croston method (Croston, 1972) is a forecasting method that utilises the SES method to combine both the sizes of demand and the intervals of demand in order to forecast demand.

Ghobbar and Friend (2003) evaluated 13 forecasting methods for intermittent parts demand in the aviation field and the study included, among others, the Additive Winter method, the Seasonal Regression method, the Weighted Regression Demand Forecaster method and the Double Exponential Smoothing method. The methods that displayed superior results in the study included the Weighted Moving Average method, the Holt Winters method and the Croston method.

The Bootstrapping method is a fairly well-known non-parametric approach for forecasting spare parts demand. Boylan and Syntetos (2010) state that bootstrapping involves “consecutive sampling, with replacement, from an available dataset, to construct an empirical distribution of the data under concern”. The primary focus of Bootstrapping is on extrapolating the past behaviour of data to the future.

Boylan and Syntetos (2010) describe the advantages of information sharing and the role of the forecast system in a fairly recent review on forecasting techniques for spare parts. Romeijnders, Teunter and Van Jaarsveld (2012) discuss a two-step approach for forecasting spare parts demand using component repair information. Additionally, Eaves and Kingsman (2004) describe the Approximation method which is a modification to Croston’s method. According to Eaves and Kingsman (2004), the Approximation method has been observed to result in significant reductions in the value of inventory on hand required to achieve a certain service level for all demand patterns. However, Ghobbar and Friend (2003) and Cavalieri *et al.* (2008) claim that the SES method is the most popular forecasting technique in practice. Bacchetti and Saccani (2012) support this statement by stating that traditional methods (such as Moving Average and SES) are preferred in practice and that the specific, more complicated methods developed for spare parts are often neglected.

2.2.4.2 Forecasting Techniques for Specific Demand Patterns

Certain forecasting techniques forecast specific demand patterns more accurately than other techniques. Therefore, it is important to investigate which forecasting techniques are more suitable for the specific demand pattern to be forecast.

Cavalieri *et al.* (2008) assert that the time-series-based models are more appropriate for smooth demand and erratic demand. Conversely, intermittent demand and lumpy demand should be forecast using more customised models. According to Du Toit (2014), traditional time-series-based forecasting models (such as SES) are generally more suitable at forecasting fast-moving items than slow-moving items. Additionally, Boylan and Syntetos (2010) claim that Exponential Smoothing methods are preferred for fast-moving inventory items in software packages. Moncrief *et al.* (2006) recommend the use of Moving Average, Linear Regression and the Least Squares Method for fast-moving inventory items, but suggest the χ^2 statistic for slow-moving inventory items. The χ^2 statistic is a hypothesised demand distribution method that uses the χ^2 distribution to predict future demand. Du Toit (2014) states that the demand for slow-moving items and new items can be forecasted with hypothesised demand distributions owing to the limited data available regarding these items.

Johnston and Boylan (1996) discovered that the Croston method performs better than the Exponentially Weighted Moving Average (EWMA) method when the inter-order interval is greater than 1.25 of the forecast review period. When lead time and inter-order interval increase, the gains from using the Croston method increase. Kalchschmidt *et al.* (2003), however, propose that the Croston method be used to forecast irregular demand patterns and that the SES method be used for stable demand patterns.

To summarise, the Moving Average method and SES method are popular for fast-moving and smooth demand. The Croston method, the Bootstrap method and the hypothesised demand distributions are more suitable for slow-moving, intermittent demand patterns. Once demand is understood and forecasted appropriately, suitable inventory control policies can be determined. Section 2.2.1 mentions authors that have investigated models for spare parts inventory policies.

2.2.5 Inventory Warehousing

Barry and Olson (2010) emphasise that the ability of suppliers to deliver MRO materials for specific maintenance tasks directly to the relevant area when required would eliminate the need for inventory such as spare parts on hand. However, the diversity of materials required and intermittent demand result in on-site inventory becoming a necessity. This inventory may be stored in central or satellite warehouses, in depots near specific equipment or in service vehicles. Gopalakrishnan and Banerji (2013, p. 402) state that warehousing or storage of spare parts is a critical, but neglected activity in SPM.

According to Gould (2013), a storage warehouse is a building utilised for storing inventory with the primary objective of supporting the movement of products from suppliers to customers in a timely and cost-effective manner. In terms of spare parts, customers would be maintenance departments or engineers that request parts while suppliers would be companies that supply the parts to the specific organisation. A storeroom can be considered a smaller version of a warehouse that is typically used for on-site purposes such as the storage and issuing of spare parts. Different types and sizes of products or parts, each with a different demand level, can be stored in a warehouse. Baker and Canessa (2009) describe that warehouse requirements and environments are unique and need to be assessed on a per-case basis with each case requiring different layouts, storage techniques and order picking policies.

2.2.5.1 Warehouse Functions

Gould (2013) describes warehouses to have the following primary (consecutive) functions:

1. *Receiving:* products (or parts) are delivered to the warehouse, usually via trucks arriving at receiving docks. A quality check is performed to ensure products (or parts) are received in the correct quantity and without damage. The items are then packed into different storage modules used by the warehouse before transfer into the warehouse. This function includes the scheduling of unloading activities.

2. *Storage:* products (or parts) are placed in storage areas within the warehouse. The Storage Location Assignment Problem (SLAP) is the issue of allocating certain locations in storage areas to store particular items. Storage is an important function, as effective storage practice can increase the utilisation of space, labour and time, as well as improve the protection of items and the accessibility to parts.

3. *Order picking:* products are retrieved from storage locations to be issued to customers based on their orders. This function may be manual or automatic. Order picking policies, routing and batch picking should

be assessed, as improvements to these may result in fewer movements (from employees, equipment and materials) as well as an increase in productivity and time utilisation.

4. *Shipping (collection):* once orders have been picked, they are checked, entered into a Warehouse Management System (WMS), packed and then either delivered or collected.

Although these functions are for warehouses in general, they apply to spare parts storage facilities. In the case of "shipping", spare parts would either be collected by maintenance employees or delivered to the relevant areas on-site.

2.2.5.2 Warehouse Design

Successful supply chain management requires decisions on three levels which vary in time frames, namely *strategy or design*, *planning* and *operations* (Wagner and Lindemann, 2008). Similarly, Blomqvist (2010) considers warehouse design to consist of three different levels which vary in time frames, namely *strategic level*, *tactical level* and *operational level*. For a coherent design, it is important to first consider issues relating to the *strategic level*, then the *tactical level* and, finally, the *operational level*.

The strategic level concerns long-term and often capital investment decisions. These decisions can be grouped into two categories, namely decisions concerning the overall design of warehouse flows and decisions regarding the selection of the types of warehousing systems to be used. Warehouse flows include the four primary functions (receiving, storage, order picking and shipping or collection), but may also involve additional processes (such as sorting processes) that affect the design of tasks and selection of equipment. The two categories of strategic level decisions are interdependent as designed or selected processes flows (such as a certain sorting process) depend on and dictate the need for specific systems (such as a sorter system capable of handling the products or parts).

Tactical level decisions are medium-term decisions that result from decisions made at the strategic level. They have less impact than strategic decisions, but still form moderate investments. These decisions typically relate to issues such as resource allocation, warehouse layout and storage policies.

Operational level decisions concern daily operational activities that support or exist as a result of strategic level and tactical level decisions. They are low-investment decisions and their impact on operations is limited. Policies typically guide operational level decision-making and dictate the manner in which operations proceed. These decisions relate to issues such as free storage location allocation, order sequencing and picking routes.

Gould (2013) highlights typical warehouse design and operation considerations which are displayed in Table 2.6. There are five primary categories related to warehouse design, namely *overall structure*, *sizing and dimensioning*, *department layout*, *equipment selection* and *operational strategy*. Warehouse operations can be categorised into three primary categories, namely *receiving and shipping (collection)*, *storage* and *order picking*.

Resources such as labour, equipment and space are generally limited. Various functions of the warehouse are allocated these resources in order to achieve desired system requirements. According to Blomqvist (2010), these system requirements typically include capacity, throughput and adequate customer service at the minimum resource cost. However, costs are incurred with resource allocation and this is a contributor to the cost per process or function. Figure 2.12 illustrates the average cost distribution of warehouse processes for a typical warehouse.

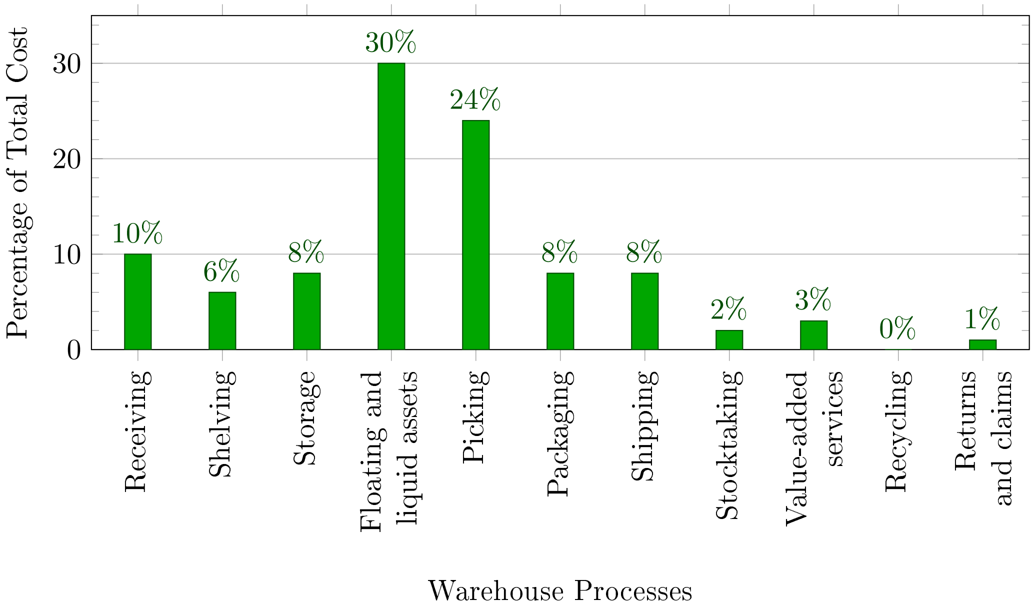


Figure 2.12: Distribution of costs associated with warehouse processes

Adapted from Blomqvist (2010)

As can be seen in Figure 2.12, order picking (24%) is the largest cost of the four primary functions of a warehouse. Receiving and Shipping together form 18% of the total warehouse costs and Storage is 8% of the total warehouse costs. If one combines shelving, packaging and storage costs to form a total storage-associated cost, the value is 22% of total warehouse costs. Therefore, a key

Table 2.6: Typical warehouse design and operation considerations

	Relevant Area or Process		**Consideration**
Warehouse design	Overall structure		- Material flow
			- Department identification
			- Location of departments
	Sizing & dimensioning		- Size of the warehouse
			- Departments: size & dimension
	Department layout		- Pallet block-stacking pattern
			- Aisle orientation
			- Aisles: number, length & width
			- Door locations
	Equipment selection		- Degree of automation
			- Storage equipment
			- Material handling equipment
	Operational strategy		- Storage strategy
			- Order picking method
Warehouse operation	Receiving & shipping		- Truck-dock assignment
			- Order-truck assignment
			- Truck dispatch schedule
	Storage	– SKU-department assignment	- Assignment of items to different departments
			- Space allocation
		– Zoning	- Assignment of SKUs to zones
			- Assignment of pickers to zones
		– Storage location assignment	- Storage location assignment
			- Specification of storage classes
	Order picking	– Batching	- Batch size
			- Order-batch assignment
		– Routing & sequencing	- Routing & sequencing of order picking tours
			- Dwell point selection
		– Sorting	- Order-lane assignment

Adapted from Gu, Goetschalckx and McGinnis (2007) focus area for warehouse design is the order picking processes. Additionally, Aminoff, Kettunen and Pajunen-Muhonen (2002) report that approximately 40% of the costs in a typical warehouse are labour-related while floating assets and liquid assets, buildings, IT, outsourced services, machinery, storage equipment and land represent smaller portions of the investment. Furthermore, increasing labour productivity can reduce warehouse operating costs. This can be achieved through investment in warehouse technologies (which are often expensive). However, to obtain an acceptable rate of return on investments, the technologies need to be selected and utilised appropriately.

2.2.5.3 Material Handling

Frazelle (2002), as cited by Gould (2013), mentions that warehouse design should be based on interrelationships between warehouse processes and space requirements. According to Gould (2013), warehousing operations aim to maximise simultaneously resource utilisation and customer satisfaction. Additionally, Gould (2013) asserts that the primary objective is to minimise both the total distance travelled during the processing of an average order and the total cost. Tompkins, White, Bozer and Tanchoco (2010) state that the following factors concerning warehousing should be maximised:

- equipment utilisation;
- space utilisation;
- labour utilisation;
- accessibility to inventory; and
- protection of inventory.

The majority of these factors are dependent on the layout of the warehouse. Blomqvist (2010) highlights three methods to reduce total process flow, namely:

- design for as few movements of flow between consecutive points as possible;
- provide materials, information and people as required to facilitate processes and eliminate unnecessary steps; and
- combine flows and operations by planning the handling of materials, information and people to be integrated into processing steps.

A U-shaped layout is the most popular and effective layout of warehouse activities for material handling process flows (Gould, 2013). Blomqvist (2010) highlights that this layout allows for fast-moving items to be placed closer than the slow-moving items, thereby supporting class-based storage.

Gopalakrishnan and Banerji (2013) provide a list of items for the evaluation of the stores function that storerooms or warehouses should perform. Some of the most important items include:

- positioning of the receiving function relative to stock issue order processing;
- security controls regarding vehicles travelling in and out of areas;
- adequate control on receipt and issue of material dispatched to subcontractors;
- having an approved list of persons that are authorised to draw spare parts from the stores;
- control of spare parts outside normal office hours; and
- segregation of slow-moving, non-moving, insurance and obsolescence spare parts.

The subsequent section discusses common SPM issues encountered in industry.

2.2.5.4 Common SPM Issues within Industry

Gopalakrishnan and Banerji (2013) indicate that obsolescence, non-moving and slow-moving spare parts are often problematic within industry. Gopalakrishnan and Banerji (2013) claim that up to one-third of spare parts inventory is non-moving in nature which may result in obsolescent stock. The challenge is to reduce, if not eliminate, the incidence of obsolescence. Gopalakrishnan and Banerji (2013) also describe various causes of obsolescence. A participant in the study reported that, in one of the previous years, his company performed a redundancy exercise and wrote off five million rand of redundant stock which employees had requested, but never used (this statement is available in Appendix C). Section 2.2 mentions that areas of waste related to spare parts in the inventory and purchasing function include: (i) excess stock of spare parts, (ii) expediting spare parts delivery, (iii) shelf life expiry, (iv) single line item purchase orders, and (v) loss or lack of record of spare parts. Furthermore, as highlighted in Section 2.2.4, it is typically difficult to forecast the demand for spare parts. However, forecasting issues related to spare parts are not within the scope of this study. Gopalakrishnan and Banerji (2013) highlight the following problems experienced by the servicing department of Original Equipment Manufacturers (OEMs):

- working capital invested in slow-moving spare parts;
- bottlenecks in transportation;
- communication issues;

- large variety of spare parts and their sizes which leads to problems regarding the identification and availability of correct spare parts at the right time;
- difficulties performing cost-benefit analyses;
- centralised service points versus decentralised service points; and
- long lead times.

A major concern regarding spare parts is the maintenance of these parts while in storage. Two employees (each from a different company participating in the validation of this thesis) raised the specific concern of motors and gearboxes not being "turned over" and lubricated appropriately between receiving and shipping of these parts. By not performing this basic lubrication process, the motor or gearbox will experience greater friction during eventual operation. This hastens the failure or need for replacement of the motor due to wear.

Additionally, the author has witnessed and been advised by managers at mining organisations that spare parts are often collected from storerooms and received in certain areas on-site, after which new ones are collected despite the available ones being at these "squirrel" stores. As explained in Section 1.1 of Chapter 1, squirrel stores are unofficial storage locations of spare parts used by users in engineering, maintenance and plant operations at their specific sites of work (Du Toit and Houston, 2013). These parts are hoarded for potential future use, which results in the issue and reorder of spare parts that are not required. Du Toit and Houston (2013) provide the following reasons for the existence of squirrel stores:

- *Lack of trust:* the lack of reliable and consistent performance of the supply chain to deliver the correct parts at the correct time results in a lack of trust. The focus of SPM on minimum working capital may lead to instances where required parts are not in store. Additionally, lead times of critical spare parts are relatively long. This results in engineering teams and maintenance staff being blamed for the downtimes. Therefore, users may decide to store spare parts, especially those with long lead times and that are critical. Lack of trust is usually the primary cause of squirrel stores;
- *Ineffective supply chain practices:* demand patterns for spare parts are usually irregular and historical data is not always a good indication of future trends. Organisations often use systems that apply general inventory planning rather than logic more applicable to the slower-moving spare parts. Furthermore, the classification of spare parts and data in the ERP system are not always updated to reflect effective replenishment of parts;

- *Policy and control:* management often denies or ignores the existence of squirrel stores. This results in policies and controls not being implemented to prevent or limit this practice. Furthermore, few companies actually have policies governing the storage of spare parts not in use and do not insist on the return of unused spare parts to the stores;

- *Risk of increased obsolescence and theft:* inventory is considered obsolete if it has diminished significantly in value or is at the end of its life. Companies typically discard or sell this obsolete inventory to avoid high levels of redundant inventory and to increase space for new stock. The lack of formal stock recording related to squirrel stores increases the difficulty to identify this obsolete stock. The lack of record-keeping also increases risk of theft;

- *Risk of increased downtime:* one may believe that by having a squirrel store, downtime is reduced. However, the lack of visibility associated with squirrel stores typically results in teams searching for spare parts and, sometimes, ordering new parts after failed attempts to find the necessary parts. This results in increased downtimes;

- *Working capital:* spare parts stored in squirrel stores contribute to working capital. However, these parts deplete business asset efficiency and liquidity measures by increasing the asset base without contributing significant value (particularly if spare parts in squirrel stores become obsolete);

- *Impeded planning cycles:* spare parts stored in squirrel stores skew the demand patterns on parts usage since the parts are not actually used when issued, but they are registered officially as being in use. This results in higher demand variability and affects forecast accuracy;

- *Demand variability:* higher demand variability results in the Reorder Point (ROP) and safety stock levels being adversely impacted (eventually increasing to account for the variability);

- *Increased uninsured stock on hand:* a lack of visibility of stock results in insurance not being applicable to that stock;

- *Increased costs and spending:* spare parts stored in squirrel stores cost the company in terms of cash being spent on new stock to replace the squirrel store parts. This cash could have been spent elsewhere within the organisation; and

- *Limitations on cross-use:* with multiple squirrel stores on-site and a lack of visibility of parts within these stores, as well as a lack of communication between teams that use different squirrel stores, there is a limitation regarding teams sharing parts.

Du Toit and Houston (2013) argue that it is vital to know what inventory is owned at any given time before inventory levels can be reduced. This includes knowledge of the location and quantity of all spare parts. Therefore, the organisation may wish to implement traceability technology (discussed in Chapter 3).

2.2.5.5 Role of Information Systems

According to Blomqvist (2010), warehouse execution systems can be categorised into two groups, namely the Warehouse Management Systems (WMS) and the Warehouse Control Systems (WCS). A WMS aims to manage the movement and storage of materials within a warehouse. A WMS directs and shares information for picking, replenishment and storage operations. A WMS may be a standalone application, but the majority of modern Enterprise Resource Planning (ERP) systems have modules providing such functionalities.

Faber, De Koster and Van de Velde (2002) differentiate three kinds of WMS:

- *Basic WMS:* supports stock and location control only. The primary purpose is to register information. The system may generate storage and picking instructions and display these on RF-terminals. The focus is on throughput analysis.
- *Advanced WMS:* offers the same basic WMS functionality, but is also able to plan resources and activities to manage the flow of goods. The focus is on throughput, stock and capacity analysis.
- *Complex WMS:* optimises a warehouse or group of warehouses. This system provides information regarding the locations of products (tracking and tracing) and the planning, execution and control of product logistics. This system handles transportation, dock doors and value-added logistics planning.

A WCS retrieves information from an upper-level host system, such as the WMS, and translates this information to be used in daily operations. Blomqvist (2010) states that a WCS aims to ensure that employees do not have to retype information as it already exists in one system or is collected automatically.

2.3 Business Process Redesign/Reengineering

Kettinger and Grover (1995) define a business process as “a set of logically related tasks that use the resources of an organization to achieve a defined business outcome”. Similarly, Greasley (2005, p. 161) defines it as “a set of activities designed to produce a desired output from a specified input”. Scheer and Nüttgens (2000) describe a business process as a procedure relevant for adding value to an organisation. Business Process Improvement (BPI), Business Process Management (BPM), Business Process Redesign (BPRD) and Business Process Reengineering (BPRE) are four concepts focused on improving or attempting to optimise these processes. BPI, BPM, BPRD and BPRE are often used interchangeably in practice. In particular, BPRD and BPRE are usually labelled merely as *BPR* (for Business Process Redesign or Reengineering). However, distinctions among these terms, in an academic sense, are required before one can apply one of these concepts or techniques to industrial applications.

Greasley (2005, p. 161) asserts that BPI and BPM are the same concept and defines BPM to be the "analysis and improvement of business processes". Similarly, Verity (2005, p. 3) describes BPM as the

> *"design, execution and optimization of automated processes – everything from line-of-business processes such as work orders, customer interactions, payroll processing, order processing, and regulatory compliance initiatives to core mission-critical processes such as payment remittance, billing, product development and logistics".*

Greasley (2005) reports that BPM is concerned with the linking corporate strategy and business processes, providing the measurement of process performance at a strategic level, the design and management of processes, and the implementation of process change (both manually by employees and by the use of Information Technology (IT) systems). Applicable to SPM, Verity (2005) also mentions that BPM can:

- connect people with information and processes regardless of location;
- reduce time-to-compliance and audit costs by providing transparency and tracking for all organisational processes; and
- result in corporate efficiencies by automating internal processes.

Grové (2007) states, regarding the implementation of BPM, that the requirements to be successful include the solution being powerful enough to accommodate complex processes, yet sufficiently flexible to handle continuous change. It also needs to be easy and simple enough to appeal to users as well as being implemented on time and within budget. Therefore, careful consideration needs to be given to both the solution being implemented and the mechanisms through which it is implemented.

BPRD is defined by Davenport and Short (2003, p. 98) as the

> *"analysis and design of work flows and processes within and between organizations".*

Hammer and Champy (1995, p. 32) define BPRE as the

> *"fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed".*

Mansar and Reijers (2007) assume BPRE to have a much broader scope than BPRD. They believe BPRD to focus on streamlining a specific business process in terms of its interdependent tasks and resources while BPRE concerns all aspects of restructuring an organisation's processes (from change management to project management). Based on this distinction, BPRE (which includes drastic change programmes) encompasses BPRD.

Evans, Towill and Naim (1995) report that there are only a few distinguishing features between BPI and BPRE (and BPRD) when they are analysed carefully. Figure 2.13 illustrates the primary differences between BPI, BPRD and BPRE. As can be seen from Figure 2.13, BPRE has the most dramatic expectations of results, greatest costs and time durations required, greatest amount of executive involvement, most radical degree of change, highest degree of risk and the greatest need for IT support. BPI, however, has the least of these characteristics while BPRD tends to lie between BPI and BPRE.

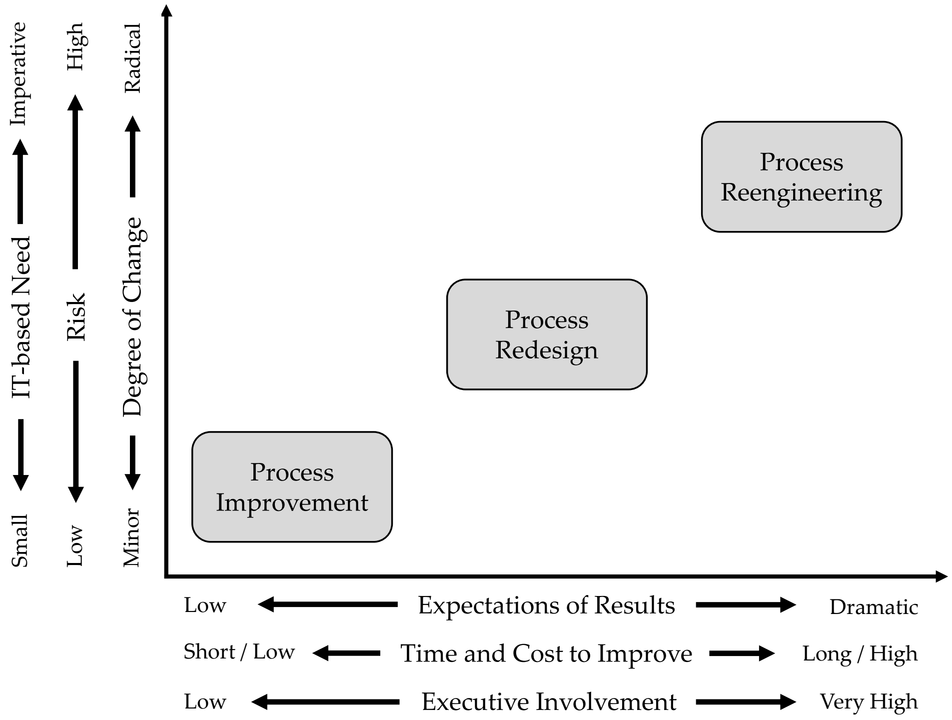


Figure 2.13: Differences between BPI, BPRD and BPRE

Adapted from Hanafizadeh, Moosakhani and Bakhshi (2009)

Ramirez *et al.* (2010) state that BPRD is an approach focused on business processes and their efficiency in order to improve organisational performance. Reijers and Mansar (2005) consider BPRD as an initiative which consists of two challenges in addition to the challenge of managing a BPRD project, namely:

1. a technical challenge owing to the difficulty of developing a solution, which is a significant improvement of the current design; and
2. a socio-cultural challenge originating from the organisational impact on the people involved who may react against any changes.

Motwani, Kumar, Jiang and Youssef (1998) report that BPRD has developed slightly to include conceptual models for assessing and executing BPRD. However, Valiris and Glykas (1999) recognise that "there is a lack of a systematic approach that can lead a process redesigner through a series of steps for the achievement of process redesign". Additionally, Reijers and Mansar (2005) suggest that prescriptive literature on BPRD, despite being advertised as a complete and concise procedure for business transformation, is actually lacking technical direction concerning the design or redesign of processes. This argument is supported by Gerrits (1994) and Sharp and McDermott (2001) with their statements of a missing link between the "*situation before*" and the "*situation after*" which actually describes the redesign process.

One relatively well-known framework that can be used for BPRD is the *Work-Centred Analysis (WCA)* framework proposed by Alter (1996). The WCA framework, depicted in Figure 2.14, comprises six elements: the internal and external *customers* of the business process, the *products (or services)* generated by the process, the actual *business process* procedure, the *participants* in the process, the *information* used or created by the process and the *technology* enabling the process.

As cited by Reijers and Mansar (2005), Brand and Van der Kolk (1995) identify four primary dimensions concerning redesign measures, namely *time, cost, quality* and *flexibility*. These four measures form a quadrangle known as the *Devil's Quadrangle*, shown in Figure 2.15, which illustrates how a redesign of a process may shorten the time the process consumes, reduce the costs involved, increase quality of the process and enhance the ability of the process to handle variation. Generally, there is a trade-off among the dimensions. For instance, a redesign of process which reduces the time consumed by the process often results in an increase in cost of the process. It is also important to realise that implementing several business process best practices or principles (discussed in Section 2.3.4) in combination may negate the desired effects of each business process practice in isolation.

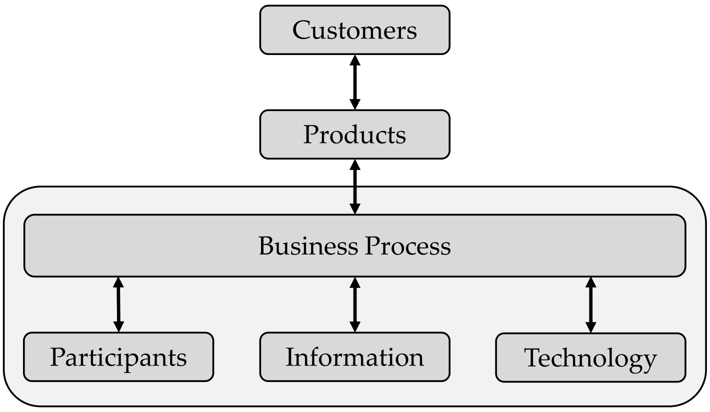


Figure 2.14: The WCA framework
Adapted from Alter (1996)

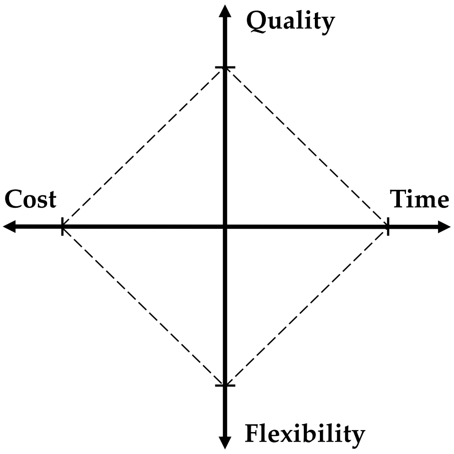


Figure 2.15: Evaluation measures for BPRD forming Devil's Quadrangle
Adapted from Reijers and Mansar (2005)

In this study, the focus for improvement of processes is on BPRD as it is narrower in scope and more practical in terms of SPM process redesign. The overall approach of the framework (discussed in Chapter 4), however, concerns BPRE. Therefore, in this study, the term *BPR* refers to BPRE (which encompasses BPRD) unless otherwise stated.

2.3.1 BPR Foundation Principles

O'Neill and Sohal (1999) mention three concepts that senior management needs to understand (in order to be successful) before implementing reengineering projects, namely:

- the change to focus on processes (as opposed to departments or areas) emphasises external objectives;
- coordinating the activities of a complex horizontal process will necessitate the creation of new boundaries and new horizontal connections which results in a culture change; and
- unmodified information that is readily available to all team members (to aid in learning process).

Similarly, Hammer (1990) establishes the following seven key principles of BPR:

1. *organise around outcomes instead of tasks*: this implies that each job should be designed around an outcome of the process rather than a single task (such that one person handles all the steps in a single process);
2. *have those who use the output of the process perform the process*: both capacity planning and overhead costs associated with managing processes can be reduced when people closest to the process perform the process;
3. *incorporate information-processing work into the actual work that generates the information*: this involves departments (that generate data) handling their own information-processing rather than having other dedicated departments process the information;
4. *consider geographically dispersed resources as though they were centralised*: decentralising a resource results in improved service to those who use it, but the drawback is redundancy, bureaucracy and missed economies of scale (databases, telecommunication networks and standardised processes allow for treating resources as centralised without sacrificing flexibility or service);
5. *link parallel activities instead of integrating their results*: this principle focuses on linking and coordinating parallel functions while their activities are in process rather than after they have completed (in order to prevent integration issues);
6. *place the decision point where the work is performed and integrate control into the process*: this principle empowers the people who perform the work by allowing them to make decisions with controls integrated into the process, such that the management hierarchy is flattened; and
7. *capture information at the source and only once*: this principle removes redundancy and potential for inconsistent entries since information can be stored in relational databases and accessed online.

Section 2.3.2 provides the primary steps for BPR whereas Section 2.3.4 discusses the best practices for BPRD based on these BPR foundation principles. However, criteria are required to identify which processes are most in need of BPRD. Section 2.3.3 provides the necessary criteria.

2.3.2 Primary Steps for BPR

Various authors propose different steps for BPR initiatives. However, some authors believe that a BPR initiative should not follow a prescriptive set of steps, but rather a general structured guideline (Hammer, 1990; Harrington, 1991; Belmonte and Murray, 1993). Davenport (2013) provides the following five high-level steps that are applicable to both BPRD and BPRE:

1. *identify processes for innovation:* processes that are critical or that can contribute significant value to the organisation should be selected. This potentially provides a large increase in performance relative to the amount of effort required. Additionally, the scope and the number of process redesign projects must be reasonable, considering the ability and experience of the organisation to execute these projects;

2. *identify change levers:* the three primary enablers or levers of change are information, IT and organisational or human resources;

3. *develop process visions:* process innovation needs to align with organisational strategy. A process vision comprises of measurable objectives and provides the link between strategy and action. Key activities include evaluating the existing organisational strategy for process direction, consulting with process customers, benchmarking process performance targets and defining process performance objectives;

4. *understand existing processes:* this is essential to develop a common understanding of the existing processes, to understand complexities, to avoid duplicating current problems and to provide a benchmark of performance for evaluation of improvements; and

5. *design and prototype the new processes:* this requires a team of relevant people that have different skills and backgrounds. Key activities include the brainstorming of design activities, the feasibility analysis of ideas, the prototyping of the design, the development of a migration strategy and the implementation of the new structure and systems.

These steps are described in more detail by Davenport (2013) in his book, *Process Innovation: Reengineering Work through Information Technology.* Similarly, Changchien and Shen (2002) describe a BPR framework based on object-oriented simulation that follows the following steps which are repeated cyclically:

1. *define vision and objectives:* review the current state of the organisation (such as the organisational structure and environment) and develop a broad strategic vision;
2. *identify core processes:* a core process analysis matrix can facilitate the identification of critical processes (Changchien and Shen, 2002);
3. *analyse current processes:* understanding the existing processes is essential in order to redesign them appropriately;
4. *perform innovative reengineering:* the processes are reengineered or redesigned;
5. *evaluate new processes:* the new processes are assessed to determine potential performance improvement;
6. *select new processes:* a Multi-criteria Decision-Making (MCDM) method can be employed to select the new processes to implement; and
7. *transform and implement:* new processes are implemented with visible engagement by management and they are benchmarked against original processes.

Hale and Cragg (1996) report that the literature on BPR suggests the following steps:

1. utilise a methodology;
2. define a business vision;
3. define process objectives;
4. identify processes that affect a large proportion of the business;
5. document and measure processes being redesigned prior to redesign;
6. consider IT as a lever for new processes;
7. actively involve managers and employees;
8. recognise and support employees; and
9. evaluate processes after implementation.

Davenport (2013) states that the selection of processes for innovation should be performed early in the BPR initiative in order to focus effort and resources. The criteria for selecting processes for BPRD are provided in the subsequent section.

2.3.3 Criteria for Selecting Processes for BPRD

In a typical organisation, there are too many existing processes to successfully implement a BPR initiative that focuses on all processes equally and that is not excessive in cost. Talluri (2000) provides a benchmarking method for BPRD and BPI that can aid in identifying potential targets for improvement. Additionally, criteria are required to identify processes that require BPRD the most. Lampathaki, Koussouris and Psarras (2013) provide the following criteria for selecting processes to redesign:

- processes that do not function properly;
- processes resulting in bottlenecks and delays;
- processes affecting cross-functional or cross-organisational units;
- core processes that have high impact;
- front-line and customer serving processes (moment of truth);
- value-adding processes;
- new processes and service opportunities; and
- feasibility of changing processes.

Similarly, Chand (n.d.) highlights the following considerations to aid selection of processes:

- processes that are problematic;
- processes that are vital to achieving company strategy and objectives;
- processes that are most likely to be successfully redesigned;
- the scope of the BPR initiative and the costs involved;
- the capabilities of the BPR team and the commitment of process owners and sponsors;
- whether continuous improvement can deliver the required improvements; and
- the relevance of the process and modernity of technology.

Once the processes to redesign have been selected, the BPRD best practices discussed in Section 2.3.4 can be applied to these processes.

2.3.4 BPRD Best Practices

Various best practices have been proposed for BPRD and applied in areas such as healthcare, manufacturing, software development and business planning. Reijers and Mansar (2005) state that there is considerable debate in literature on whether one should implement BPRD by using the existing process as an initial reference point or by designing the process from scratch. However, they claim that the most common approach in practice for developing a new business process is to use the existing process as an initial reference point.

Reijers and Mansar (2005) further identify best practices from various literature sources and industry experience which align toward the framework which they adopted for BPRD. They believe that the best practices are applicable within the context of any business process irrespective of the product or service. The best practices have been categorised under *Customer-Oriented Best Practices, Business Process Operation Best Practices, Business Process Behaviour Best Practices, Organisation-Focused Best Practices, Information-Oriented Best Practices, Technology-Aligned Best Practices* and *External Environment Best Practices*. These best practices are discussed in Sections 2.3.4.1 to 2.3.4.7. Table 2.7 displays the effect that these best practices have on the four primary dimensions concerning redesign measures, namely *cost, time, quality* and *flexibility*. It is important to recognise that a reduction (or increase) in a dimension is not necessarily undesirable (or desirable), depending on the measure. For instance, a reduction in cost or time has a *positive* effect on the cost or time measure since reduced cost or time to complete the process is favourable. A reduction in quality or flexibility results in a *negative* effect.

Furthermore, Campos and De Almeida (2015) discuss the various MCDM models that have been developed for BPR and, specifically, in order to rank BPR best practices for efficient design. Many of these models use the AHP which is discussed in Section 2.4.

2.3.4.1 Customer-Oriented Best Practices

Customer-oriented best practices involve improving contact with customers. The term "*customers*" in this sense is not limited to typical end-users, but may include the next phases receiving the product from the process.

Control relocation: controls may be moved towards the customer. By allowing customers to have more control over the process, customer satisfaction may improve and the number of errors in the process may decline. The risk, however, is that there will be a higher probability of fraud or self-interest. This best practice is mentioned by Klein (1995).

Table 2.7: Effect* of BPRD best practices on redesign measures

Framework Category	**Best Practice**	**Cost**	**Time**	**Quality**	**Flexibility**
Customer	Control relocation	−	#	+	#
	Contact reduction	−	+	+	#
	Integration	+	+	#	−
Process operation	Order types	+	+	−	−
	Task elimination	+	+	−	#
	Order-based work	−	+	#	#
	Triage	+	+	+	−
	Task composition	+	+	+	−
Process behaviour	Resequencing	+	+	#	#
	Knock-out	+	−	#	#
	Parallelism	−	+	−	−
	Exception	#	+	+	−
Organisation structure	Order assignment	#	+	+	−
	Flexible assignment	#	+	+	#
	Centralisation	−	+	#	+
	Split responsibilities	#	−	+	−
	Customer teams	#	+	+	−
	Numerical involvement	−	+	+	#
	Case manager	−	#	+	#
Organisation population	Extra resources	−	+	#	+
	Specialist-generalist (more specialists)	#	+	+	−
	Empower	+	+	−	#
Information	Control addition	+	−	+	#
	Buffering	−	+	#	#
Technology	Task automation	−	+	+	−
	Integral technology	−	+	+	#
External environment	Trusted party	+	+	−	−
	Outsourcing	+	+	−	−
	Interfacing	+	+	+	#

*Note: +, positive effect; #, neutral effect; −, negative effect
Adapted from Reijers and Mansar (2005) and Hanafizadeh et al. *(2009)*

Contact reduction: the number of contacts with customers and third parties should be reduced. Exchange of information with third parties is typically a time-consuming and tedious process. By reducing the number of contact points, both throughput time and the quality of the process may improve (owing to fewer errors). The drawbacks may include handling of too much data as a result of combining contacts (which increases costs as well) and quality loss through loss of essential information. Hammer and Champy (1995) describe this best practice.

Integration: business processes may be integrated with a business process of a customer or supplier. Integrated business processes should ideally result in a more cost- and time-efficient execution of processes. The disadvantage is that mutual dependence increases and flexibility decreases. Klein (1995) and Peppard and Rowland (1995) discuss this best practice.

2.3.4.2 Business Process Operation Best Practices

Business process operation best practices focus on how to implement the workflow.

Order types: tasks should be assessed whether they relate to the same type of order and if they do, new business processes should be identified. By identifying these “subflows” and considering them as different business processes, higher efficiencies, lower costs and faster processing times may be achieved. However, there may be issues regarding the quality of the business process and the possibilities for rearranging the entire business process (lack of flexibility). As cited by Reijers and Mansar (2005), Hammer and Champy (1995), Rupp and Russell (1994), Peppard and Rowland (1995) and Berg and Pottjewijd (1997) describe this best practice in various forms.

Task elimination: unnecessary tasks should be eliminated from a business process. A task is considered unnecessary when it adds no value from a customer’s point of view. Control tasks in a business process often add little or no value since they are incorporated in the system to solve problems deriving from previous steps. These tasks are identified by their iterative nature. Redundant tasks are also considered unnecessary in most circumstances. Applying this best practice increases processing speed and reduces the cost of handling orders. The quality of the process may be adversely affected by this best practice though. This best practice is explained by Peppard and Rowland (1995), Berg and Pottjewijd (1997) and Van der Aalst and Van Hee (2004). It is also displayed by Buzacott (1996) through his demonstration of the quantitative effects of eliminating iterations.

Order-based work: periodic activities or those that involve batch-processing should be removed from business processes when possible. Handling of individual orders may be faster when periodic activities (such as processing only occurring occasionally due to computer systems being occupied) or batch-processing activities are eliminated. However, costs incurred from ensuring available resources to prevent periodic activities should be taken into account. Additionally, efficiencies of scale can be reached by batch-processing so this needs to be weighed against the downsides. Reijers and Mansar (2005) derived this best practice from personal experience.

Triage: some general tasks should be divided into two or more alternative tasks. Additionally, two or more alternative tasks that can merge into one general task should be integrated. Through this best practice, it is possible to design tasks that are better aligned with the capabilities of resources. The characteristics of the orders being processed are also taken into account. Klein (1995), Berg and Pottjewijd (1997) and Van der Aalst and Van Hee (2004) highlight the *Triage* best practice while Dewan, Seidmann and Walter (1998) investigated the impact of this best practice on cycle-time within an organisation.

Task composition: small tasks should be combined into composite tasks as far as possible. Conversely, larger tasks should be divided into smaller, but manageable tasks. By combining tasks, a reduction in setup times is possible. Quality of the process may also improve. However, larger tasks result in less flexibility and quality decreases as these tasks become less manageable. This best practice is one of the most cited BPRD best practices in literature being mentioned by Hammer and Champy (1995), Rupp and Russell (1994), Peppard and Rowland (1995), Berg and Pottjewijd (1997), Seidmann and Sundararajan (1997), Reijers and Goverde (1998), Van der Aalst (2001) and Van der Aalst and Van Hee (2004). Furthermore, quantitative support is provided by Seidmann and Sundararajan (1997), Van der Aalst (2001) and Burkett *et al.* (2002) regarding the optimality for simple models.

2.3.4.3 Business Process Behaviour Best Practices

Business process behaviour best practices focus on when to execute workflow.

Resequencing: tasks should be rearranged in the most appropriate sequence. It is often better to postpone a task not required to be completed before the following tasks as its execution may become unnecessary. Tasks can also be scheduled closer to similar tasks, thus reducing setup times and costs. This best practice is also referred to as *process order optimisation* and has been described by Klein (1995).

Knock-out ordering: knock-outs should be ordered in an increasing order of effort and a decreasing order of termination probability. In layman's terms, the knock-out that requires the least effort (and greatest termination likelihood) is performed first when possible. A *knock-out* is a check of condition that must be satisfied otherwise the corresponding part of the business process may be terminated. Ideally, all knock-outs will be arranged from the most favourable ratio to the least favourable ratio of expected knock-out probability versus expected effort. This arrangement typically results in the least expensive business process execution. Van der Aalst (2001) investigated this best practice.

Parallelism: tasks may be most appropriately executed in parallel. The most evident result of this best practice is a reduction of throughput time. According to Reijers and Mansar (2005), tasks they encountered while analysing existing business processes in practice were mostly ordered sequentially despite the lack of logical restrictions prescribing such an order. The drawbacks to parallelism include an increase in the cost of business process execution and increased complexity with coordination of concurrent tasks (which may further lead to errors and lack of flexibility concerning runtime adaptations). Rupp and Russell (1994), Buzacott (1996), Berg and Pottjewijd (1997) and Van der Aalst and Van Hee (2004) discuss this best practice while Van der Aalst (2001) supplies quantitative support.

Exception: business processes should be designed such that exceptional orders are isolated from normal flow. Exceptions cause disturbances in the process by requiring employees to understand the exception and the reason for it even if they are not able to handle it. This results in longer setup times or failure to handle the orders. Exceptions should rather be isolated by using methods such as triage, thus not disturbing the normal flow. Overall performance of business processes may increase as the efficiency of handling normal orders increases and the employees handling the isolated exceptions develop expertise regarding the exceptions. The downside, however, is that more complex processes exist which may decrease flexibility. The *Exception* best practice is mentioned by Hammer and Champy (1995) and Poyssick and Hannaford (1996).

2.3.4.4 Organisation-Focused Best Practices

Organisation-focused best practices involve both the structure of the organisation and the population of the organisation. Structure refers to the allocation of resources while population refers to the types and numbers of resources involved. The following seven best practices relate to the *structure* of the organisation:

Order assignment: each worker should perform as many steps as possible for the same single orders. For task execution, this best practice selects a resource (from available resources capable of performing the specific task) that has already handled the order in the past if possible. People involved in task execution become acquainted with specific orders and require less setup time. Furthermore, the quality of the process may improve. The adverse effects include lack of flexibility of resource allocation and substantial queue time when resources assigned to the task are not available. Hammer and Champy (1995), Rupp and Russell (1994), Reijers and Goverde (1998) and Van der Aalst and Van Hee (2004) describe this best practice.

Flexible assignment: resources should be assigned such that maximal flexibility is preserved for the near future. In the case where two resources are available to execute a task, the more specialised resource should perform the task as this increases the possibilities for another task to be completed (by the general resource). The benefits of this best practice include reduction in overall queue time and increase in overall quality as employees with the highest specialisation can be expected to handle most of the work. Disadvantages include the potential for less job satisfaction as a result of unbalanced work load. Van der Aalst and Van Hee (2004) highlight this best practice.

Centralisation: geographically dispersed resources should be treated as if they are centralised. This best practices focuses on the benefits of a Workflow Management System (WfMS) since the location of resources is less relevant when a WfMS assigns tasks (Jablonski and Bussler, 1996). An advantage of this best practice is the increased flexibility of assigning resources tasks which results in greater utilisation and possible reduced throughput time. Disadvantages include the new technology resulting in additional expenses (both financial and non-financial), as well as the new technology potentially arousing fear among employees. Van der Aalst and Van Hee (2004) refer to the *Centralisation* best practice.

Split responsibilities: allocation of task responsibilities to *different* functional units should be avoided as far as possible. The belief is that when different departments share responsibility of tasks, the result is often conflict or neglect of tasks. Reduction in overlapping responsibilities should increase quality of processes and allow for higher responsiveness to tasks. However, the reduction in the effective number of employees available for tasks may increase queue time. This best practice is referred to by Rupp and Russell (1994) and Berg and Pottjewijd (1997).

Customer teams: teams should consist of different departmental employees to allow for the entire handling of specific types of orders. This best practice is a variation of the *Order assignment* best practice and shares the same advantages and disadvantages. Hammer and Champy (1995), Peppard and Rowland (1995) and Berg and Pottjewijd (1997) describe this best practice.

Numerical involvement: the number of departments, groups and employees involved in a business process should be minimised. This eases coordination of tasks which eventually allows for more processing time. Additionally, this best practice may reduce the division of responsibilities among departments, which results in the advantages and disadvantages highlighted in the *Split Responsibilities* best practice previously described. Reijers and Mansar (2005) state that the smaller number of specialised units may affect build expertise and ability for routine, resulting in lower quality and higher cost respectively. Hammer and Champy (1995), Rupp and Russell (1994) and Berg and Pottjewijd (1997) mention this best practice.

Case manager: one person should be appointed as the specific case manager responsible for the handling of each type of order. This best practice does not imply that the case manager is the resource or only resource that will handle the specific order. Rather, the case manager is responsible for the management of the process. This best practice allows for a single point of contact regarding orders and increases transparency. This results in customer satisfaction and improved process quality. The downside is the requirement for increased capacity and, therefore, higher costs. Hammer and Champy (1995) and Van der Aalst and Van Hee (2004) describe this best practice. Buzacott (1996) offers quantitative support regarding a specific interpretation of the *Case Manager* best practice.

The following three best practices relate to the *population* of the organisation:

Extra resources: the number of resources should be increased if the current capacity is not sufficient. This best practice reduces queue time and increases flexibility by having more resources to handle orders, but the result is an increase in costs. This best practice contrasts the *Numerical Involvement* best practice. Berg and Pottjewijd (1997) consider this best practice while Van Hee, Reijers, Verbeek and Zerguini (2001) discuss the optimal allocation of additional resources in business processes.

Specialist-generalist: resources should be developed into more specialist or more generalist resources depending on requirements. A specialist can be converted into a generalist through training in other areas of expertise. A generalist can be converted into a specialist by being assigned to work of the same nature for long durations such that his other qualifications become less relevant. The required ratio of specialists to generalists depends on the specific scenario. A specialist can develop routine quicker and generally has more profound knowledge than a generalist. This leads to higher quality and faster execution of processes. Alternatively, having more generalists increases flexibility and can result in better utilization of resources. Poyssick and Hannaford (1996) and Berg and Pottjewijd (1997) emphasise the advantages of generalists. Rupp and Russell (1994) and Seidmann and Sundararajan (1997), however, describe both generalists and specialists.

Empower: middle management should be reduced by assigning most of the decision-making authority to the employees. Reduction of middle management decreases labour costs expensed on processing orders. Additionally, lower throughput times are possible (largely owing to less delay time for authorisation) when employees are empowered to execute decisions independently. However, the quality of decision-making may be lower and errors more likely to occur. This may then lead to greater costs relating to rework if decisions are not adequate. This best practice is referred to by Hammer and Champy (1995), Rupp and Russell (1994), Poyssick and Hannaford (1996) and Seidmann and Sundararajan (1997). Buzacott (1996) illustrates performance improvements using this best practice through use of a simple quantitative model.

2.3.4.5 Information-Oriented Best Practices

Information-oriented best practices concern the manner in which the organisation creates, uses and manages its information.

Control addition: the completeness and accuracy of information relating to incoming materials, as well as the output before being sent to the customers, should be checked. Having better control measures in place results in higher quality of the business process and less rework. The additional control measure will require time and other resources though. Hammer and Champy (1995), Poyssick and Hannaford (1996) and Buzacott (1996) mention this best practice.

Buffering: information should be buffered through an update subscription rather than requested from external sources. The process of obtaining information can be tedious and time-consuming. By having information readily available through a form of caching, the process can be less time-consuming. However, the subscription fee to receive information updates as well as the cost of storing a copy of large amounts of data may be excessive. Reijers and Mansar (2005) derived this best practice from personal experience.

2.3.4.6 Technology-Aligned Best Practices

Technology-aligned best practices describe the technology an organisation uses. Nevertheless, it is important to understand that BPRD is not an IT initiative, but a business initiative with the objective of reassessing and reconstructing business practices to satisfy the needs of customers and other stakeholders (Davenport and Stoddard, 1994).

Task automation: the automation of tasks decreases the time required for the execution of tasks. However, it reduces the flexibility of handling tasks since systems are usually less capable of processing variations than humans. Automation also involves a high capital cost to develop the system. E-commerce, defined as the application of technology towards the automation of business transactions and workflows, forms one of the best examples of the application of this best practice. Hammer and Champy (1995), Peppard and Rowland (1995) and Berg and Pottjewijd (1997) describe this best practice as a redesign measure.

Integral technology: implementing new technology can relieve physical constraints in a business process. Reijers and Mansar (2005) describe how a Workflow Management System (WfMS) can reduce time required to execute logistical tasks while a Document Management System can result in a better quality service by making information on orders available to all employees. Nevertheless, implementation of new technology is typically met with resistance to change and this may reduce the quality of business process. Klein (1995), Peppard and Rowland (1995), Berg and Pottjewijd (1997) and Van der Aalst and Van Hee (2004) mention this best practice in one form or other.

2.3.4.7 External Environment Best Practices

External environment best practices attempt to improve collaboration and communication with third parties.

Trusted party: results from a trustworthy third party should be used instead of determining information oneself. This best practice reduces costs and throughput time, but it relies heavily on the trustworthiness of sources. The quality of the business process may decline depending on the quality of the third party's processes. Flexibility also decreases as coordination among third parties is required. Reijers and Mansar (2005) derived this best practice from their own reengineering experience.

Outsourcing: it may be necessary or beneficial to allow other parties to handle or perform a business process in part or its entirety. The third parties may be more efficient in performing the same work and, therefore, able to perform the job at a reduced cost. The possible drawbacks include lower quality and more complex business processes as a result of a greater amount of coordination required. The primary difference between this best practice and the *Trusted Party* best practice is that outsourcing a task results in the task being performed by another party at runtime instead of using historical information. Hammer and Champy (1995), Klein (1995) and Poyssick and Hannaford (1996) discuss the *Outsourcing* best practice.

Interfacing: a standardised interface should be developed for customers and partners. A standardised interface will lower the probability of errors, incomplete entries and unintelligible communication. This best practice may lead to higher quality of processes, faster processing and lower costs (less rework required). Hammer and Champy (1995) and Poyssick and Hannaford (1996) describe this best practice.

2.3.5 The Role of IT in BPRD

Ramirez *et al.* (2010) highlight that BPRD has historically had conflicting evidence regarding the success of its implementation. They state that the success of a BPRD initiative is based upon various factors, including the challenge of implementing Information Technology (IT) to support the process redesign. Additionally, Hammer and Champy (1995) consider IT as a key enabler of BPR. Whitman (1996) states that BPR and IT together have the ability to create "more flexible, team-oriented, coordinative and communication-based work capability".

According to Attaran (2004), IT roles can be categorised into the following three phases relating to BPR: *before* the process is redesigned, *during* the process redesign and *after* the redesign is complete (and during implementation). Table 2.8 displays the various IT roles in their corresponding phases. Attaran (2004) highlights that many organisations ignore IT capabilities until after a process is designed. He argues that an awareness of IT capabilities should influence the process design. Hammer and Champy (1995) propose that companies redefine processes first and then automate them as required. Once the redesign process begins, there are two activities in the *during* phase: technical design and social design.

Table 2.8: Various IT roles within the three phases (before; during; after) of process redesign

Before Redesign	**During Redesign**	**After Redesign**
– Construct infrastructures and manage information that support evolving organisation – Promote process thinking – Identify and select processes for redesign – Assist in predicting change and the information that facilitates change – Train IT staff in non-technical issues such as customer relationships and marketing – Design measures of success or failure of reengineering	– Introduce large amounts of information into the process – Use complex analytical methods to aid the process – Enhance ability of employees to make informed decisions without formal instruction – Identify enablers for process design – Align IT strategy to proposed change – Propagate knowledge and expertise to improve the process – Communicate ongoing results of the initiative – Convert unstructured processes into standard transactions – Reduce or replace labour in a process – Monitor performance of current process – Define performance goals and objectives – Define the scope of the process	– Create a digital feedback loop – Establish resources for critical evaluation of new process – Improve IT processes such that they adequately support reengineered processes – Institute a program of damage control for failures – Communicate ongoing results of the implementation – Support commitment to BPR – Evaluate the potential investment

Adapted from Attaran (2004)

The technical design phase involves consolidation of information, redefining alternatives, reassessing process connections and relocating controls prior to technology implementation. In the social design phase, human aspects are the focus and employees who will affect corporate changes are considered. This includes defining jobs and teams, defining skills and staffing needs and designing incentive programs. Once objectives are determined, the existing processes are mapped, measured, analysed, and benchmarked. The information obtained is then used to develop a new business process. Integration of people, processes and technology begins in this *during* phase.

The final phase is the *after* phase. In this phase, the new process is piloted, results are monitored and extensive retraining of employees undergone. It is important to redefine performance objectives, maintain a strong commitment to the vision, break down barriers between the departments, and be flexible as the business environment changes (Attaran, 2004). Most importantly, IT is only useful if it aids employees in successfully completing their jobs. Attaran (2004) states that the greatest benefit derived from IT is obtained when existing processes are not merely automated, but rather that crucial business processes are improved.

2.3.6 Barriers to Effective Implementation

Attaran (2004) states that BPR is unsuccessful due to implementation issues, particularly when organisations perform BPR initiatives. He finds that this lack of success is not due to the concept itself being flawed. In this regard, he observes that the most common barriers to effective BPR implementation include:

- *Misunderstanding the concept:* it is important to understand that BPR is not focused on downsizing of jobs or people, restructuring organisations (but rather the workflows or processes), or automation of existing processes. Instead, reengineering is a combination of process design, process management and process innovation. It involves re-evaluating existing organisational processes and reconfiguring workflows. Reengineering focuses on redesigning processes around the desired outcomes rather than functions or departments. Attaran (2004) asserts that the vertical organisational structures, the promotion and compensation schemes, as well as the decision-making approaches from the past are no longer valid.

- *Misapplication of the term:* BPR is not a term for change within organisations. It is often seen as something that can be used instead of tools or approaches such as Total Quality Management (TQM). However, without continuous improvement, BPR cannot be successful.

- *Lack of proper strategy:* BPR often fails as a result of efforts not being aligned to organisational objectives. Reengineering initiatives should focus on understanding the existing process before redesign and implementation of a new process. The output objectives should be stated in clear and quantitative terms.

- *Unrealistic objectives:* Attaran (2004) states that past evidence indicates that reengineering "takes longer than expected, always involves more people resources than are available, and always presents problems no one anticipates". These issues result in failure if they are not expected and managed appropriately.

- *Failure of management to change:* according to Sutcliffe (1999), BPR implementation requires both a "top-down, directive leadership style" as well as a non-directive leadership style for the management of motivated, skilled and independent-thinking people performing non-programmable tasks. Reengineering requires changes in management style yet managers are usually reluctant to change their approaches.

- *Failing to recognise the importance of people:* BPR typically affects the way jobs are performed and the skills required. Attaran (2004) highlights that a lack of proper approach to handling the employees involved will result in failure of the implementation. This echoes sentiments stated in Section 2.1.7 which emphasise the importance of recognising concerns and involvement of people during change initiatives.

- *Failure to change Information System:* Attaran (2004) claims that many reengineering initiatives have not commenced since the radical changes would require Information System (IS) redesign. Furthermore, resistance from IS personnel often adversely affects BPR success.

It is important to be aware of the barriers to effective BPR implementation as they need to be avoided or managed adequately for successful initiatives.

2.4 Analytic Hierarchy Process

The AHP is a MCDM approach introduced by Dr Thomas L. Saaty in the 1970s. Other popular MCDM approaches, as highlighted by Velasquez and Hester (2013), include Multi-Attribute Utility Theory, Fuzzy Set Theory, Case-based Reasoning, Data Envelopment Analysis, Simple Multi-Attribute Rating Technique, Goal Programming, ELECTRE, PROMETHEE, Simple Additive Weighting, and TOPSIS. According to Saaty (1990), the AHP originated in response to a lack of readily available, easily understood and easy-to-implement methodologies to enable complex decision-making. Owing to the simplicity and ease of use of the AHP (while still remaining powerful enough to aid quality complex decision-making), the AHP has penetrated a range of domains globally. These domains are primarily business, government, defence and R&D sectors involving decisions dependent on choice, prioritisation and forecasting. Bhushan and Rai (2004) mention that the AHP has been applied to alternative selection and Business Process Reengineering (BPRE) applications.

Bhushan and Rai (2004) state that the AHP provides the structure of a formalised approach derived from mathematical principles to decision-making based on experience, intuition and heuristics. It essentially aids in structuring the complexity, measurement and synthesis of rankings regarding comparisons. Furthermore, Bhushan and Rai (2004) claim that the AHP has proven to be capable of generating results that agree with perceptions and expectations. Wei, Chien and Wang (2005) developed an AHP-based approach to aid with Enterprise Resource Planning (ERP) system selection.

2.4.1 Description of the AHP

Saaty and Vargas (2012) provide a comprehensive overview and explanation of the AHP in *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*. The AHP deconstructs the specific problem into a hierarchy of sub-problems which can more easily be comprehended. A hierarchy is simply a more orderly form of a network. An inverted tree structure (in which the AHP usually results) is an example of a hierarchy with the root at the top and the nodes "branching" out below. Laininen and Hämäläinen (2003) explain that the sub-problems are subjectively evaluated by the comparison of attribute or alternative pairs to determine which option of a pair is deemed more important. As a result, only two alternatives are considered at a time and are compared according to the given criterion. Thereafter, the subjective evaluations are assigned numerical values and these values are used to rank each alternative. The AHP ultimately produces weight values for each alternative based on the perceived importance (subjective evaluation) of one alternative relative to another with respect to a common criterion (Bhushan and Rai, 2004; Fülöp, 2005).

Figure 2.16 illustrates the generic hierarchic structure of the AHP where the objective function of the problem under analysis is at the root of the hierarchy. The leaf nodes are the alternatives to be compared. Bhushan and Rai (2004) highlight that a decision-maker only needs to compare elements in a level with respect to the contribution that these lower-level elements provide towards the upper-level element. This aspect of focussing on only a part of the whole problem at a time is a powerful feature of the AHP.

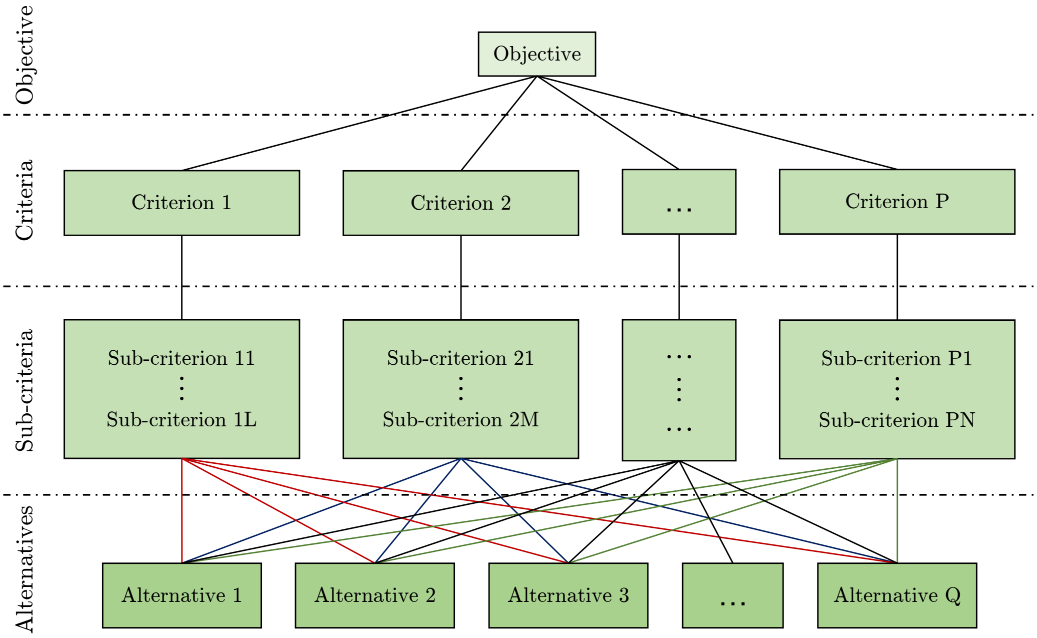


Figure 2.16: Illustration of the AHP hierarchical structure
Adapted from Bhushan and Rai (2004)

2.4.2 Steps of the AHP

As discussed by Bhushan and Rai (2004), the AHP consists of six primary steps. These steps can easily be processed by software specially developed for the AHP or organisations can set up a Microsoft Excel spreadsheet (as was done for this study) that quickly calculates the necessary values. An example in Section 2.4.4 illustrates the process using the following steps:

Step 1: The specific problem is deconstructed through a top-down approach into a hierarchy of objective, criteria, sub-criteria and alternatives. This hierarchical structure is depicted in Figure 2.16. The objective forms the root of the hierarchical structure with the various criteria, sub-criteria and alternatives forming branches from the root. This decomposition phase is considered by Bhushan and Rai (2004) to be the most important and creative part of the decision-making process. A fundamental aspect of the AHP is the structuring of the problem as a hierarchy. A hierarchy depicts relationships among elements in one level with the elements in the level immediately below. These relationships link through the hierarchy to the lowest levels and every element is connected to another one in either a direct or an indirect manner. Regarding the structuring of the hierarchy, Saaty recommends working down from the objective as far as possible and then to work up from the alternatives until the levels of the two processes are linked such that comparisons are possible.

Step 2: Once the hierarchy has been constructed, experts can be asked to evaluate each criterion and alternative in pairwise comparisons (as depicted in Figure 2.17). First the criteria are assessed in pairwise comparisons and, thereafter, alternatives can be compared. According to Burnett (2013), expert decision-makers are required for this evaluation as the alternatives (and criteria) should be well understood. The experts provide data by making pairwise comparisons of alternatives and criteria (as illustrated in Figure 2.17) using a qualitative scale (tabulated in Table 2.9). The scale consists of five primary gradation categories, namely *Equal*, *Marginally Strong*, *Strong*, *Very Strong* and *Extremely Strong*. These categories assess the preference (or impression of the amount of influence) of the one option in the pairwise comparison over the alternative based on the specific criterion being tested. "X" in the column marked *Very Strong* indicates that the expert deems alternative B to have a stronger importance or preference than alternative A in terms of the criterion on which the comparison is made. The comparisons of criteria, as well as comparisons of alternatives made for each criterion (the node before branching to alternatives occurs), are converted into quantitative numbers using Table 2.9.

A								X		B
	Extremely Strong	Very Strong	Strong	Marginally Strong	Equal	Marginally Strong	Strong	Very Strong	Extremely Strong	

Figure 2.17: Qualitative scale format for pairwise evaluations

Adapted from Bhushan and Rai (2004)

Table 2.9: Typical AHP gradation scale

Preference	**Value(s)**	**Description**
Equal	1	The two attributes contribute equally to the criteria
Marginally Strong	3	Experience and judgement slightly in favour of the one attribute over the other
Strong	5	Experience and judgement strongly in favour of one attribute over the other
Very Strong	7	An attribute is strongly favoured and its dominance demonstrated in practice
Extremely Strong	9	The evidence favouring one attribute over another is of the highest possible order of affirmation

Adapted from Bhushan and Rai (2004) and Bevilacqua and Braglia (2000)

Step 3: Data generated from the pairwise comparisons according to the various criteria (performed in *Step 2*) are organised into an $n \times n$ square matrix referred to as the comparison matrix (as shown in Equation 2.4.1). Following a top-down approach, the highest level attributes are evaluated first. These are usually the most important criteria of the problem. Each level of the hierarchy is evaluated as the expert evaluates downwards to the alternatives considered as potential solutions. The diagonal elements of the matrix are each equal to 1. The criterion or alternative in the i^{th} row is better than criterion or alternative in the j^{th} column if the value of element (i, j) is greater than 1. If the value of element (i, j) is less than 1, the criterion or alternative in the j^{th} column is better than the one in the i^{th} row. The (j, i) element of the matrix is merely the reciprocal of the (i, j) element.

$$C = \begin{array}{cc} & \begin{array}{ccc} j_1 & j_2 & j_3 \end{array} \\ & \begin{pmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{pmatrix} \begin{array}{c} i_1 \\ i_2 \\ i_3 \end{array} \end{array} \tag{2.4.1}$$

Step 4: The priority vector (eigenvector) of the comparison matrix is determined. There are various methods of determining the eigenvector, including the *Additive Normalisation Method* (Gnanasekaran, Velappan and Manimaran, 2006; Srdevic, Blagojevic and Srdevic, 2011), the *Eigenvector (or Eigenvalue) Method* (Saaty and Hu, 1998; Gnanasekaran *et al.*, 2006; Srdevic *et al.*, 2011), the *Geometric Mean (or Logarithmic Least Squares) Method* (Crawford, 1987; Saaty and Hu, 1998; Mikhailov and Singh, 1999; Dong, Zhang, Hong and Xu, 2010), the *Direct Least Squares Method* (Srdevic *et al.*, 2011) and the *Weighted Least Squares Method* (Mikhailov and Singh, 1999; Srdevic *et al.*, 2011). Golany and Kress (1993) assert that there is no single prioritisation method that is superior to others in all cases. Therefore, the Eigenvector Method (which is the fundamental method proposed by Saaty) is used in this study.

The comparison matrix is first squared (Burnett, 2013). Then the elements in each row of the squared comparison matrix are added to form the first-iteration eigenvector referred to as the first priority vector. Thereafter, each element in this eigenvector is divided by the sum of the elements in the column (or vector) to obtain the first normalised priority vector. The squared comparison matrix is squared again, the elements in the row added to obtain a second priority vector and each element in the single column (or vector) is divided by the sum of the elements to obtain a second-iteration normalised priority vector. This is iterated until the values in the eigenvector do not vary significantly (usually until four decimal places remain constant) from one iteration to the next. This steady-state eigenvector is also considered to be the priority vector representing the individual priorities of each criterion or alternative. If the hierarchy consists of three criteria and four alternatives, all four alternatives will have a separate priority for each criterion. The elements of the normalised steady-state eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives. Eigenvectors are calculated for both criteria comparisons and alternatives for each criterion.

Step 5: The consistency of the matrix of order n is evaluated to ensure that comparisons are reasonably consistent and, therefore, meaningful. Bhushan and Rai (2004) warn that comparisons made by the AHP are subjective and the AHP tolerates any inconsistency only through the amount of redundancy incorporated into the approach. Burnett (2013) reveals the process of determining consistency through the calculation of the *Consistency Ratio* (CR) in Equation 2.4.2 which includes calculating a *Consistency Index* (CI) according to Equation 2.4.3:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2.4.2}$$

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{2.4.3}$$

where n is the order of the comparison matrix, RI is the *Random Consistency Index* determined from Table 2.10 using n, and $\lambda_{\max}$ is the maximum eigenvalue of the decision matrix. $\lambda_{\max}$ can be calculated according to Equation 2.4.4,

$$\lambda_{\max} = \sum^{n}(\sum^{j} r_{jn})E_n \tag{2.4.4}$$

where n is the order of comparison matrix (matrix size), $\sum^{j} r_{jn}$ is the sum of the j number of elements in column n of the comparison matrix, and E_n is the priority value (from the eigenvector or priority vector) for the n^{th} criterion. A decision-maker is considered to be more consistent as the value of CR decreases (Burnett, 2013). Thus, a Consistency Ratio (CR) of 0 (as a result of $\lambda_{\max} = n$) implies that the decision-maker is 100% consistent. Saaty (1987) states that answers to comparisons may require re-evaluation if the CR value is above 0.1. Escobar, Aguarón and Moreno-Jiménez (2004) discuss group decision-making approaches (involving more than one decision-maker) regarding the AHP and the consistencies of these.

Step 6: The final step requires that the priority vectors for the alternatives (per criterion) to be placed in matrix form with n columns (number of criteria) to form priority matrices. The priority matrices (ratings of alternatives) are

Table 2.10: AHP Random Consistency Index (RI) values

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.48

Adapted from Burnett (2013) and Saaty and Vargas (2012)

then multiplied by the priority vector for criteria (weights of the criteria). This results in the final decision priority values for all alternatives.

2.4.3 Theory behind the AHP

Saaty and Vargas (2012) recognise seven pillars of the AHP to be:

- ratio scales, proportionality and normalised ratio scales;
- reciprocal paired comparisons;
- the sensitivity of the principal right eigenvector;
- clustering and using pivots to extend the scale (from 1–9 to 1–∞);
- synthesis of tangibles and intangibles to create a one-dimensional ratio scale for representing the overall outcome;
- rank preservation and reversal; and
- integrating group judgements.

According to Bhushan and Rai (2004), the AHP is based on the following four axioms provided by Saaty:

1. Axiom 1: The decision-maker can perform paired comparisons, a_{ij}, of two alternatives, i and j, based on a criterion or sub-criterion on a ratio scale that is reciprocal ($a_{ji} = \frac{1}{a_{ij}}$);
2. Axiom 2: The decision-maker never evaluates one alternative to be infinitely better than another alternative based on the specific criterion ($a_{ij} \neq \infty$);
3. Axiom 3: The decision problem can be formulated as a hierarchy; and
4. Axiom 4: All criteria or sub-criteria that have some impact on the given problem, as well as all the relevant alternatives, are considered together in a single hierarchical structure.

Bhushan and Rai (2004) observe that there are essentially three fundamental concepts behind the AHP, namely that the AHP:

- *is analytic*: the mathematical and logical reasoning used by the AHP assists in quantifying decision-makers' intuition and subjective judgements while maintaining the evidence of the thought process;
- *structures the problem as a hierarchy*: hierarchic decomposition of complex problems into sub-problems is typically the natural approach for human decision-makers. Additionally, evidence from psychological studies suggests that human beings can only compare 7±2 items at a time, therefore hierarchic structures are important for complex decision-making; and
- *defines a process for decision-making*: the AHP formalises the process of capturing decision-makers' inputs, mathematically evaluating alternatives and communicating final decisions to others through mathematical and logical reasoning.

The subsequent subsection provides an example of the AHP, following the steps described in Section 2.4.2, that a user may encounter in the proposed framework (in Chapter 4).

2.4.4 AHP Example

A company wishes to implement a traceability technology (barcode technology, RFID technology, GPS technology or a hybrid system) to trace and/or track assets. The company identifies five potential systems (BC1, BC2, RF1, RF2 and RFG) that appear to be appropriate for the specific environment. *BC1* and *BC2* are systems that utilise barcode technology. *RF1* and *RF2* are systems that utilise RFID technology. *RFG* is a RFID-GPS hybrid system. The company wishes to select the most appropriate system for the specific environment considering three important criteria, namely *Cost*, *Usefulness* and *Complexity*. The company uses a panel of experts to judge options based on the *Usefulness* criterion since this is a significantly subjective measure. The company decides to employ the AHP to solve the problem. The AHP structure for this problem is presented in Figure 2.18.

The company first evaluates Cost versus Usefulness and ascertains Cost to have a *Strong* impact (more important) relative to Usefulness on the selection of technology. Similarly, Usefulness is rated as *Marginally Strong* relative to Complexity. Cost, in turn, is evaluated to be *Very Strong* relative to Complexity. Table 2.11 illustrates the pairwise comparison of the criteria.

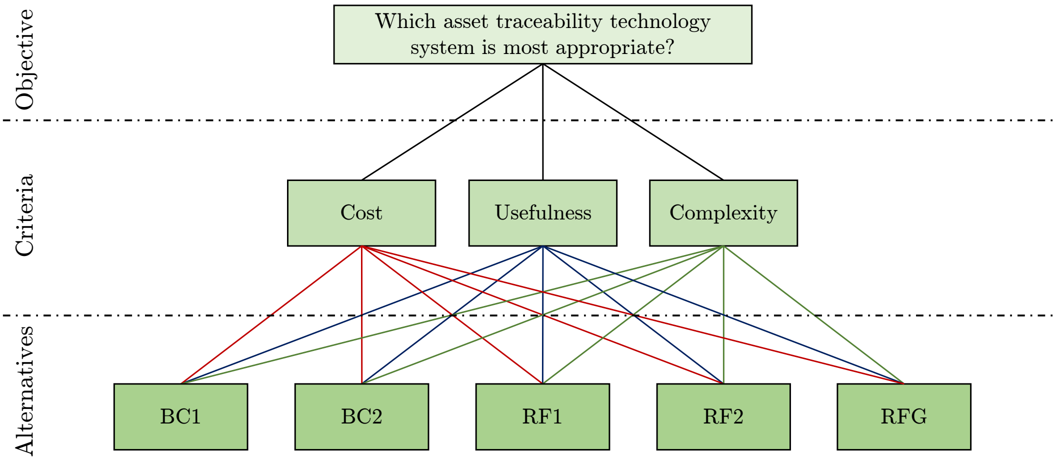


Figure 2.18: AHP example: hierarchical structure

Table 2.11: AHP example: criteria comparison

Criteria	**9** Extremely Strong	**7** Very Strong	**5** Strong	**3** Marginally Strong	**1** Equal	**3** Marginally Strong	**5** Strong	**7** Very Strong	**9** Extremely Strong	**Criteria**
Cost			X							*Usefulness*
Usefulness				X						*Complexity*
Complexity								X		*Cost*

M represents Cost, U represents Usefulness and D represents Complexity. The comparison values (obtained from selections made in Table 2.11) are placed into matrix form (the comparison matrix), as displayed:

$$C = \begin{array}{cc} \begin{array}{ccc} M & U & D \end{array} & \\ \begin{pmatrix} 1 & 5 & 7 \\ \frac{1}{5} & 1 & 3 \\ \frac{1}{7} & \frac{1}{3} & 1 \end{pmatrix} & \begin{array}{c} M \\ U \\ D \end{array} \end{array}$$

where $x_{MU} = 5$, for instance, represents the comparison value obtained for Cost relative to Usefulness.

This is performed for all the alternatives with respect to each criterion. As a result, each alternative will have a priority value for each criterion. As mentioned in Section 2.4.2, there are many methods available to determine eigenvectors, but this study uses the Eigenvector Method. The comparison matrix is first squared and the calculation is performed as follows:

$$C^2 = \begin{pmatrix} 1.000 & 5.000 & 7.000 \\ 0.200 & 1.000 & 3.000 \\ 0.143 & 0.333 & 1.000 \end{pmatrix}^2 = \begin{pmatrix} 3.000 & 12.333 & 29.000 \\ 0.829 & 3.000 & 7.400 \\ 0.353 & 1.381 & 3.000 \end{pmatrix}$$

Then the elements in each row of C^2 are added to form the first-iteration eigenvector referred to as the first priority vector. Thereafter, each element in this eigenvector is divided by the sum of the elements in the column (or vector) to obtain the first normalised priority vector. The first iteration of the process is illustrated below:

$$\begin{pmatrix} 3.000 & + & 12.333 & + & 29.000 \\ 0.829 & + & 3.000 & + & 7.400 \\ 0.353 & + & 1.381 & + & 3.000 \end{pmatrix} \Rightarrow \begin{pmatrix} 44.333 \\ 11.229 \\ 4.734 \end{pmatrix} \Rightarrow \begin{pmatrix} 0.7353 \\ 0.1862 \\ 0.0785 \end{pmatrix}$$

The squared comparison matrix is squared again, the elements in the row added to obtain a second priority vector and each element in the single column (or vector) is divided by the sum of the elements to obtain a second-iteration normalised priority vector. This is iterated until the values in the eigenvector do not vary significantly (usually until four decimal places remain constant) from one iteration to the next. The second iteration is as follows:

$$\begin{pmatrix} 29.461 & + & 114.047 & + & 265.264 \\ 7.586 & + & 29.443 & + & 68.441 \\ 3.263 & + & 12.640 & + & 29.456 \end{pmatrix} \Rightarrow \begin{pmatrix} 408.772 \\ 105.470 \\ 45.359 \end{pmatrix} \Rightarrow \begin{pmatrix} 0.7305 \\ 0.1885 \\ 0.0811 \end{pmatrix}$$

The following steady-state eigenvector is obtained after four iterations:

$$\text{Priority vector (normalised eigenvector)} = \begin{pmatrix} 0.7306 \\ 0.1884 \\ 0.0810 \end{pmatrix}$$

The steady-state eigenvector which is also the priority values, shows that Cost is the most important criterion and Complexity the least important criterion. The consistency of the decision-maker's judgement are now calculated as discussed previously. The eigenvalue, $\lambda_{\max}$, is calculated according to Equation 2.4.4.

	M	*U*	*D*
M	1	5	7
U	0.2	1	3
D	0.14	0.33	1
Sum	1.34	6.33	11

$$\begin{aligned}\lambda_{\max} &= (1.34)(0.7306) + (6.33)(0.1884) + (11.00)(0.0810)\\ &= 3.0649\end{aligned}$$

The Consistency Index (CI) is obtained from Equation 2.4.3:

$$\begin{aligned}\text{CI} &= \frac{3.0649 - 3}{3 - 1}\\ &= 0.0324\end{aligned}$$

followed by the CR for the criteria comparison which is calculated according to Equation 2.4.2:

$$\begin{aligned}\text{CR} &= \frac{3.0324}{0.58}\\ &= 0.059\end{aligned}$$

The CR is less than 0.1, which means the criteria ratings were performed in a reasonably consistent manner, and the results can be used for further analysis.

The same procedure is used to calculate the priority weights for the alternatives for each criterion together with the related CR's. The preference of each alternative over another with regards to a specific criterion is evaluated. The following matrices show the pairwise comparison values. A_M, A_U and A_D represent the pairwise comparisons for *Cost*, *Usefulness* and *Complexity*, respectively. The five alternative solutions are indicated in the matrices as BC1, BC2, RF1, RF2 and RFG.

$$A_M = \begin{array}{ccccccc} & BC1 & BC2 & RF1 & RF2 & RFG & \\ \left(\right. & 1 & 3 & 7 & 5 & 9 & \left.\right) BC1 \\ & 0.33 & 1 & 5 & 3 & 7 & BC2 \\ & 0.14 & 0.2 & 1 & 0.33 & 3 & RF1 \\ & 0.2 & 0.33 & 3 & 1 & 5 & RF2 \\ & 0.11 & 0.14 & 0.33 & 0.2 & 1 & RFG \end{array}$$

$$A_U = \begin{array}{cccccc} BC1 & BC2 & RF1 & RF2 & RFG & \\ 1 & 0.33 & 0.2 & 0.14 & 0.11 & BC1 \\ 3 & 1 & 0.33 & 0.2 & 0.11 & BC2 \\ 5 & 3 & 1 & 0.33 & 0.14 & RF1 \\ 7 & 5 & 3 & 1 & 0.33 & RF2 \\ 9 & 9 & 7 & 3 & 1 & RFG \end{array}$$

$$A_D = \begin{array}{c} \begin{array}{ccccc} BC1 & BC2 & RF1 & RF2 & RFG \end{array} \\ \begin{pmatrix} 1 & 3 & 5 & 9 & 7 \\ 0.33 & 1 & 5 & 9 & 7 \\ 0.2 & 0.2 & 1 & 5 & 3 \\ 0.11 & 0.11 & 0.2 & 1 & 0.33 \\ 0.14 & 0.14 & 0.33 & 3 & 1 \end{pmatrix} \end{array} \begin{array}{c} \\ BC1 \\ BC2 \\ RF1 \\ RF2 \\ RFG \end{array}$$

The eigenvector for each matrix is determined, resulting in the following values which are also the priority values:

$$A_M = \begin{pmatrix} 0.513 \\ 0.262 \\ 0.063 \\ 0.129 \\ 0.033 \end{pmatrix}, \ A_U = \begin{pmatrix} 0.032 \\ 0.057 \\ 0.115 \\ 0.244 \\ 0.551 \end{pmatrix}, \ A_D = \begin{pmatrix} 0.493 \\ 0.313 \\ 0.109 \\ 0.030 \\ 0.055 \end{pmatrix}$$

These calculated priority values and the values in the priority vector obtained for the criteria are placed into the AHP structure. Figure 2.19 displays the AHP structure with the priority of each asset for each criterion.

It is evident that in terms of Cost, BC1 has the highest priority (least expensive). RFG has the highest priority with regards to Usefulness and BC1 for Complexity (implying preferred for least complexity). Thus, if only one of the aspects needs to be improved, attention should be given to these technologies first. The CR results for the alternative comparisons for each criterion are provided in Table 2.12.

Table 2.12: AHP example: CR results for alternative comparisons per criterion

Rated w.r.t.	$\lambda_{\max}$	**CI**	**RI**	**CR**
Cost	5.220	0.0549	1.11	0.050
Usefulness	5.255	0.0638	1.11	0.058
Complexity	5.338	0.0845	1.11	0.076

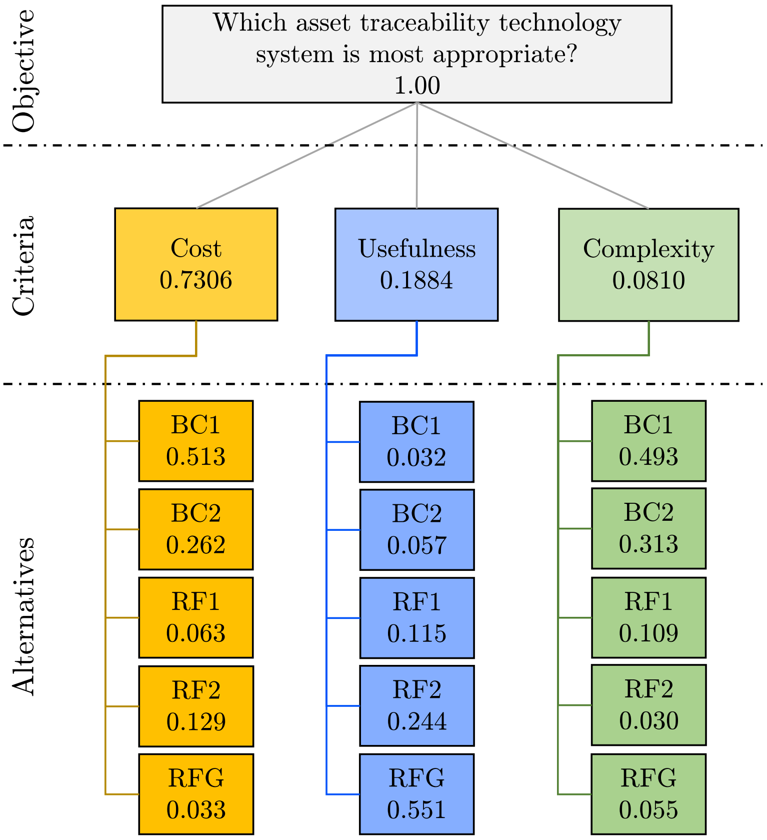


Figure 2.19: AHP example: structure with alternative priority values

With all of the CR values in Table 2.12 lower than 0.1, the results can be accepted as meaningful. For the final prioritisation, the priority values of the alternatives are combined into one matrix which is then multiplied by the criteria priority values:

$$\begin{array}{cc} & \begin{array}{ccc} \;M\; & \;\;U\;\; & \;\;D\;\; \end{array} \\ \begin{array}{c} BC1 \\ BC2 \\ RF1 \\ RF2 \\ RFG \end{array} & \begin{pmatrix} 0.513 & 0.032 & 0.493 \\ 0.262 & 0.057 & 0.313 \\ 0.063 & 0.115 & 0.109 \\ 0.129 & 0.244 & 0.030 \\ 0.033 & 0.551 & 0.055 \end{pmatrix} \end{array} \times \begin{array}{c} M \\ U \\ D \end{array} \begin{pmatrix} 0.7306 \\ 0.1884 \\ 0.0810 \end{pmatrix} = \begin{array}{c} BC1 \\ BC2 \\ RF1 \\ RF2 \\ RFG \end{array} \begin{pmatrix} 0.4208 \\ 0.2275 \\ 0.0765 \\ 0.1426 \\ 0.1324 \end{pmatrix}$$

It is evident that BC1 is the most appropriate technology solution based on the selected criteria and ratings while RF1 is the least appropriate. Consequently, the AHP provides a logical quantitative framework to calculate the benefit of each alternative relative to the criteria. The AHP is a systematic and accurate process. However, it is also time-consuming and expert judgement is required.

2.4.5 Pitfalls and Issues Concerning the AHP

Belton and Gear (1983) highlight that the "derivation of priorities or weights which reflect the relative importance of options in a multi-attribute judgement problem" is a fundamental issue of decision-making theory. The AHP, more specifically, has been criticised from various perspectives despite its success in a variety of applications in different domains. It is inherently powerful as a decision-making tool and easy to use, but there is a degree of imprecision in the specification of the factors that should be considered when determining weights. The AHP approach seems to generate anomalous results in certain scenarios where there is a misunderstanding regarding specification of inputs (Belton and Gear, 1983).

One of the greatest issues of the AHP is *rank reversal*. *Rank reversal* is when the ranking of alternatives reverses as a result of additional alternatives being added to the AHP. Raharjo and Endah (2006) report that a larger number of alternatives increases the probability of rank reversal occurrence. Belton and Gear (1983) elucidate this scenario through use of two examples where the second example is the first example with an additional alternative. Belton and Gear (1983) explain that there was no change in the relative preferences of Option A over Option B between the first example and the second example. Therefore, it would be reasonable to expect the overall preference order to remain unchanged. However, this was not the case.

The ranking of Option A and Option B in their second example happened to be the reversed ranking of the same options from the first example. The only aspect that changed was the normalisation factor which happens to be the root of the inconsistency. Through the normalisation procedure, the belief is that the relative importance of criteria is proportional to the arithmetic mean value of the options for each criterion. Belton and Gear (1983) argue that the majority of decision-makers do not necessarily consider this proportionality in their assessment of relative importances of criteria. The solution to this issue is to normalise the eigenvectors such that the maximum entry is 1 rather than the entries summing to 1. Preference order in this case will be preserved. Finally, Belton and Gear (1983) state that "the questions asked about the relative importance of criteria should be made more specific to ensure that the decision-maker's interpretation of the weights is consistent with the method".

Burnett (2013) indicates that the ranking process may become repetitive due to the fact that all ranking values change when an alternative is added. Additionally, Bhushan and Rai (2004) mention briefly the following problems relating to the application of the AHP:

- vendors get improperly penalised;

- the ratio scale is considered to be inaccurate; and
- the process can generate inconsistencies that have nothing to do with the consistency of comparisons (as a result of its inherent calculations or rating scale).

However, Belton and Gear (1983) conclude that the AHP approach is one with which numerous decision-makers feel at ease. They also note that this approach can handle fuzzy problems involving several attributes when some of these are difficult or impossible to compare other than subjectively.

2.5 Chapter Summary

Chapter 2 represents the first part of the literature review (the second part is Chapter 3 which provides an overview of asset traceability technologies). The chapter begins with a thorough discussion of *AM*. This includes a definition of an *asset* after which *AM* is defined. The scope of AM is described and, thereafter, the standardisation of AM is considered, including a discussion on two important series of documents: PAS 55 and ISO 55000. The characteristics and benefits of AM are also provided. AIM is discussed, in addition to Change Management which is an essential aspect for implementations concerning AM. AM specifically within the mining industry (a capital-intensive industry) is considered and cases herein highlighted.

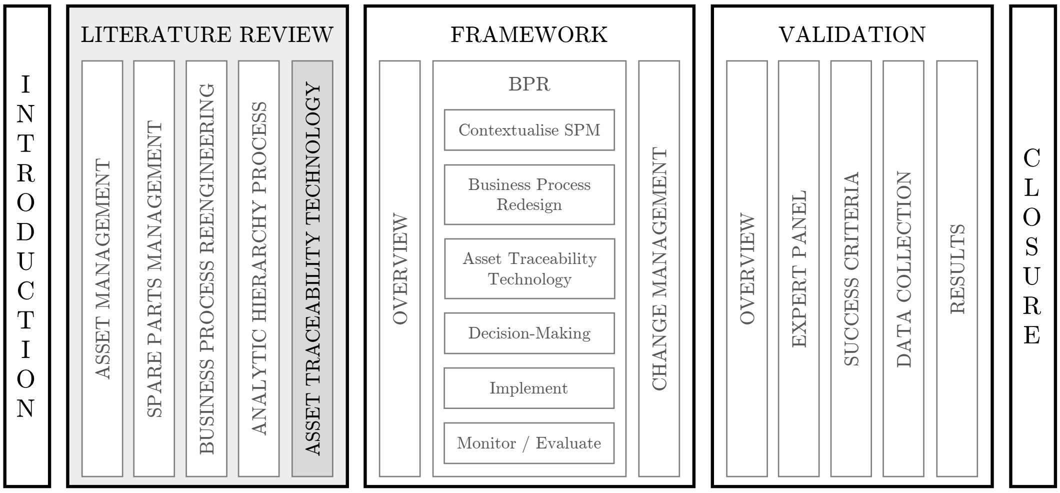
Thereafter, *SPM*, a subset of AM, is addressed. In this section, literature papers addressing different aspects of SPM are highlighted. The characteristics of spare parts (which are a type of inventory) and how they differ from that of general inventory are indicated. The classification criteria and classification techniques for spare parts are discussed. Demand forecasting for spare parts is also explained due to its prevalence in and importance for SPM. The SPM section concludes with inventory warehousing management, including warehouse functions, warehouse design, material handling, common SPM issues and the role of information systems in warehouse management.

Various aspects and principles of *Business Process Reengineering (BPR)* are described in order to support the proposed framework (in Chapter 4). These include criteria for selecting processes to redesign, BPR best practices, the role of IT in BPR and typical barriers to effective implementation of BPR. The *AHP* is also explained in detail as this is to be used as an aid for decision-making, specifically for the selection of asset traceability technology (which is discussed in Chapter 3). An example of the AHP specifically related to the selection of asset traceability technology is provided in order to support the proposed framework.

Chapter 3

Overview of Asset Traceability Technology

This chapter continues the review of literature by providing an overview of *asset traceability technology*. This is addressed in a separate chapter owing to the importance and size of the content. The technology aspects described in this chapter are utilised in the proposed framework and the *AHP* supports the selection of technology based on some of these aspects. The chapter focuses on *barcode technology*, *RFID technology* and *GPS technology*. Performance metrics, operational characteristics and current asset tracking applications of each technology are considered.



3.1 Introduction to Asset Traceability Technology

Ouertani *et al.* (2008) assert that Automatic Identification and Data Capture (AIDC) technologies, technologies used to collect information without manual data entry, could significantly improve asset lifecycle management. This is largely due to the ability which these technologies possess to capture and manage automatically information that describes events relating to an asset's lifecycle. AIDC technologies can also improve AM in general by facilitating (through reduction or elimination of manual processes related to) stocktaking, asset health assessments (using sensors) and asset tracing/tracking. Similarly, McCathie and Michael (2005) report that automation has provided companies such as Procter & Gamble double-digit productivity gains. Figure 3.1 illustrates various AIDC and wireless technologies.

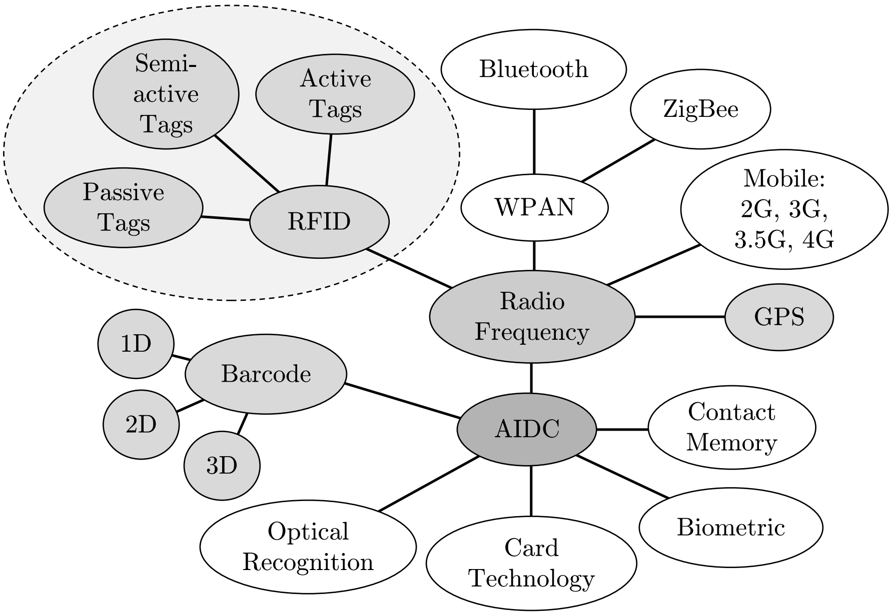


Figure 3.1: AIDC and wireless technologies landscape
Adapted from Castro and Wamba (2007)

AIDC technologies include, among others, barcode technology, optical recognition technology, biometrics technology, smart card technology, touch or contact memory technology and Radio Frequency Identification (RFID) technology. A Global Positioning System (GPS) is a radio frequency technology used primarily for tracking movement across geographic locations and also forms part of the major AIDC technologies landscape, primarily through integration with RFID or barcode technology. However, GPS is not typically considered an AIDC on its own since it provides location updates of a receiver rather than automatic identification or data capture.

Hassan, Ali, Aktas and Alkayid (2015) report that the primary motivations of warehouse management to use AIDC technology, in order of frequency, include: *optimisation of operational performance*, *enhanced customer service*, *improved resource management*, *improved security* and *increased and sustained competitive position and advantage*. Riley (2009) considers the six major AIDC technologies to be:

- one-dimensional (1D) barcodes;
- two-dimensional (2D) barcodes;
- RFID;
- optical character recognition (OCR);
- magnetic stripe cards and smart cards; and
- biometric identifiers (including voice recognition).

The study does not investigate magnetic stripe cards and biometric identifiers as these require human intervention and are normally used exclusively for security purposes and to trace human movements. Figure 3.2 illustrates the different Wireless-based Positioning Systems (WPS) and their characteristic scale (of where they operate) and resolution (in metres).

Before the various technologies can be discussed individually (beginning at Section 3.3), it is important to consider the typical positioning system performance metrics or operational characteristics that one may assess in order to evaluate system performance or compare the different technologies.

3.2 Positioning System Performance Metrics

A positioning technique or system is assessed on many metrics. These metrics provide a measure of the capabilities of the system to be used for its intended purpose (such as precision tracking). They also provide a benchmark to use when comparing other similar systems. Accuracy is usually the focus of assessment, but other factors can play a pivotal role in the success of the system, depending on the scenario and desired outcomes. Metrics to be used for assessment, as indicated by Tekinay, Chao and Richton (1998) and Liu *et al.* (2007), include *cost*, *accuracy*, *precision*, *complexity*, *robustness* and *scalability*. Some of these factors (and an additional interference susceptibility factor) are discussed with relevant values or considerations corresponding to barcode technology, RFID technology and GPS technology in Section 3.3.3, Section 3.4.5 and Section 3.5.2, respectively. A brief comparison or summary

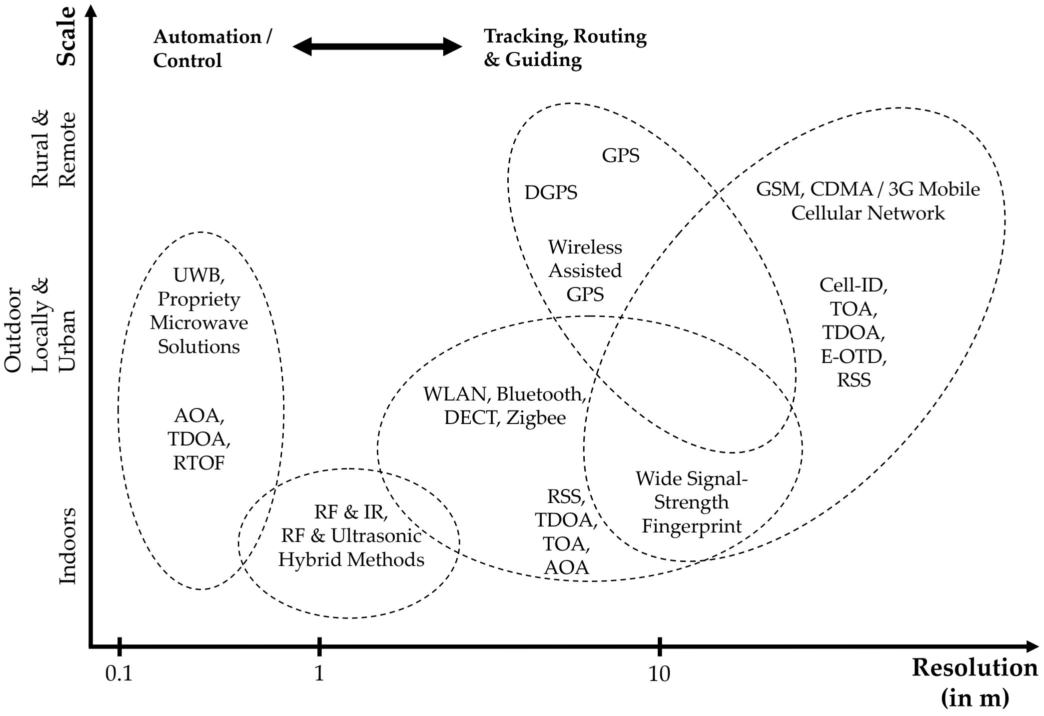


Figure 3.2: Current Wireless-based Positioning Systems
Adapted from Liu, Darabi, Banerjee and Liu (2007)

of the technologies and their characteristics is provided in Section 3.7. Many of the values mentioned are obtained from various websites (which are cited in the applicable sections) to reflect more accurately the most relevant, up-to-date information pertaining to the different technologies.

3.2.1 Cost

Expanding upon Liu *et al.* (2007), the cost of a positioning system depends on various factors such as initial financial capital, time, size, weight, system capacity, read distances and energy consumption. The time factor consists of installation time required and maintenance time while the size and weight of the system depend on the location where the tags and routers need to be installed. A system that can cover further read distances is generally more expensive than one that only has a read range of one metre. Additionally, energy consumption is an operating cost and should be considered. For instance, passive RFID tags (which do not require a power source, but instead receive power from the reader's signal) are less expensive than active RFID tags. It is also important to be aware of existing infrastructure since an organisation may already have hardware installed that can be used.

3.2.2 Accuracy

Accuracy (also known as location error) is arguably the most important requirement of a positioning system. Mean distance error, which is the average Euclidean distance between the estimated location and the actual location, is often the metric used to measure accuracy (Liu *et al.*, 2007). A higher accuracy is normally desired, but a trade-off with other factors is always present. Therefore, it is important to determine the minimum desired level of accuracy for a given system. A similar concept to accuracy is precision and the differences are explained in Section 3.2.3.

3.2.3 Precision

Precision concerns the standard deviation in position error. Liu *et al.* (2007) state that accuracy involves mean distance errors, but precision is a measure of the robustness of the positioning technique by the variation in performance over many trials. An accurate system may never provide the true location of an asset, but the mean distance from the true location will be small (with the estimated positions surrounding the true location). A precise system, however, will achieve the same result in every trial as long as the conditions remain the same. Thus, the estimated position may always be off-centre from the true position, but the same estimated position will be determined with each trial. Figure 3.3 displays the difference between accuracy and precision using a dartboard illustration. Typically, the cumulative probability density function of the distance error is used to measure the precision of a system (Liu *et al.*, 2007).

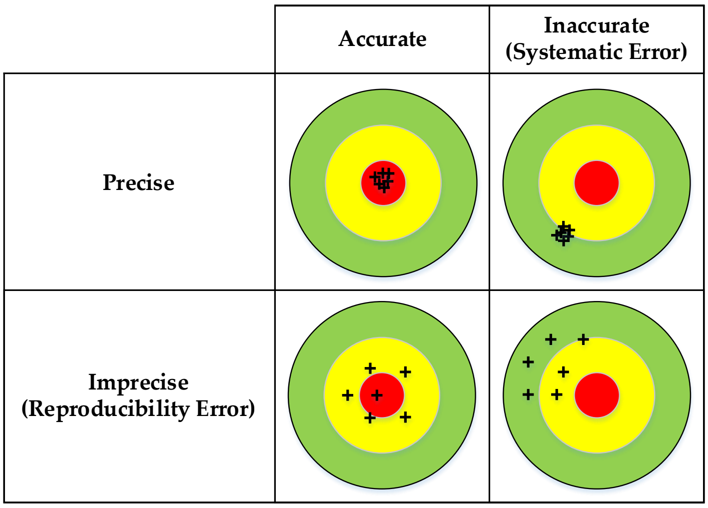


Figure 3.3: Illustration of accuracy versus precision
Adapted from Anderson (2015)

3.2.4 Complexity

Complexity refers to the state of the system being intricate or complicated. The system complexity is derived from hardware, software and operational factors (Liu *et al.*, 2007). Ouertani *et al.* (2008) describe complexity as a multidimensional, multidisciplinary concept arising from:

- *Physical complexity of the asset:* referring to the number of parts and dependencies of parts.
- *Manufacturing operations complexity:* referring to the intricacy in which assets are manufactured, the costs involved and lead times required.
- *Information management complexity:* referring to the process of data capture, storage, retrieval and analysis of asset information.
- *Maintenance complexity:* relating to the responsibilities, costs and time involved with maintenance of the assets.
- *Decision making complexity:* referring to the level of decision-making constrained by managerial, feasibility, scheduling and other constraints.

In terms of software complexity (computing complexity of the positioning algorithm) under *information management complexity*, the positioning could be calculated quickly if the computation is handled on a centralised server due to its powerful processing capability and sufficient power supply (Liu *et al.*, 2007). However, if the computation is performed on a mobile unit, the complexity could result in a lack of performance owing to the short battery life and weak processing power of a mobile unit.

Liu *et al.* (2007) further indicate that both the location rate and the location lag are important indicators of complexity. Location rate is the frequency of reporting location updates by the system while location lag is the delay between the time that a mobile target changes position and the time that the system reflects the new location of the target.

3.2.5 Robustness

Robustness refers to the system's ability to perform under any conditions or with any obstacles. A very robust system can operate normally even when the signals are somewhat obstructed or if some are not available. If the signal from a transmitter unit is completely obstructed, then the only information available is from other units. A robust system should still be able to determine location of an object using information from other transmitter units. This allows the system to still function despite some units not functioning due to harsh environments or being unable to transmit signals due to obstructions.

3.2.6 Scalability

Scalability refers to a system's ability to cover an increased geographic space or density. Geographic space refers to the area or volume of space forming the coverage zone. Density refers to the number of units located per unit of geographic space per time period. According to Liu *et al.* (2007), a system's positioning performance normally degrades as the distance between transmitter and receiver increases or when the number of units being tracked increases in the same coverage area. They state that, as wireless signal channels become congested (through increased coverage space or higher density), more location positioning computational processing and communication infrastructure may be required. A highly scalable system can cover broader areas and handle a larger number of units without performance degradation relative to a less scalable system.

3.3 Barcodes

A barcode is a series of characters represented in the form of a sequence of parallel lines (referred to as bars) and spaces. McCathie and Michael (2005) state that autodiscrimination (a feature whereby the symbology being scanned is recognised) allows barcode scanners to read a large number of symbologies (the protocols for arranging the bars and spaces that form a barcode). Barcodes are widely used in a number of industries – almost every company at present has adopted the use of barcodes. It is this uniformity, in addition to the low cost of barcode technology, that may make barcodes the preferred solution for product tracing and tracking applications for the majority of companies.

Barcodes are divided into three types: *one-dimensional (1D)*, *two-dimensional (2D)* and (recently) *three-dimensional (3D)*. 1D and 2D barcodes are read or scanned using barcode readers that either use laser or imaging technology to decipher the barcode. Additionally, modern cellphones are capable of scanning both 1D and 2D barcodes. Special models of barcode scanners can also be connected to cellphones, thereby increasing the transmission range considerably (McCathie and Michael, 2005). 3D barcodes are not read by variances in reflected light, but rather through determination of the height of each line (depth perception). As such, 3D barcodes are fundamentally similar to 1D and 2D barcodes, differing primarily in the manner in which barcodes are read and the 3D physical characteristics such as the barcodes being engraved into objects. Therefore, only 1D and 2D barcodes are discussed in this section.

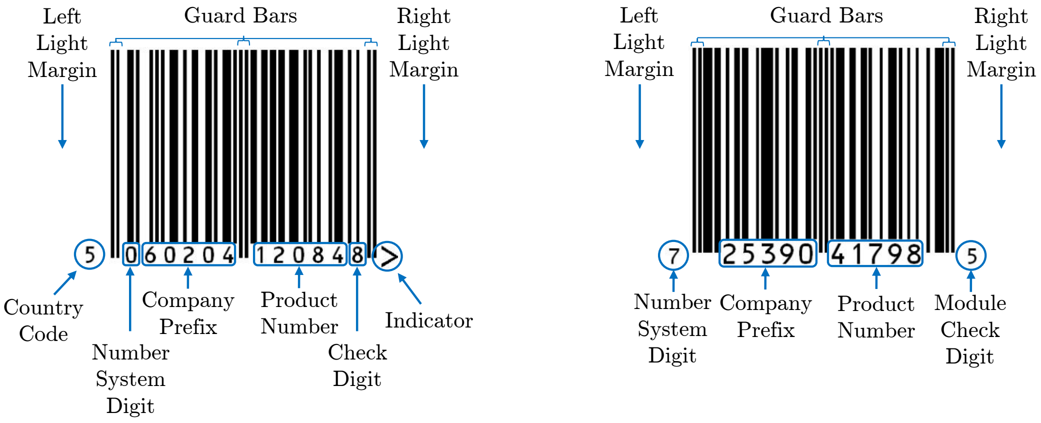
3.3.1 One-dimensional Barcodes

One-dimensional barcodes can further be divided into two categories, namely *width-modulated* and *height-modulated*. Width-modulated barcodes (such as those displayed in Figure 3.5) consist of bars and spaces of varying width. Conversely, height-modulated barcodes (such as those used in the Postnet system or the more recent Intelligent Mail Barcode system) consist of evenly spaced bars that vary in height. Figure 3.4 displays an Intelligent Mail Barcode height-modulated barcode. The height-modulated barcodes have limited use and are primarily used in the document and mail tracking industries.

1070012345612345678912345678901

Figure 3.4: Height-modulated barcode (Intelligent Mail Barcode)
Adopted from Bar Code Graphics, Inc. (2015)

There are various formats of 1D barcodes. The Universal Product Code (UPC) is popular throughout the USA while the rest of the world (including South Africa) predominantly uses the International Article Number (EAN) barcodes (International Barcodes, 2015; Barcodes Limited, 2015*a*). *EAN* was originally the abbreviation for *European Article Number* and has been retained for the new name. Most modern barcode scanners, however, are capable of interpreting both UPC and EAN formats. Figure 3.5 illustrates the different structures of EAN-13 and UPC-A. The primary difference is that the EAN barcode includes a country code (which actually forms part of the number system code).



a) EAN-13 barcode

b) UPC-A barcode

Figure 3.5: Structures of width-modulated barcodes: a) EAN-13 vs b) UPC-A
Adapted from Terrapin Solutions Limited (2015)

Barcodes are obtained either through GS1, the global organisation that develops and maintains standards concerning supply chains, or barcode resellers. Table 3.1 summarises the most common 1D barcodes that are available.

Table 3.1: Types of 1D barcodes

Type	Character Set	Length	Description	Example
EAN	Numbers only	Fixed length, 8 or 13 digits	European Article Numbering system; used throughout Europe; two versions: EAN-8 and EAN-13	5 901234 123457 >
UPC	Numbers only	Fixed length, 7 or 12 digits	UPC-A uses 12 digits; UPC-E uses 7 digits; barcode number assigned by Uniform Code Council	0 123454 3
Code 39	43 characters: 0-9, A-Z, and space, \$, %, +, -, ., /	Variable	Alphanumeric barcode; most widely used non-retail barcode	1234
Code 93	47 characters: 43 as with Code 39; another 4 special characters for full ASCII encoding	Variable	Compressed form of Code 39; not as widely used as Code 39	12AB
Code 128	Full alphanumeric as well as high density numeric mode	Variable	Internationally recognised; high density; used for large amount of data in small area	ABC123
Interleaved 2 of 5	Numbers only	Variable	High density barcode; can only encode pairs of numbers	1234

Adapted from Riley (2009)

Benefits provided by 1D barcodes include low cost, high accuracy, excellent reliability and fast reading speeds. The greatest disadvantage, however, is the limit on the amount of data that can be stored.

3.3.2 Two-dimensional Barcodes

2D barcodes were developed as a space efficient alternative to the conventional 1D barcodes and have a greater storage capacity than 1D barcodes. Therefore, 2D barcode technology is more suitable for information-dense applications. Typically, 2D barcode scanners can automatically read 1D barcodes. There are presently more than 30 different types of 2D barcodes available (Riley, 2009). Table 3.2 summarises the most common ones available.

Table 3.2: Types of 2D barcodes

Type	**Character Set**	**Length**	**Description**	**Example**
Aztec Code	Full ASCII, FNC1 and ECI control codes	Variable; min 12, max 3,832	Designed for ease of printing and encoding	
Datamatrix	All ASCII characters	Variable	Max theoretical density of 500 million characters to an inch; encoded by absolute position instead of relative dot position: high level of redundancy	
MaxiCode	All ASCII characters	93	Consists of hexagons instead of square dots: 15% denser than square dot code	
QR Code	All ASCII characters	Variable; max 7,366 numeric or 4,464 alphanumeric	Symbology has ability to encode Japanese Kanji and Kana characters directly	
PDF417	All ASCII characters	Variable	Stacked symbology; high density printers (thermal transfer or laser) should be used for printing	

Adapted from Riley (2009)

3.3.3 Important Operational Characteristics

Technologies have certain characteristics that need to be considered when selecting the appropriate technology to use for a specific application. This section discusses some of the most important operational characteristics (cost, range, interference susceptibility, accuracy and precision) concerning barcode technology that should be evaluated against the characteristics of other technologies.

3.3.3.1 Cost

In 2002, GS1 initiated an annual renewal fee for barcodes which results in smaller companies preferring to purchase barcodes from resellers (Van Jaarsveld, 2015). This annual fee is typically €150 for 100 barcodes or €50 for 10 barcodes (GS1, 2014*a*). SA Barcodes (2015), a barcode reseller, provides registered barcodes (in both EAN-13 and UPC-A formats) ranging in price from R164.95 per barcode in a bundle of 20 to R275 per single barcode (as at 25 July 2015). This cost includes the codes (each barcode represents a product and can be printed multiple times for any quantity of units of that product), the image files, the template and certification. Similarly, Barcodes Limited (2015*b*) offers EAN-13 barcodes ranging in price from R110 per barcode in a bundle of 100 or more, to R275 per single barcode (as at 25 July 2015). McCathie and Michael (2005) report that typical barcode printing costs have reduced to less than one cent per barcode.

The price of a barcode reader or scanner depends on the sophistication, accuracy, precision and range of the specific reader. Some readers are handheld while others are fixed. Furthermore, some readers are USB-wired while others are wireless (either sending data via Bluetooth technology or storing information on the battery-operated reader until it is plugged into a computer). ComX Computers (2015) indicates typical retail prices of barcode scanners (as at 27 July 2015) in the range of R558 (Astrum USB Laser Barcode Scanner – a USB2.0-wired laser barcode scanner capable of reading up to 250 mm away from a 0.33 mm (13 mil) barcode) to R11,975 (Motorola LS3578 Rugged Cordless Scanner – a wireless, Bluetooth-equipped, industrial-grade laser barcode scanner capable of reading up to 610 mm away from a 0.33 mm UPC barcode). uPrice.co.za (2015) indicates similar pricing of 1D and 2D imaging and laser barcode scanners at various online stores. The majority of barcode scanners are priced in the R500 – R4,000 range.

Figure 3.6 displays various tracking technologies (including barcode technology) and their corresponding levels of automation against costs relative to one another. RFID technology and GPS technology, including their costs and other attributes, are discussed within Section 3.4 and Section 3.5, respectively.

As can be seen from Figure 3.6, GPS technology is more expensive than both barcode technology and RFID technology, but offers greater automation. Active RFID is also more expensive than passive RFID and barcode technology. However, active RFID also provides greater automation by allowing for active tracking. Finally, barcode technology typically requires human intervention to scan items and, therefore, has a lower level of automation. This is the least expensive of the technologies displayed in Figure 3.6.

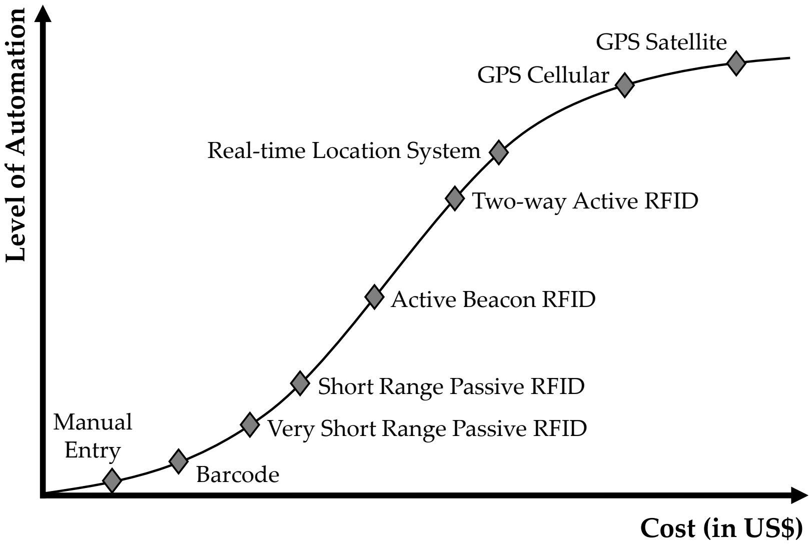


Figure 3.6: Level of automation versus cost of various traceability technologies
Adapted from Johnson (2007)

3.3.3.2 Range

A barcode scanner requires a direct line of sight from the reader to the barcode being scanned. The distance that this line of sight may be depends on the type of barcode scanner. According to Van Vlack (2014), Honeywell's Granit 1280i laser scanner can read barcodes from more than 50 feet (approximately 15 metres) away. Barcode Datalink (2015) offers a Motorola LS3408-ER long-range barcode scanner that can scan large barcodes from a distance of up to 14 metres. However, typical industrial barcode scanners have read distances of less than two metres (Van Vlack, 2014). Additionally, retro-reflective polyester material used for barcodes can increase read distances.

3.3.3.3 Interference Susceptibility

Any obstructions in the line of sight from the reader to the barcode interfere with the ability of the technology to read tags properly. Additionally, dusty or smoke-filled environments may also obstruct the line of sight. Keyence Corporation (2015) highlights a few points that influence the probability of successful reading using barcode scanners. The first point is that a barcode scanner reading a barcode label at a perfect right angle may experience strong specular reflection (light reflected from a smooth surface at a definite angle) which affects the accuracy of reading. Extraneous light (such as light from a photoelectric sensor) may also affect the accuracy of readings. Furthermore, barcodes printed on metallic or glossy surfaces can increase specular reflection and, thereby, affect readability.

3.3.3.4 Accuracy and Precision

Garg (2012) and Zebra Technologies Corporation (2007) claim that the error rate for manual typing is one substitution error for every 300 characters (keystrokes) typed (for skilled typists; less-skilled warehouse workers result in higher error rates). However, according to Garg (2012), the error rate for scanning barcodes ranges from one substitution error for every 15,000 to 36 trillion characters scanned. McCathie and Michael (2005) state that the error rate is approximately one error in one million characters scanned. Despite the high accuracy rates for scanning, one of the greatest weaknesses of barcode technology (which also affects its accuracy) is that it typically requires the involvement of people to perform the scans.

The accuracy of information depends on the manner in which the information relating to each barcode is stored in the database. For instance, if the person responsible for inputting the information (relating to a product) into the database assigns the information to the incorrect product code; then the incorrect information will be processed and displayed during a scan of the relevant barcode. Furthermore, if a person stores the same code twice for two different products, changes any information without appropriate permission (security checks) or enters the incorrect kinds of data into certain fields (such as alphanumeric values into an alphabetic field); then the accuracy of the system is compromised. It is, therefore, important to have proper controls in place to minimise the potential for duplicate (redundant) codes, security risks or input errors.

3.4 Radio Frequency Identification

Radio Frequency Identification (RFID) is considered “one of the most pervasive computing technologies in history” (Roberts, 2006). RFID was first introduced during World War II by the British Air Force to distinguish Allied aircraft from enemy aircraft using radar systems (Castro and Wamba, 2007). RFID is an electromagnetic proximity identification and data transaction system that improves an organisation's ability to track, monitor and manage assets. Alternatively, it is classified as a wireless Automatic Identification and Data Capture (AIDC) technology (Wamba, Bendavid, Lefebvre and Lefebvre, 2006).

Olivero, Teal and Hidaka (2010) and Arora, Mallinson, Kulkarni, Brusey and McFarlane (2007) describe RFID as a technology that operates through communication between radio devices known as tags and RFID readers. Unique identification data about the object that is tagged is stored on the tag. Arora *et al.* (2007) elucidate that when the object (containing the tag or transponder) enters the range of the RFID reader, the transponder's antenna (in the tag) receives radio waves (transmitted energy) from the reader's antenna of which some is reflected back to the reader using backscatter modulation. Through this process, encoded digital data stored on the tag is received by the reader which captures the data and sends it to a software application using suitable communication channels.

An RFID system comprises three primary components, namely:

- tags;
- a reader and its antennae; and
- a middleware application that is integrated into a host system.

RFID is considered a means of enhancing data processes and complements existing technologies such as barcode technology or Computerised Maintenance Management Systems (CMMS). It allows for the accurate and automatic identification and tracking of each product throughout the supply chain from the factory, through shipping and warehousing, to the retail location without human intervention (Lai, Hutchinson and Zhang, 2005). According to Roberts (2006), RFID is a similar concept to barcoding, but is an improvement thereupon due to its:

- non-optical proximity communication;
- information density; and
- two-way communication ability.

Olivero *et al.* (2010) and Lu, Bateman and Cheng (2006) highlight additional advantages of using RFID as being:

- shorter lead times;
- reduction of inventory;
- decrease in store and warehouse labour expenses;

- preventing out-of-stock items;
- reduction of damage, pilferage and shrinkage;
- increase in security;
- enhanced management and tracking of materials, tools and spare parts; and
- minimisation of human error.

An emerging technology which forms a High Frequency (HF) subset within RFID technology is Near Field Communication (NFC) technology. This technology is used for very short-range applications and is currently being employed within mobile phones and smart cards, among other devices. This section further discusses the RFID tags, readers and middleware that constitute an RFID system as well as the applicable RFID frequency allocations and regulations, the important operational characteristics and the limitations of RFID.

3.4.1 RFID Tags

A tag, also known as a transponder (*trans*mitter/res*ponder*), is an RFID device that contains a chip and an antenna. The chip generally stores product information such as manufacturer, product lot, size and category, production date and final destination (Castro and Wamba, 2007). The antenna enables the tag to respond to a signal transmitted from the RFID reader. The nature of transmission to and from the tag allows for it to be attached to or embedded in a physical object.

There are three broad categories of tags, namely:

1. passive tags;
2. active tags; and
3. semi-active/semi-passive tags.

Passive tags do not have a power supply, but use the radio frequency signal from the reader to energize themselves and transmit their stored data to the reader (Olivero *et al.*, 2010). They are generally read-only. They have extremely long lifetimes with end of life typically only being the result of damage to the tag (such as from extreme temperatures or cutting of the tag). They are also smaller, lighter and less expensive than active tags. In 2009, Omni-ID (2009) reported that passive tags can be manufactured and delivered for as little as $0.25 each. These advantages, however, are at the expense of limited storage capacity, shorter read ranges and the requirement for readers that have greater power (Roberts, 2006). Furthermore, their performance is reduced in environments that experience large amounts of electromagnetic noise. Olivero *et al.* (2010) state that passive tags are able to provide information about location of objects based on when the tag was last read (zoned location or proximity).

Active tags have their own power supplies (batteries or solar panels) and are typically read/write devices. The on-board power source allows for further read/write ranges than passive tags as well as for the use of microprocessors, sensors and input/output ports (Olivero *et al.*, 2010). The on-board power source also enables the tag to beacon instead of merely responding to reader interrogation. The beacon feature of active tags allows for triangulation (real-time spatial positioning) when three readers are in proximity of a tag. However, the dependency on a battery results in a limited life of the active tag, although this lifetime may be as long as ten years (Roberts, 2006). The tags are larger and more expensive than passive tags. Omni-ID (2009) reported that these tags are typically priced between \$10 and \$100 each.

Semi-active/semi-passive tags use batteries to power the circuitries of the chips (for memory or applications). This improves backscatter (reflection of signals back to the point from which they were propagated) performance and read/write ranges (Intelleflex Corporation, 2014). In order to communicate, each tag draws power from the signal of the reader. The tags do not beacon (send out signals), but rather respond to reader interrogation. This enables use in secure environments. Battery life of semi-active tags (usually up to five years) is superior to active tags since the semi-active tags respond only when interrogated and do not beacon (which drains the batteries). According to Intelleflex Corporation (2014), semi-active tags are also superior to passive tags in terms of the range of applications since they have support for on-chip memory and condition monitoring sensors.

3.4.2 RFID Reader

RFID readers are electronic devices that emit and receive radio signals via the antennas coupled to the readers. RFID readers handle information flow between tags and the host system via RFID middleware. The readers capture the data from tags and, when tags are not read-only (most passive tags are read-only), they can overwrite data on tags.

Castro and Wamba (2007) state that there are three primary types of RFID readers, namely:

1. fixed readers;
2. mobile readers; and

3. handheld readers.

Fixed readers are usually permanently mounted at stationary choke points (access points) on walls, dock doors or conveyor belts. *Mobile readers* are often mounted on equipment such as forklifts which allows for greater flexibility and portability. *Handheld readers* are battery-operated and extremely portable.

3.4.3 RFID Middleware

Castro and Wamba (2007) state that the RFID middleware is “responsible for monitoring readers, managing, filtering, processing and aggregating all the data collected from products by readers and then routing the data to the dedicated information systems”. Typical information systems include Enterprise Resource Planning (ERP) systems, Warehouse Management Systems (WMS) and Manufacturing Execution Systems (MES). The RFID middleware can also be used to control and manage the infrastructure of the RFID readers.

According to Han, Zhao, Cheng, Wong and Wong (2012), several approaches have been proposed to achieve authentication in RFID applications to prevent tags from being tracked without the necessary authority to do so. Hash Lock is a hash-function-based authentication approach often used for this purpose. It, however, has a slow authentication speed due to its O(N) key search complexity where N is the total number of tags in the system (Han *et al.*, 2012). This results in complexity of the system on the software side, but the user of the system is not practically affected besides experiencing a slower system response.

3.4.4 RFID Frequency Allocations and Regulation

Han *et al.* (2012), Thrasher (2013) and Poole (n.d.) highlight distinct frequency bands at which passive RFID tags typically operate, namely:

- Low Frequency (LF): 125 kHz – 134.2 kHz and 140 kHz – 148.5 kHz (for applications such as animal tracking and vehicle identification);
- High Frequency (HF): 13.553 MHz – 13.567 MHz (for applications such as access control and electronic ticketing); and
- Ultra-High Frequency (UHF): 856 MHz – 960 MHz (for applications such as remote car keys and supply chain tracking).

Additionally, Han *et al.* (2012) and Poole (n.d.) mention a relatively newly-used fourth frequency band named Super-High Frequency (SHF) that ranges from 2.400 GHz to 2.454 GHz for RFID (5.725 GHz to 5.875 GHz is also part of SHF, but not widely used for RFID). This band is mostly used for long-range tracking with active RFID tags. However, according to IDTechEx (2004), "433 MHz is the optimal frequency for global use of active RFID in crowded, multi-tag environments". This frequency is used with backscatter coupling for applications such as remote car keys (Poole, n.d.). At this frequency, signals are capable of diffracting around vehicles, containers and other large objects.

Europe, the USA and Canada have various frequency and maximum power regulations. Many of these regulations have been adopted by other countries. Therefore, it is important to be cognisant of the local regulations in which an RFID system is to operate and installers need to ensure that the hardware abides by these regulations. GS1's Electronic Product Code (EPC) Gen2 air interface protocol, initially published by EPCglobal in 2004, defines the physical and logical requirements for an RFID system of readers and passive tags operating in the UHF range. According to GS1 (2014*b*) and SkyRFID Inc. (2015*a*), the current EPCglobal frequency (as well as power and technique) allocations authorised for RFID applications (specifically within the 860 MHz to 960 MHz band) in South Africa are: (i) 865.6 MHz – 867.6 MHz (2 W Effective Radiated Power, European Telecommunications Standards Institute); (ii) 915.4 MHz – 919 MHz (4 W Effective Isotropic Radiated Power, Frequency Hopping Spread Spectrum); and (iii) 919.2 MHz – 921 MHz (4 W Effective Isotropic Radiated Power, non-modulating).

3.4.5 Important Operational Characteristics

This section discusses the cost, range, interference susceptibility, accuracy and precision of RFID technology which should be evaluated against the characteristics of other technologies under consideration.

3.4.5.1 Cost

Figure 3.6 in Section 3.3.3 illustrates the level of automation of traceability technologies relative to cost. The cost of an RFID tag depends on various factors. There are different types, sizes and storage capacities of tags as well as ways in which tags can be mounted on or embedded within objects. The combination of these factors determines the price of an RFID tag. The RFID Journal (n.d.*d*) states that most companies do not quote the prices of RFID tags readily since the various options available (including the volume of tags to be purchased) need to be selected before a quote can be provided for a specific tag order. However, the RFID Journal (n.d.*d*) claims that typical active RFID tags are priced at $25 each with the more specialised active tags that have longer battery life, special protective housing and sensors, priced at $100. In 2009, Omni-ID (2009) reported that active tags may cost between $10 and $100 each. Supporting this statement, Thrasher (2013) observes that the price of an active RFID tag ranges between $20 and $100, depending on the tag's capabilities and features. In 2009, Omni-ID (2009) reported that passive tags can be manufactured and delivered for as little as \$0.25 each. More recently, a typical passive 96-bit Electronic Product Code (EPC) inlay (chip and antenna mounted on a substrate) was reported to cost between \$0.07 and \$0.15 (RFID Journal, n.d.*d*). The price rises to \$0.15 or more when the tag is embedded within a thermal transfer label which allows the printing of barcodes.

The price of RFID readers also varies greatly depending on selected options. Active RFID readers are usually purchased as part of a whole system which includes tags and mapping software that determines the locations of tags. According to the RFID Journal (n.d.*b*), the price of Ultra-High Frequency (UHF) readers range from \$500 to \$2,000. These prices are declining as UHF readers are becoming more prevalent within industries. A High Frequency (HF) reader module (a circuit board that can be inserted into another device) is typically \$200 to \$300 while a standalone HF reader may cost \$500 (RFID Journal, n.d.*b*). Additionally, a Low Frequency (LF) reader module might cost under \$100 while a standalone LF reader may cost \$750 (RFID Journal, n.d.*b*). In some cases, companies may be required to purchase antennae and cables separately from readers. The RFID Journal (n.d.*b*) indicates typical antenna prices to be \$200 or more.

The RFID Journal (n.d.*c*) highlights that the most difficult cost to quantify in general is the complete system cost as this depends on the application, the size of the installation, the type of system and many other factors. Middleware is often required in conjunction with the readers and tags, and a system integrator may be necessary to integrate the RFID system into existing Warehouse Management Systems (WMS). Furthermore, network facilities may need to be upgraded to support the RFID system.

3.4.5.2 Range

The read range of an RFID tag is the distance from which the tag can be read by an RFID reader. The read range depends on the frequency of radio waves used, any interference present (such as liquid or metal), the power output of the reader, the sizes of antennae and the mechanism by which the tag responds to the reader (either by broadcasting its own signal as in the case of the battery-powered active tags or by “reflecting” the signal from a reader back to the reader in the case of passive tags).

Generally, the read range increases as the frequency increases, but the ability of the radio wave to penetrate liquids and metals decreases (Thrasher, 2013). Additionally, the presence of metal and liquids (such as water) reduces possible read ranges (RFID Journal, n.d.*a*; SkyRFID Inc., 2015*b*; Arora *et al.*, 2007). An increase in power output of the reader may increase the read range, but most governments restrict the possible output of readers to prevent interference with other radio frequency devices (such as cellphones). The RFID Journal (n.d.*a*) states that the read range decreases dramatically when the size of antenna is reduced, specifically for UHF readers.

Han *et al.* (2012), the RFID Journal (n.d.*a*) and Thrasher (2013) claim that battery-powered (active Ultra-High Frequency (UHF) RFID) tags, such as those used in toll collection systems, typically have a read range of approximately 100 metres. The passive UHF RFID tags (often used for tracking pallets and cases in supply chains) have read ranges of approximately five metres to under ten metres (RFID Journal, n.d.*a*; Roberti, 2013*a*). Roberti (2008) reports that Mojix, a startup company based in Los Angeles, developed the Mojix STAR system that reads passive UHF RFID tags at approximately 600 feet (183 metres). High Frequency (HF) RFID tags, such as those used in smart cards, usually have read ranges up to one metre (RFID Journal, n.d.*a*; Impinj Inc., n.d.). According to SkyRFID Inc. (2015*b*) and Impinj Inc. (n.d.), Low Frequency (LF) passive RFID tags have read ranges up to 30 cm (but typically 10 cm).

3.4.5.3 Interference Susceptibility

Sabesan, Crisp, Penty and White (2014) state that conventional RFID systems experience multipath fading (from signals reflecting off objects) which results in dead spots in radio environments. Furthermore, the ability of a radio wave to penetrate liquids and metals decreases as the frequency increases. The RFID Journal (n.d.*e*) supports this statement by highlighting that LF and HF RFID tags work better than UHF RFID tags in the presence of metal and water. Additionally, Arora *et al.* (2007) investigated the interference that RFID technologies experience when in the presence of liquids and metals. However, Thrasher (2013) and the RFID Journal (n.d.*e*) assert that technology has advanced over recent years to such an extent that specialised UHF RFID tags are capable of operating adequately near water and metal surfaces. Many types of tags have been designed for use on metal objects such as the *Ironside Micro* industrial RFID tag developed by Confidex (2015). The manner in which products are tagged with RFID tags also affects performance.

Signal collision is another important aspect to consider. According to Han *et al.* (2012), there are two types of signal collision, namely *tag collision* and *reader collision*. Tag collision occurs when more than one transponder (tag) reflect back a signal simultaneously, thus "confusing" the reader. Reader collision occurs when a region is overlapped by the scanning signals of two or more readers. The RFID Journal (n.d.*f*) states that different air interface protocol standards use different techniques to have the tags respond to the reader only one at a time. Section 3.4.4 mentions the various RFID frequency bands and standards applicable to UHF RFID for South Africa. The techniques involve algorithms that “singulate” the tags such that each tag is read separately, but so quickly (in milliseconds) that it appears as if all the tags are being read simultaneously (RFID Journal, n.d.*f*). The anti-tag-collision approaches are categorised into either Framed-Slotted-ALOHA-based (FSA-based) or Binary-Tree-based (BT-based) algorithms (Han *et al.*, 2012). Anti-reader-collision approaches include assigning different channels to adjacent readers and scheduling interrogations into different rounds.

3.4.5.4 Accuracy and Precision

RFID systems experience the same database issues as barcode systems. The controls necessary for correct database entry, as discussed in Section 3.3.3.4, are applicable to RFID systems.

Roberti (2015) claims that active tag RFID systems typically have read accuracies of 100%. The tag detection accuracy of passive tag RFID systems, however, is considerably affected by interference. Walker (2014) states that researchers at the University of Cambridge have been able to increase the read range and accuracy of RFID systems by employing distributed antenna systems. The research presented by Sabesan *et al.* (2014) focuses on a long-range, effectively error-free UHF RFID interrogation system. Sabesan *et al.* (2014) demonstrate that dead spots, caused by multipath fading, can be shifted by varying the phase and frequency of the interrogation signals in a multi-antenna system. This results in improved coverage. Their research indicated an increase in tag detection accuracy over conventional switched multi-antenna systems of 50% to 100% for a 20 metre by 15 metre area. Furthermore, reliable detection range increased from three metres (tag detection accuracy typically attenuates at a distance of two or three metres) to 20 metres (Walker, 2014; Sabesan *et al.*, 2014).

Han *et al.* (2012) investigated three-dimensional (3D) RFID localisation technology and the improvement it offers in location accuracy. In the experiment performed by Han *et al.* (2012), the average location estimation error of eight active UHF tags (spaced one metre apart) within a 3D space of 1.5 m by 1.5 m by 1.5 m adjacent to the reader was 0.54 m. Roberti (2013*a*) mentions that Mojix developed a phased-array antenna passive UHF RFID system that locates tags in 3D space to within one square metre [radius of 0.3 m (Roberti, 2008)]. Furthermore, Roberti (2013*a*) and Clarke and Park (2006) assert that an active Ultra-Wideband (UWB) RFID system can have accuracies of a few centimetres (at excessive cost) since UWB systems compensate for multipath (Roberti, 2015). Mahfouz, Fathy, Kuhn and Wang (2009) observe that UWB systems may have specified 3D real-time accuracies of 10 cm to 15 cm with indoor operating ranges of over 50 m.

3.5 Global Positioning System

A Global Positioning System (GPS), also referred to as NAVSTAR (Navigational Satellite Timing and Ranging System), allows the accurate tracking of locations of objects through communication with satellites via radio signals. It was originally developed in the 1970s, primarily for USA military purposes (Mintsis, Basbas, Papaioannou, Taxiltaris and Tziavos, 2004). According to the NCO for Space-Based PNT (2014), the US Air Force manages the GPS constellation of satellites to ensure the availability of at least 24 GPS satellites, 95% of the time. Over the last few years, 31 operational GPS satellites (with an additional three to five decommissioned satellites that can be reactivated if required) have been orbiting Earth. The satellites orbit in six different 12-hour orbital paths positioned such that at least five are in view from every location on Earth (Bajaj, Ranaweera and Agrawal, 2002).

Bajaj *et al.* (2002) describe that at least three satellites (in view of the object) are required to determine the 3D spatial position (latitude, longitude and altitude) of an object relative to Earth (through triangulation or, more precisely, trilateration). Four or more satellites allow for more accurate and reliable readings. A GPS determines the location of an object by calculating the lengths of time it takes certain satellite signals to reach the GPS receiver. Each satellite in the constellation transmits a radio signal with its corresponding time signal. The GPS receiver then calculates the distance between the receiver and each satellite after calculating the delay between the sending and receiving of each satellite signal. Once at least three distances (each distance between the receiver and a satellite) has been calculated, the location of the object can be determined.

Since a GPS relies on time signal delays and the satellites are approximately 20,000 km away from Earth, a miscalculation of signal delay time by as little as a few milliseconds can result in a location error of as much as 300 km (Bajaj *et al.*, 2002). Therefore, satellites utilise precise atomic clocks and receivers use timing correction methods.

Perhaps the greatest drawback of GPS technology is the dependency on available signals between the GPS transmitter or receiver and the satellites. GPS signals are obstructed by objects such as walls and this severely limits the use of GPS for indoor applications.

3.5.1 GPS Correction Methods

Two cost-effective methods aid in minimising errors associated with GPS, namely Differential GPS (D-GPS) and Assisted GPS (A-GPS).

3.5.1.1 D-GPS

According to Bajaj *et al.* (2002), *Differential GPS* (D-GPS) utilises both roving receivers (that determine satellite positions) and stationary receivers (that use their fixed positions as reference points) to compute signal timing. The receivers are close to each other relative to the distances between the satellites and the receivers. The signals that reach both kinds of receivers essentially have identical errors and, therefore, the reference (stationary) receiver can determine the difference between the projected signal travel time and the actual signal travel time. Trimble Navigation Limited (2015) states that all errors that are common to both the reference receiver and the roving receiver can be eliminated. This does not include multipath errors since these occur around the receiver. Essentially, D-GPS involves a stationary receiver measuring timing errors and then providing correction information to other receivers that are roving around (Trimble Navigation Limited, 2015). Bajaj *et al.* (2002) state that D-GPS can improve accuracy to three feet (0.91 metres) or better.

3.5.1.2 A-GPS

Assisted GPS (A-GPS) uses a reference receiver (such as one at a cellular network tower or base station) that provides navigation data and signal timing data to a location server (Bajaj *et al.*, 2002). This server then relays the information to a GPS-enabled device [such as a cellphone or a Personal Digital Assistant (PDA)] when the information is requested. The relevant satellites for the specific location are already identified and GPS computations are processed by third-party servers. Additionally, A-GPS utilises proximity to cellular towers in order to calculate location when GPS signals to the device are not available. This results in faster location acquisition [with reduced Time-To-First-Fix (TTFF)], less processing power required by the cellphone or PDA and improved location tracking for indoor applications (Rubino, 2009). According to Bajaj *et al.* (2002), A-GPS provides an accuracy of 50 feet (15.24 metres) when the GPS device is outdoors and 160 feet (48.77 metres) when the GPS device is indoors. Rubino (2009) mentions that A-GPS can result in a precision fix in tens of seconds and has an accuracy ranging 5 to 50 metres.

3.5.2 Important Operational Characteristics

This section discusses the cost, range, interference susceptibility, accuracy and precision of GPS technology which should be evaluated against the characteristics of other technologies under consideration.

3.5.2.1 Cost

Figure 3.6 in Section 3.3.3 illustrates the level of automation of traceability technologies relative to cost. The general cost of a GPS to a user is difficult to quantify due to the manner in which a GPS is provided. The most common use of GPS is for navigation purposes and costs associated with these activities usually only involve the purchase of GPS devices (without subscription fees). Most mobile devices have GPS receivers integrated within their circuitry and allow users to access GPS services without cost (besides the cost of the mobile devices themselves and applicable data usage costs). However, certain instances of navigation require subscription fees. Additionally, a GPS is typically provided as a service to customers when the focus is on tracking various assets and, therefore, annual fees often apply. Bajaj *et al.* (2002), however, report that the cost of integrating GPS technology into vehicles, machinery and other devices is decreasing.

Malcolm (2014) describes three factors that affect the cost of an industrial GPS tracking system. One can either purchase the GPS devices and pay a monthly service fee, or rent the GPS devices, in which case the larger upfront cost of bundling the device and monthly service fee is replaced by the rental. Altech Netstar (2015) offers a top of the range product (for vehicle tracking) that features GSM for communication and GPS for pinpoint positioning at R2,950 for the device and a monthly subscription fee of R245. Alternatively, the unit can be rented for R299 per month (including the service subscription fee) on a 36 month contract. Similarly, Altech Netstar (2015) provides the Boomerang product for tracking smaller assets at R1,599 for the unit with a separate R80 monthly subscription fee. Brickhouse Security (2015) claims that reasonable pricing packages for GPS tracking may cost up to $20 per month per tracker. Furthermore, devices and services often can be obtained at discount when purchased in large quantities.

The second factor affecting cost is the required update frequency of the location information from the GPS. Malcolm (2014) claims that the industry standard for update frequencies relating to vehicles is 12–30 times per hour (every two to five minutes). Information updates for industrial assets (or generic assets) are typically performed on-demand (the device requests information updates). The third factor is whether the company itself performs the installation of GPS devices or whether the second or a third party performs the installation. Malcolm (2014) and Brickhouse Security (2015) state that the cost for this installation on vehicles is typically between $75 and $100 per vehicle.

3.5.2.2 Range

A GPS is not limited in terms of range as long as the GPS receivers are within view of at least three satellites. This implies that GPS is well-suited for outdoor applications with the range being unlimited for all practical purposes where interference (from tunnels, cloud coverage or other obstructions) is not substantial. However, the coverage of a GPS for indoor applications is limited

(Ting, Kwok, Tsang and Ho, 2011). As a result, a GPS is often integrated with other technologies such as RFID systems (Kourogi, Sakata, Okuma and Kurata, 2006; Song, Haas and Caldas, 2007; Lee, Yang, Oh and Gerla, 2009) that are better suited for indoor applications. This allows for both indoor and long-range outdoor tracking.

3.5.2.3 Interference Susceptibility

As previously mentioned, GPS signals are obstructed by objects such as walls and this severely limits the use of GPS for indoor applications. However, signals from other devices (such as radio frequency transmitters) can also cause interference, as highlighted by Dimos, Upadhyay and Jenkins (1995). Balaei and Dempster (2009) emphasise the importance of knowing whether a GPS signal has been disturbed or jammed in order to ascertain whether the GPS data is reliable. Trinkle and Gray (2001) allege that the rapid growth of telecommunications and other wireless data transmission systems is likely to result in greater interference to civilian GPS receivers. Despite the fact that these systems typically do not transmit on the same frequency as GPS, related intermodulation products and other out-of-band transmissions may communicate within the GPS band.

3.5.2.4 Accuracy and Precision

Bajaj *et al.* (2002) discuss the several factors that affect GPS accuracy. One of the most common sources of error is the variability in radio signal speed through the atmosphere (since radio signal speed is constant only in a vacuum). *Propagation delay* is when water vapour and other particles in the atmosphere inhibit the speed at which signals travel between two points. Additionally, *multipath fading* occurs when signals reflect off objects before reaching the antenna of the GPS receiver. Further sources of error include atomic clock discrepancies and receiver noise.

A GPS lacks the capability to achieve high positioning precision for indoor applications (Ting *et al.*, 2011). Wing, Eklund and Kellogg (2005) report that positional accuracies (from true position) of top-tier consumer-grade GPS receivers are typically approximately five metres for open sky settings, seven metres for young forest conditions and ten metres under closed canopies. Bajaj *et al.* (2002) claim that the typical GPS receiver is accurate to approximately 18 to 90 metres while more sophisticated GPS models (which are too expensive for the average user) can provide accuracies to within 1.5 cm. More recently, Rubino (2009) states that A-GPS can result in a precision fix in tens of seconds and has an accuracy ranging 5 to 50 metres.

3.6 Microdots

Microdots are popular in South Africa for the identification of vehicles and other assets. However, their use for tracking and tracing in the supply chain is still limited. The technology is primarily used in South Africa as an asset (specifically vehicle) recovery tool and the South African National Road Traffic Act requires all vehicles registered on or after 1 September 2012 to be fitted with microdots. Seggie (2011) states that thousands of tiny dots (that are 1 mm by 1 mm) are sprayed onto various parts of assets (such as the sub-assembly, engine and inside of the rims for vehicles). Each dot has identification numbers that can identify the asset or owners. In the case of vehicles, each dot contains a 17-digit Vehicle Identification Number (VIN) or Personal Identification Number (PIN) that is registered to the owner of the vehicle. The adhesive used to glue the microdots into place has ultraviolet properties which allow the VIN or PIN to become visible under ultraviolet light or with a special magnifying lens.

There are various uses for microdots, but they remain primarily anti-theft technology. In addition to the cost per asset, the drawbacks of using microdots include difficulties in obtaining microdots, placing microdots on assets and reading microdot information, as well as the inability to edit identification information once placed on the asset. The advantages of microdot technology include endurance, reliability and invisibility to the naked eye. The technology, however, has not yet developed or been utilised enough in terms of asset tracing (as opposed to merely identification of ownership) to be considered as a tracing technology suitable for the purposes of this thesis.

3.7 Comparison of Traceability Technologies

Section 3.3, Section 3.4 and Section 3.5 describe barcode technology, RFID technology and GPS technology, respectively. This section provides a brief comparison between the technologies and summarises the important operational characteristics of each technology (discussed in Section 3.3.3, Section 3.4.5 and Section 3.5.2).

A barcode is a series of characters represented in the form of a sequence of parallel lines (referred to as bars) and spaces. There are three primary types of barcodes, namely 1D barcodes, 2D barcodes and the rarer 3D barcodes. These barcodes are read using imaging or laser scanners. RFID technology is an electromagnetic proximity identification and data transaction system. Alternatively, it is classified as a wireless Automatic Identification and Data Capture (AIDC) technology. It operates through communication between radio devices known as tags and RFID readers. Three primary types of tags (and systems) are available, namely active RFID tags, semi-active/semi-passive RFID tags and passive RFID tags. Finally, GPS technology allows the accurate tracking of locations of objects through communication with satellites via radio signals. Table 3.3 briefly summarises the characteristics of each technology.

Table 3.3: Comparison between barcode, RFID and GPS characteristics

Characteristic	**Technology**		
	Barcode	**RFID**	**GPS**
Cost	GS1 annual fee: €50 per 10 barcodes, €150 per 100 barcodes; reseller once-off fee: R110 – R275 per barcode; scanner cost: R500 – R4,000 (up to R11,975 for industrial-grade)	Active tag: \$10 – \$100; passive tag: \$0.07 – \$0.25; UHF reader: \$500 to \$2,000; HF reader: \$500; HF reader module: \$200 – \$300; LF reader: \$750; LF reader module: \$100; antenna: \$200	Device: R1,599 – R2,950; monthly fee: R20 – R245 (or R299 if bundled to include device cost); installation: \$75 and \$100 (per vehicle)
Range	<2 m – 14 m (line of sight)	Active UHF tag: 100 m; passive UHF tag: 5 m – 10 m (183 m possible in specialised systems); HF tag: 1 m; LF tag: 10 cm – 30 cm	Unlimited (on Earth) without interference; varies with interference (limited indoor range)
Interference	Line of sight obstructions, strong specular reflection, extraneous light	Multipath fading (due to reflection of signals); signal collision; EMI, particularly from liquids and metals	Obstructions in line of sight to satellites (tunnels, cloud coverage, etc.); signals from other devices; EMI; multipath fading

Accuracy or Precision	1 error for every million characters	Read accuracy of active systems: 100%; passive systems: strongly dependent on interference; reliable detection range: 3 m – 20 m; UHF RFID location accuracy: 0.3 m to 0.54 m; UWB RFID location accuracy: 10 cm – 15 cm over read range of 50 m	Open sky settings: 5 m; young forest conditions: 7 m; under closed canopies: 10 m; sophisticated models: 1.5 cm

RFID is a relatively immature AIDC technology (Arora *et al.*, 2007) and the cost of implementing such a system is currently too high to definitively consider this system as a more ideal AIDC technology than barcode technology. Furthermore, there are certain advantages and disadvantages unique to RFID and barcodes, respectively. For instance, barcodes are manually readable while RFID tags are typically not readable without RFID readers (McCathie and Michael, 2005). This allows for easy manual reading of barcodes when scanning attempts fail. However, as previously mentioned, barcode technology typically requires that people perform the scans and, therefore, it is less automated than RFID technology.

Furthermore, Arora *et al.* (2007) state that the performance of RFID systems can be severely reduced when the tagged products contain or are in the presence of metal or liquids. Additionally, extreme conditions in the environment can hamper performance. It is, therefore, important to assess the practical feasibility of RFID for certain tagged parts and in the specific environment. However, a barcode reader relies on a direct line of sight between the scanner and the barcode and this requires that each item be scanned one at a time (McCathie and Michael, 2005). The line of sight can also be obstructed by smoke, dust or other obstructions. Therefore, environmental conditions affect both RFID technology and barcode technology, but in different ways.

GPS is the most versatile technology in terms of long-distance tracking, but it is limited in terms of indoor application. However, a hybrid system of RFID and GPS can overcome the indoor limitations of a GPS technology, although this is brought about at greater cost. Hence, the desired function of the AIDC technology and environment in which it is to be used needs to be assessed before one can select which technology to use for a specific application. The subsequent section describes some of the current applications of asset tracking for RFID and GPS.

3.8 Current Asset Tracking Applications

Barcode technology is primarily used for tracing ("last seen" updates) rather than tracking (real-time awareness) and is widely adopted in all industries. However, asset tracking technologies (such as RFID and GPS) are also used in different applications in various fields. This section highlights the most notable instances of RFID or GPS asset tracking in the retail, logistics and shipping industry, fleet management, the manufacturing and automotive industry, the pharmaceutical industry and, finally, the mining industry.

3.8.1 Retail, Logistics & Shipping

RFID: Retailers as well as their supply chain partners have been among the earliest adopters of RFID technology. Wal-Mart is one of the best examples with its roll-out of passive RFID at the pallet and case level in many of its distribution centres and retail locations in January 2005 (Olivero *et al.*, 2010). The supply chain management process was re-engineered and the company placed pressure on its suppliers to adopt RFID technology.

GPS: Theiss, Yen and Ku (2005) highlight the use of GPS within the shipping industry. Container shipping companies are heavily focused on optimising their available storage space efficiently in order to maximise profits. As a result, shipping containers are typically stacked as closely together as possible (often centimetres apart). A port generally has a GPS base station and each crane that transfers the containers has two GPS receivers attached to it (Theiss *et al.*, 2005). Specialised software then calculates the exact location (accurate to within a few centimetres) of the containers as they are placed.

GPS is also used for both security purposes and order delivery status updates regarding cargo and shipments. Various companies employ GPS to improve the security and tracking of expensive, hazardous or weapon-related cargo and shipments (Theiss *et al.*, 2005). GPS transmitters or receivers are attached to cargo or shipment containers and the devices continuously communicate the locations (real-time tracking) of the containers with headquarters. This location and time information is received by the organisation and corresponds to order information contained within the organisation's database. In this manner, shipments can be traced based on when they were received and who signed for them.

3.8.2 Fleet Management

RFID: According to Olivero *et al.* (2010), RFID tags are attached to transportation items such as power units, trailers, containers, dollies and vehicles. Readers are placed at locations (such as access-controlled gates, fuel pumps, dock doors and maintenance bays) through which the tagged items travel. These readers may be fixed or mobile readers which automatically read the data from the tags and relay it to distributed or centralised data centres as well as an AM system. The system can then allow or deny vehicles access to gates, fuel pumps or maintenance bays. Therefore, RFID enables an AM system to "locate, control and manage resources to optimize utilization on a continuous, real-time basis" (Olivero *et al.*, 2010). Since the data is captured automatically (eliminating the need for manual entry methods) and with the data being timely and accurate, there is a reduction in wait times in lanes as well as dwell times for drivers and equipment.

Furthermore, improved fleet management is possible by integrating tags with on-board sensors of vehicles to transmit critical vehicle information such as fuel levels, oil levels and temperatures, and tyre pressures to a reader. This allows for online management of a company's fleet. An example of this scenario is described in Section 2.1.8.2 where the Qic-Fleet product is capable of utilising important operational information (D'Oliveira, 2013).

GPS: Tracking of vehicles enables logistics companies to manage the routes that their vehicles follow as efficiently and practically as possible. According to Theiss *et al.* (2005), taxis (particularly in Australia) have GPS transmitters or receivers attached to them to allow taxis nearest to users' locations to be dispatched to them. The popular *Uber* application for mobile devices, developed by Uber Technologies Inc., is a prime example of taxi services using the GPS receivers in mobile devices in an attempt to optimise taxi transportation. A user of Uber would share the location where he or she would like to be picked up and, thereafter, the nearest available Uber driver would arrive at this location. Uber drivers, using the same Uber application, receive pick-up location requests from customers and accept them if they are willing to travel to this location. As a result, customers do not have to wait as long for taxis to arrive and fuel is conserved.

Similarly, GPS is used for fleet management based on traffic conditions. Theiss *et al.* (2005) describe how GPS receivers mounted on trucks are integrated with software applications that receive traffic updates. When traffic congestion occurs on planned routes, the GPS receivers automatically reroute the trucks after receiving the traffic updates. This reduces costs by increasing the efficiency of dispatches.

Additionally, many rental car companies use GPS to track their vehicles. Rental car companies typically charge customers additional fees for crossing certain territorial borders such as when leaving a state. However, it is often difficult to prove that a customer has crossed these borders unless some form of tracking device is mounted on the vehicle. Therefore, rental car companies are equipping vehicles with GPS devices to track the movements of their vehicles and charge their corresponding customers as required. Furthermore, the GPS devices allow these companies to monitor the speed at which their vehicles travel and the risks associated with each customer can be determined for future rentals (Theiss *et al.*, 2005).

3.8.3 Manufacturing & Automotive Industry

Castro and Wamba (2007) state that handling of goods in production facilities may account for up to 50% of the overall product cost. This is in addition to the large proportion of time allocated to handling of goods. Therefore, as Lu *et al.* (2006) argue, implementation of technologies which improve the management of materials and efficiency of the production process within facilities is a priority for manufacturers.

RFID: Olivero *et al.* (2010) mention how improved visibility and optimised Just-In-Time (JIT) inventory is achieved within the automotive industry by using RFID. Furthermore, modern automobiles are manufactured with a large number of possible features and configurations. This complexity makes forecasting of required parts a difficult task. However, RFID tags are used to reduce the time-to-market of particular configurations. RFID is also faster than barcode technology regarding the scanning of multiple parts and it enables the determination of part location and stock levels.

3.8.4 Pharmaceutical Industry

RFID: The USA's Food and Drug Administration (FDA) has adopted RFID and encouraged its industry participants to follow suit. Olivero *et al.* (2010) state that "[g]rowers, distributors, and producers of food and food products use it [RFID] to track location and monitor the temperature of food as it moves through the supply chain". RFID is also used to prevent counterfeit drugs from entering the pharmaceutical supply chain. It aids with the prevention of theft of pharmaceutical product shipments. Finally, RFID is used to collect pedigree data. Torrey (2013) defines a pedigree to be an audit trail that follows a pharmaceutical drug from date of manufacture to the pharmacy. The pedigree data is considered to be a useful tool in the fight against counterfeiting and to ensure pharmaceutical product safety.

According to Clarke and Park (2006), RFID is also being used more extensively in hospital business processes and various safety-critical clinical applications have been suggested. Clarke and Park (2006) investigated the use of wireless technology, specifically RFID, for tracking of people, objects and documents in the medical environment.

3.8.5 Mining Industry

This subsection highlights the use of RFID and GPS in the mining industry.

3.8.5.1 RFID

Roberti (2013*b*) describes a few instances of how RFID is being applied in the mining sector. Below are examples obtained from Roberti (2013*b*).

Safety: PervCom Consulting has developed PervTrack, a system that is a combination of a Real-Time Location System (RTLS) and a Real-Time Sensing System (RTSS) utilising active RFID systems, routers and sensors compliant with the IEEE 802.15.4 standard (Roberti, 2013*b*). The system simultaneously tracks both people (with 2.4 GHz active RFID tags attached to miners' hardhat lamps) and assets, in addition to monitoring environmental conditions (including detection of toxic gases, smoke and fire). The system was tested by the Central Institute of Mining and Fuel Research (CIMFR) Dhanbad in the Bagdigi coal mine in India with six R-101 routers placed at strategic locations to form a wireless mesh network. The routers have a transmission range of up to 1.3 kilometres (Roberti, 2013*b*). The system uses temperature, humidity and air-contaminant sensors capable of monitoring the air quality in buildings and detecting smoke and fire. The tags can also act as communication devices by receiving alerts from remote stations or sending pre-coded messages to a central station when specific buttons are activated.

Tracking materials mined: According to Roberti (2013*b*), Vale Inco is using RFID technology to track the grade (material concentration) of ore as it is mined. At the company's Stobie mine in Canada, geologists encode ore grade onto the RFID tags using handheld devices and place these tags into ore piles. The ore is crushed and then transported or conveyed for further processing. The tags, designed to survive the crushers, indicate the ore grade to RFID readers throughout the process. This information is communicated from the RFID readers to a computer that stores the information in a database. The RFID system replaces the typical manual, paper-based process and allows for more accurate forecasting of the kind of ore mined and the time it takes to haul the ore to the surface. Additionally, the mills are provided with more accurate and timely information regarding the ore blend to be expected which allows for proper chemical preparation. Similarly, South African gold mines such as Goldfields, Harmony Gold Mining Co., AngloGold Ashanti and the Amplats Group use Oretrak, an RFID-based tracking system, to ensure that extracted material is not misrouted (Roberti, 2013*b*).

Tracking vehicles and pickups: Various mines use RFID systems to prevent vehicular collisions. Anglo American uses RFID and GPS systems at many of its mines for this purpose. Roberti (2013*b*) states that Byrnecut Mining, a contractor in Australia, utilises an RFID system at its Telfer gold mine (in Telfer, Australia). An increase in vehicular collisions (as a result of an increase in production) prompted the deployment of the RFID system to alert drivers of nearby vehicles and employees.

Sesa Goa Ltd., India's largest private sector producer and exporter of iron ore, implemented an RFID system to decrease the overall time required for their trucks to complete delivery cycles. The company conducts more than 7000 truck runs daily between mines, plants and jetties. The logistics involved were complicated and Sesa Goa Ltd. decided to automate internal processes in order to reduce bottlenecks, develop a single master database for logistics operations and achieve faster turnaround times of trucks. Similarly, V.M. Salgaocar & Bro., an Indian mining organisation that sells iron ore, has implemented a Near Field Communications (NFC) solution to simplify tracking of trucks from the company's iron mines to various weigh stations and the processing plant.

Tracking equipment and employees: BHP Billiton's Mitsubishi Alliance (BMA) coal mine, in Australia, tracks miners and their gear with RFID tags. Costs and availability of miners and equipment can be controlled accurately and efficiently using RFID's automatic data capturing and tracking capabilities. According to Roberti (2013*b*), RFID was selected over other tracking technologies "due to its ability to track people and equipment quickly and unobtrusively at a competitive cost". One of the world's largest producers of gold, Newmont Mining, implemented a Wi-Fi-based RFID solution in 2009 to track more than 600 miners and 95 vehicles. This was an attempt to improve worker safety and operational facilities at the organisation's Leeville and Midas mines (in Nevada, USA). The project was deemed successful and Newmont Mining has included RFID in its standard business model. Similarly, Anglo American has deployed RFID systems at mines such as its El Soldado mine in Chile where mine managers receive aboveground real-time information about the locations of more than 800 employees. This system also prevents employees from entering restricted or hazardous zones. Glencore Xstrata, the international mining group, also uses a Wi-Fi-based RFID system at its Beltana coal mine (in New South Wales, Australia) to track employees in order to improve safety and productivity.

Managing contract labour and rental equipment: Contractors provide workers, tools, vehicles and equipment to mining organisations. According to Roberti (2013*b*), thousands of contract workers and items of equipment can be on-site at any given moment (often during projects extending over years). This becomes problematic when organisations need to verify the work performed by contractors and pay contractors for the correct hours worked. Additionally, rental equipment is often misplaced. Bechtel, a construction company in Chile, used an RFID system to manage contract workers as they constructed a new copper mine for Anglo American at Los Bronces in 2008 – 2009 (Roberti, 2013*b*). Each contract worker was issued an RFID-enabled ID badge containing the worker's name, photo, company's name and tax identification number. The amount of time required for a busload of contract workers to pass through access points decreased from 25 minutes to 7 minutes. Furthermore, the system allowed employees to be clocked into timed payroll systems simply by being scanned instead of being asked for details.

3.9 Chapter Summary

Owing to the importance and size of the content, *asset traceability technology* has been discussed in a dedicated chapter. After a description of asset traceability technology, the various performance metrics typically pertaining to positioning systems are discussed. The three primary traceability technologies, namely barcode technology, RFID technology and GPS technology are addressed. Microdots are also mentioned, but this technology is typically only utilised for security purposes and, therefore, not considered in detail.

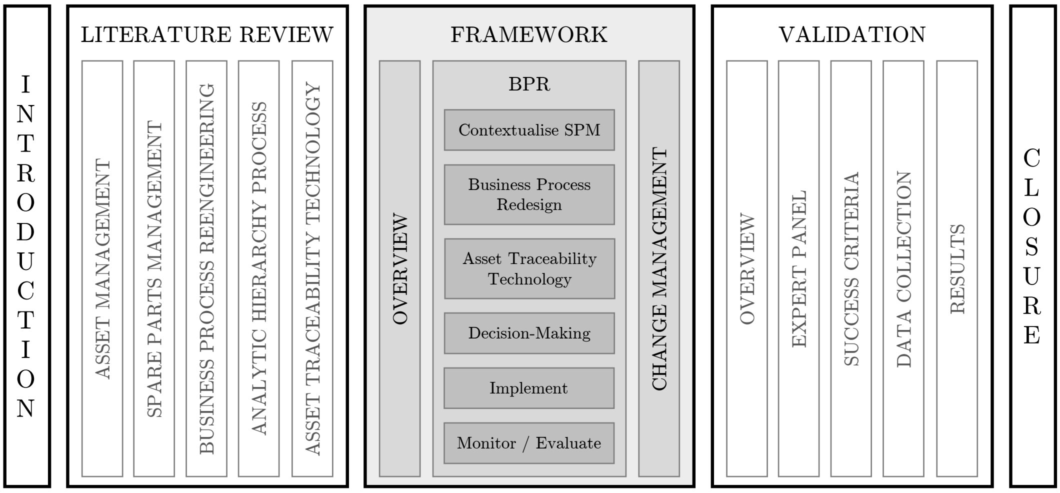
Important operational characteristics (such as *Cost*, *Range*, *Interference Susceptibility* and *Accuracy and Precision*) are analysed (including relevant, up-to-date values) for each of the three primary traceability technologies. The *AHP* supports the selection of technology in the proposed framework (Chapter 4) based on some of these aspects. Finally, the chapter concludes with various applications of asset tracking technologies in different industries such as Retail, Logistics & Shipping, Fleet Management, Manufacturing & Automotive, Pharmaceutical and Mining.

The next chapter provides a detailed discussion of the proposed framework.

Chapter 4

Proposed Framework

The literature review consists of Chapter 2 which discusses Asset Management (AM), Change Management, Spare Parts Management (SPM), Business Process Reengineering (BPR) and the Analytic Hierarchy Process (AHP), and Chapter 3 which discusses asset traceability technology. Chapter 4 proposes a framework that serves as a stepwise guide for the BPR of spare parts processes while considering Change Management elements, and that supports the selection (through use of the AHP) of asset traceability technology for integration within SPM. The framework is based on the extensive literature review provided in Chapter 2 and Chapter 3. The chapter begins with an overview of the framework (including a description of the desired framework attributes and framework structure) and, thereafter, each stage, phase and step of the framework is described.



4.1 Overview

As described in Section 1.1, few companies actually adopt proper structural, factual and quantitative approaches to manage spare parts despite the relatively vast body of literature on spare parts. Thus, Bacchetti and Saccani (2012) emphasise that integrated approaches to manage spare parts and to supplement theoretical models with practical guidelines are required in order to bridge the gap between research and practice. One approach to improve any processes in an organisation is a Business Process Reengineering (BPR) initiative, but a framework is required to guide such an initiative and, thereby, bridge the gap between research and practice.

A BPR initiative is a very complex, time-consuming project that requires coordination of various elements and consideration of a multitude of factors. Additionally, organisations typically require implementation of modern technology in order to remain competitive by reducing process costs, improving productivity, increasing efficiency and enlarging capacity. Section 2.3.5 described IT as a key enabler for BPR. Focusing on this technology alone, however, often leads to failure of such technology implementations. Therefore, it is important for technology to be integrated into processes with the focus on (i) improving the business processes (not merely automating them, as mentioned by Attaran (2004) in Section 2.3.5) and (ii) the impact on people (as mentioned in Section 2.1.6.4, a successful CMMS implementation is typically 60% people-orientated, 25% process-orientated and 15% technology-orientated).

This chapter provides a proposed framework that serves as a guide for (i) a BPR initiative focused on improving processes within Spare Parts Management (SPM) and (ii) the selection of traceability technology for integration within the SPM environment while considering Change Management aspects. The framework is based on the extensive and comprehensive literature review presented in Chapter 2 and Chapter 3. The framework includes generic steps and it is not intended to be applied exactly as is. Rather, the user is expected to have fairly extensive knowledge, or access to this level of knowledge, on the specific SPM environment as well as basic knowledge of BPR. This approach is supported by various authors that believe a BPR initiative should follow a structured, but not prescriptive guide (Hammer, 1990; Harrington, 1991; Belmonte and Murray, 1993). The user should follow the steps and apply them sequentially as required. The steps may also cause the user to consider other aspects (not mentioned herein) that would otherwise not have been considered.

This chapter continues with a description of the framework attributes deemed necessary. Thereafter, Section 4.1.2 discusses the development and structure of the proposed framework. The stepwise framework that can be followed during a BPR initiative begins at Section 4.2.

4.1.1 Framework Attributes

As mentioned in Section 1.3, the proposed framework is to have the following attributes:

- *Generic and adaptable*: the framework should be applicable to various environments in different organisations (within capital-intensive industries) and should not be restricted to a specific site only.
- *Holistic and comprehensive*: the framework should be a multi-discipline-integrated, holistic approach that considers all, or at least the majority, of the relevant aspects concerned with the problem studied.
- *Objective- or outcome-oriented*: the framework and the steps therein should be structured in such a way that outcomes or objectives are the focus and are clearly stated.
- *Practical*: the framework should be applicable to industrial practice.
- *Structured*: the framework should be logical, organised and sequential. Its steps should guide the user towards an appropriate solution.

The framework should be generic and adaptable as SPM environments differ among organisations. Furthermore, the framework needs to be holistic and comprehensive since redesign of processes affects more than merely the processes themselves and implementing technology affects different departments and disciplines. The framework should also be logical, well-defined and practical. This increases the probability that the framework would actually be used within industry. To facilitate the use of the guide, it should be objective- or outcome-oriented such that the users know what the end-goal of each step is. The *Structured* attribute and the *Objective- or outcome-oriented* attribute will be grouped together henceforth since the structure is intended to support the attainment of the objectives or outcomes. The framework is also required to contextualise the SPM environment before any process redesign or technology implementation can commence. The following subsection discusses the development and structure of the proposed framework.

4.1.2 Framework Development and Structure

Figure 4.1 illustrates the proposed framework. The framework is partly inspired from the research undertaken by Hassan *et al.* (2015). Furthermore, it is loosely based on phases from various BPR models investigated by Abdel-Fattah (2015) and the primary steps of BPR proposed by Davenport (2013) and Changchien and Shen (2002) in Section 2.3.2.

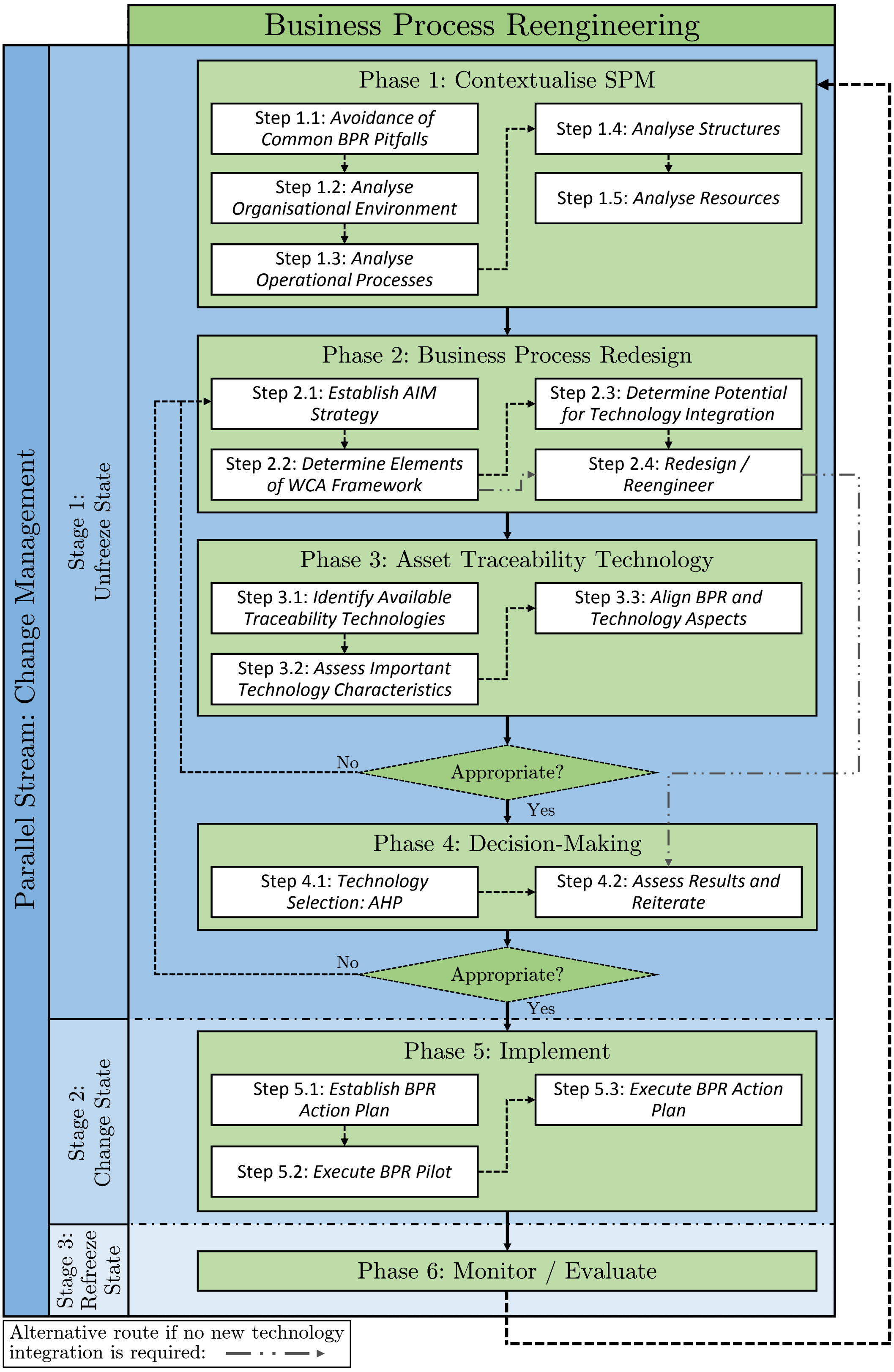


Figure 4.1: Framework outline

During the development of the framework, two Subject-Matter Experts in Industrial Engineering with extensive experience in BPR were consulted regarding the framework, its structure and the validation thereof. The framework aims to provide a stepwise guide to undergoing a BPR initiative, particularly one that incorporates traceability technology into the SPM environment while considering Change Management elements. The focus of the framework is on asset traceability technology being selected through the Analytic Hierarchy Process (AHP) and integrated into improved (redesigned) business processes. However, various generic steps are included to provide a comprehensive guide for a BPR initiative.

The framework consists of two streams, namely the primary BPR stream (Section 4.2) and a parallel Change Management stream (Section 4.3). The parallel Change Management stream consists of three stages that correlate with certain phases of the BPR stream. The BPR stream consists of phases which each contain multiple steps that guide the user through the activities or processes involved in such an initiative. The steps of the framework follow a logical progression and are numbered in the sequence in which they should be performed. The steps (and their respective sub-steps) are generic and should be modified and applied as required by the specific area of application.

Each step is structured into four sections, namely *Purpose*, *Inputs*, *Sequence & considerations* and *Outputs*. This structure is similar to the structure proposed by the NIST (1993) in IDEF0 for function modelling. The *Purpose* section provides the reason or motivation for the specific step. The *Inputs* section indicates the information or knowledge from other steps or from outside the framework that is required for the specific step to be performed. The *Sequence & considerations* section provides the sequence of sub-steps to be performed and/or the necessary considerations of which to be cognisant. The *Outputs* section indicates the final outputs of the specific step such as the knowledge or information generated which are used in other steps in the framework. Table A.1 and Table A.2 in Appendix A summarise the various inputs required and outputs obtained, respectively, corresponding to each step of the framework.

When a step is mentioned in text, the corresponding section is provided in parentheses. With multiple steps listed, this may somewhat impact on the readability of the *Inputs* and *Outputs* sections adversely. However, it improves the user's ability to find the relevant step within this framework. Since this framework is intended to be a guide and contains multiple cross-references to various steps, the aim of this structure is to improve the ease of identifying and following the steps of the framework. Additionally, this document may be read in electronic format in which case the cross-references include hyperlinks to the relevant sections.

Section 4.2 is the departure point of the framework and indicates the sequence of phases that form part of the BPR stream and the corresponding section describing each phase. Each section that corresponds to a certain phase contains steps that are described in detail within that section. Figure 4.1 indicates the sequence of steps.

4.2 Stream: Business Process Reengineering

Typically, a BPR initiative involves various elements and phases, including Project Management, Change Management, evaluation of existing processes, redesign of processes and the actual implementation of planned changes (as depicted in Figure 2.7 in Section 2.1.6.3). Table 2.8 in Section 2.3.5 tabulates the roles IT can play in the *before* phase, *during* phase and *after* phase of a BPR initiative. Additionally, Wei *et al.* (2005) developed an AHP-based approach to ERP system selection which is somewhat fundamentally similar to (yet less comprehensive than) this BPR framework process incorporating the technology selection process.

This framework, in its entirety, is to be considered a BPR initiative with reference to specific phases that occur within the overall BPR stream (initiative). This section indicates the sequence of the phases, as depicted in Figure 4.1, which are addressed separately within this chapter. These phases include:

1. contextualising the SPM environment (Section 4.4) — Poon, Choy, Chow, Lau, Chan and Ho (2009) highlight that an efficient technology solution in the warehouse environment can be formulated by assessing the actual physical and internal environment before considering available technology solutions;
2. redesign of business processes (Section 4.5);
3. consideration of asset traceability technology aspects (Section 4.6);
4. decision-making for selection of technology (Section 4.7);
5. implementation of redesigned processes and technology integration (Section 4.8); and
6. monitoring or evaluation of the final solution (Section 4.9).

The *Implement* phase and the *Monitor and Evaluate* phase are not the core focus of the framework, but are briefly addressed for completeness.

The *Change Management* stream, discussed in Section 4.3, involves three stages and flows in parallel to, and correlated with, the six BPR phases. The first stage is to unfreeze the existing state (*Unfreeze State*) and this relates to Phase 1, Phase 2, Phase 3 and Phase 4 of the BPR initiative. The second stage involves the actual transition from existing state to new state (*Change State*) and correlates with the *Implementation* phase. The third stage focuses on evaluating and sustaining the new changes (*Refreeze State*) and relates to the *Monitor and Evaluate* BPR phase. It is important to remember that the Change Management stream (in Section 4.3) occurs in parallel to the BPR phases and, therefore, both streams should be performed simultaneously. A concise explanation (significantly shorter than described in this chapter) of the framework is provided in Appendix B.

The framework requires a certain degree of general knowledge and should ideally be followed in consultation with experts of the processes under review. This is due to experts in the field understanding the interdependencies that exist between processes and the manner in which the overall process structure may be affected through BPR. Furthermore, the user is advised to consult decision-making frameworks relating to spare parts such as those proposed by Driessen *et al.* (2014), Du Toit (2014) and Cavalieri *et al.* (2008), as well as relevant literature discussed in Section 2.2. These frameworks consider additional aspects and the actual operational management of spare parts from which the organisation may benefit.

4.3 Parallel Stream: Change Management

A BPR initiative affects and involves many people and their jobs. Additionally, as highlighted in Section 2.1.6.4, people can have a significant impact on the success of a technology implementation. Therefore, Change Management is a critical aspect to consider. As cited by Hale and Cragg (1996), this is supported by Duck (1993) who considered the adequate management of change to be fundamental in any successful BPR initiative. Change Management does not occur only in the implementation phase of a BPR initiative, but rather is present parallel to other phases throughout the entire project. Change Management is discussed in Section 2.1.7 regarding planned and managed change. Table 2.5 in Section 2.1.7.3 provides various theoretical approaches and their associated tasks to facilitate change. This stream follows the PDCA cycle described in Section 2.1.4.1 and, more specifically in terms of AM, in Table 2.2. The following stages occur throughout the BPR initiative:

4.3.1 Stage 1: Unfreeze (Existing) State

The existing state of an organisation or process (including existing social habits) needs to be "unfrozen". This means that the current state should be understood completely and that all necessary preparations for change should be made prior to implementing the changes. This involves creating an understanding as to why change is necessary and explaining to stakeholders that change is inevitable. The characteristics and tasks associated with this stage are described in Table 2.4 in Section 2.1.7.2. This stage initiates the *Plan* phase of the PDCA cycle and relates to Phase 1 (Section 4.4), Phase 2 (Section 4.5), Phase 3 (Section 4.6) and Phase 4 (Section 4.7) of this framework. The following items should be addressed:

1. consider why and how any resistance to change could be created (Section 2.1.7.1) and identify the different responses to change by referring to Table 2.3 in Section 2.1.7.1;
2. identify the relevant tasks to facilitate change efforts as provided in Table 2.5 in Section 2.1.7.3 and perform them;
3. management should explain to relevant parties why change is necessary;
4. include relevant or affected parties in all discussions or negotiations regarding change efforts;
5. listen to and consider opinions, hesitations and concerns regarding change efforts (this may involve satisfaction surveys or questionnaires); and
6. motivate staff for change implementation.

This stage transitions into *Stage 2: Change State (Transition)* where changes are actually performed.

4.3.2 Stage 2: Change State (Transition)

Once the appropriate atmosphere for the change initiative has been set, the actual process to implement change efforts may proceed. The characteristics and tasks associated with this stage are described in Table 2.4 in Section 2.1.7.2. This stage continues the *Plan* phase of the PDCA cycle and transitions to the *Do* phase. It relates to Phase 5 (Section 4.8) of this framework. The following steps are to be performed:

1. establish both long-term and short-term objectives of implementation;
2. determine roles and procedures for change implementation;
3. establish schedule and budget for change efforts;
4. perform risk assessment of change initiative, assessing impact of actions on people, jobs, existing technology, existing structures, methods and processes;

5. order necessary elements for the change initiative, including technology systems required;
6. implement planned change initiative (*Do* phase of PDCA cycle);
7. ensure management visibility;
8. update employees of progress regarding change efforts; and
9. evaluate actual milestones and achievements with objectives, schedule and budget (portion of *Check* phase of PDCA cycle).

This stage transitions into *Stage 3: Refreeze (New) State* where the changes are "frozen".

4.3.3 Stage 3: Refreeze (New) State

After changes have been made, there is a period of time in which people have to become accustomed to the new changes. This stage attempts to initiate measures to sustain the new procedures or structures. The characteristics and tasks associated with this stage are described in Table 2.4 in Section 2.1.7.2. This stage also incorporates the *Check* and *Act* phases of the PDCA cycle after transitioning from the *Do* phase. It relates to Phase 6 (Section 4.9) of this framework. The following items should be considered:

1. incorporate changes into strategy, policies, plans and organisational identity;
2. standardise procedures;
3. retrain employees as required;
4. continuously monitor new processes (*Check* phase of PDCA cycle); and
5. address unforeseen issues (*Act* phase of PDCA cycle).

This is the final stage and typically involves continuous improvement.

4.4 Phase 1: Contextualise SPM

The framework begins with Phase 1 which requires that the specific context and environment be determined. In this phase, the user identifies the existing state-of-being of the organisation, particularly the environments in which spare parts processes may operate or impact. This allows the user to implement the framework in a holistic manner, being aware of problem areas of the current state-of-being and of the potential limitations or restrictions that may affect possible solutions. Furthermore, Hassan *et al.* (2015) state that warehouse contextual factors such as structure, workflow and resources are major considerations in technology selection decisions.

As mentioned in Section 4.2, literature discussed in Section 2.2 [particularly the frameworks proposed by Driessen *et al.* (2014), Du Toit (2014) and Cavalieri *et al.* (2008)] should be consulted as this may be useful for benchmarking existing organisational strategies and policies relating to spare parts, as well as providing approaches that the organisation may wish to adopt. Additionally, Table 2.6 in Section 2.2.5.2 highlights important considerations concerning the warehouse design and operation. These should be considered in this phase and the most important aspects (such as *degree of automation* and *warehouse dimensions*) are reiterated in the steps in this section.

4.4.1 Step 1.1: Avoidance of Common BPR Pitfalls

Purpose: Before undergoing a BPR initiative, the user must be familiar with the foundation principles of BPR (Section 2.3.1) and common pitfalls (Section 2.3.6) in order to guard against failure.

Inputs: Knowledge of the definition and concept of BPR.

Sequence & considerations: It is important for the user to recognise:

- the proper definition of BPR and the concept of BPR (refer to Section 2.3);
- the proper strategy (align BPR to organisational objectives);
- realistic objectives (do not underestimate cost and time required);
- the focus on processes as opposed to departments or areas;
- the focus on outcomes instead of only tasks;
- geographically dispersed resources as though they were centralised;
- the necessity for new boundaries and new horizontal connections which results in a culture change;
- availability of unmodified information to aid learning process;
- the value of capturing information as few times as possible and at the source;
- the possible need for change in management styles;

- the importance of people during initiatives;
- the empowerment of employees by placing decision points closer to the actual work (with the necessary controls in place); and
- the need for changes to Information Systems (IS).

Outputs: Awareness of pitfalls before undergoing subsequent steps in framework. User may proceed to Step 1.2 (Section 4.4.2).

4.4.2 Step 1.2: Analyse Organisational Environment

Purpose: The organisational environment needs to be evaluated to understand the organisation's strategy and how the inventory management policies and systems align to this overarching strategy. Since a holistic inventory solution is required, it is important to consider environments outside the inventory warehouses or storerooms.

Inputs: Awareness of BPR pitfalls from Step 1.1 (Section 4.4.1).

Sequence & considerations: The following items should be determined, particularly where it relates to inventory management:

1. business objectives and organisational scope;
2. IT knowledge, capabilities, education and training;
3. amount of top management support (both in general and specifically for new programmes, inventory management programmes and technological innovation); and
4. internal warehouse problems, needs and requirements.

Outputs: Understanding of the organisational environment, including: the business objectives to which SPM objectives should be aligned, the support available to ensure the success of a BPR initiative and the problems, needs and requirements experienced in the warehouse and storerooms; this contextualises Step 1.3 (Section 4.4.3), Step 1.4 (Section 4.4.2) and Step 1.5 (Section 4.4.5), as well as the BPR initiative in general; information from this step is required in Step 2.1 (Section 4.5.1), Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 4.2 (Section 4.7.2) and Step 5.1 (Section 4.8.1).

4.4.3 Step 1.3: Analyse Operational Processes

Purpose: Once the understanding of the organisational environment has been established, the user may begin the consideration of existing operational processes. This step lays the foundation for Phase 2: Business Process Redesign (Section 4.5) which is when the spare parts processes are redesigned or reengineered.

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; criteria, provided in Section 2.3.3, for selecting processes to improve; understanding of the Work-Centred Analysis (WCA) process described in Step 2.2 (Section 4.5.2).

Sequence & considerations: Table 2.6 (in Section 2.2.5) provides many applicable considerations (under *Warehouse operation*) regarding this step. The user may also wish to use tools or methods for process modelling such as the Integrated Definition (IDEF) for function modelling methods, Business Process Modelling Notation (BPMN), the Flowchart Technique, Coloured Petri Nets (CPN) and/or the Workflow Technique. This allows for an easier and more methodological approach to understand and analyse processes. The following points should be addressed in this step:

1. understand key processes;
2. identify processes to be improved [criteria for selecting processes to improve are provided in Section 2.3.3 and this may require a benchmarking method such as that proposed by Talluri (2000)] — Davenport (2013) highlights the importance of selecting processes for redesign early within a BPR initiative in order to focus resources and effort;
3. evaluate (and benchmark) the existing business process design and identify points to improve (this includes a Work-Centred Analysis (WCA) described in Step 2.2 (Section 4.5.2) in Phase 2); and
4. identify the organisation's preferred warehouse process flows and system requirements.

Outputs: Identification of existing processes to be improved and evaluation of process elements both required primarily for Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3) and Step 2.4 (Section 4.5.4), as well as for reference in Step 1.5.

4.4.4 Step 1.4: Analyse Structures

Purpose: Existing structures need to be evaluated so that potentially viable solutions can be identified. The existing structures will also determine how existing processes can be altered without redesigning the entire facility. Additionally, Bhuptani and Moradpour (2005) assert that physical and environmental factors, such as the size of the storerooms, the number of aisles, the types of material handling equipment and types of parts stored, can affect the readable range and accuracy of RFID.

Inputs: Understanding of the various part classifications described in Section 2.2.3; understanding of organisation's preferred method of part classification; awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; consideration of existing processes from Step 1.3 (Section 4.4.3).

Sequence & considerations: Table 2.6 (in Section 2.2.5) provides many applicable considerations (under *Warehouse design*) regarding this step. This step requires an assessment of the:

1. number, value and types of spare parts (including consideration of different part classifications used by the organisation, such as those described in Section 2.2.3), as well as the types of materials — Hassan *et al.* (2015) identified the product or material type to be the most important structural factor for AIDC technology implementation;
2. warehouse dimensions;
3. layout of departments or important areas;
4. number, sizes and material types of racks and aisles;
5. manner in which parts are moved around and issued (in cases, pallets or items);
6. degree of mechanisation or degree of automation — Hassan *et al.* (2015) identified this to be the second most important structural factor for AIDC technology implementation;
7. electric fields (E-plane) and magnetic fields (H-plane) — Hassan *et al.* (2015) identified the assessment of electric fields (E-plane) to be the third most important structural factor for AIDC technology implementation; and
8. existing IT infrastructure and potential for adopting new technology.

Outputs: Understanding of existing structures (such as infrastructure) available to support or be utilised in BPR initiative; information from this step is required primarily in Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3) and Step 2.4 (Section 4.5.4).

4.4.5 Step 1.5: Analyse Resources

Purpose: The final step of contextualisation involves an assessment of the available resources such as employees, equipment and storage systems. This assessment is important in order to be aware of existing resources that can or should be incorporated into redesigned processes and those that may be available for utilisation during the BPR initiative.

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; understanding of types of WMS discussed in Section 2.2.5.5; processes under examination [selected from Step 1.3 (Section 4.4.3)].

Sequence & considerations: Table 2.6 (in Section 2.2.5) highlights many applicable considerations (under both *Warehouse design* and *Warehouse operation*) relating to this step. This step requires an evaluation of the:

1. warehouse and storeroom employees — Hassan *et al.* (2015) report warehouse labour to be the third most important resource-related factor for AIDC technology implementation;
2. equipment that is used for inventory handling — Hassan *et al.* (2015) report this to be the most important resource-related factor for AIDC technology implementation;
3. overall Warehouse Management System (WMS) and type of WMS such as the kinds described in Section 2.2.5.5 — Hassan *et al.* (2015) identified WMS to be the second most important resource-related factor for AIDC technology implementation;
4. storage systems;
5. storage units; and
6. space capacity.

Outputs: Indication of resources that should be incorporated into redesigned processes, that may be available for utilisation during BPR initiative and that may be available for utilisation elsewhere after BPR initiative; information from this step is required primarily in Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9).

4.5 Phase 2: Business Process Redesign

Phase 2 involves the redesign of the spare parts processes. The point of departure is to assess existing processes and layouts of the organisation's SPM and redesign the processes as efficiently and effectively as possible using BPR principles (discussed in Section 2.3.1) and best practices (discussed in Section 2.3.4). Thereafter, integration of new technology is considered following the steps in Phase 3 (Section 4.6). This results in a somewhat iterative process whereby Phase 2 is initially considered (as suggested by Hammer and Champy (1995) in Section 2.3.5), then new technology integration is considered in Phase 3, after which Phase 2 is consulted again considering the changes required as a result of the new technology integration.

As mentioned in Section 2.3, a combination of BPR best practices may negate the effects of each BPR best practice in isolation. This is important to consider when redesigning any processes. The user may also wish to use tools or methods for process modelling such as the Integrated Definition (IDEF) for function modelling methods, Business Process Modelling Notation (BPMN), the Flowchart Technique, Coloured Petri Nets (CPN) and/or the Workflow Technique.

4.5.1 Step 2.1: Establish AIM Strategy

Purpose: This step establishes the Asset Information Management (AIM) strategy as described in Section 2.1.6. This strategy describes the manner in which asset information is processed and aids with identification and selection of suitable technology (addressed in Section 4.6 and Section 4.7, respectively).

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: The approach, as mentioned in Section 2.1.6.2, is to first design possible strategies for AIM, then evaluate the strategies and finally select the most suitable strategy. Figure 2.4 in Section 2.1.6.2 illustrates the various stages and elements of both the top-down and bottom-up approaches regarding AIM strategy development. The following items relating to AIM, mentioned in Section 2.1.6.2, are important to consider:

- the type of data to capture;
- the method of capturing the data;
- the method to measure the data;

- the method to evaluate the data;
- the manner in which to interpret results;
- the value of information generated by the technology; and
- the Return on Investment (ROI).

Outputs: Establishment of AIM strategy that indicates the management of data and affects selection of technology as well as redesign of processes; information from this step is required in Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 3.3 (Section 4.6.3), Step 4.2 (Section 4.7.2) and Phase 6 (Section 4.9).

4.5.2 Step 2.2: Determine Elements of WCA Framework

Purpose: It is important to decompose existing and planned processes into elements such that all the relevant components can be considered and integrated successfully. Once the processes to redesign have been selected and the various elements of these processes identified, the user can determine the potential for any technology integration regarding these processes in Step 2.3 (Section 4.5.3).

Inputs: Existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: The existing business processes for redesign were identified in Step 1.3 (Section 4.4.3) of Phase 1: Contextualise SPM. Step 2.2 requires that the elements for each existing business process, as described by the Work-Centred Analysis (WCA) framework mentioned in Section 2.3, be determined. This is also to be performed for the desired (new) processes during redesign of the existing processes. Figure 2.14 illustrates the WCA framework graphically. There are six elements to be considered and identified, namely the:

1. *customers*: these are the people that receive the products, such as technicians requesting spare parts;
2. *products*: these are the end-products (or services) of the process, such as spare parts being delivered to technicians or certain documents being completed for ordering parts;

3. *business process*: this is the actual process procedure, such as an order-picking process;
4. *participants*: this refers to the people involved in performing the process, such as storeroom staff;
5. *information*: relevant information used or created by the process, such as details of persons requesting parts and the parts available; and
6. *technology*: technology that enables the process, such as a sorting machine for a sorting process.

Outputs: Allocation and recognition of elements for each process; information from this step is required primarily in Step 1.3 (Section 4.4.3), Step 2.4 (Section 4.5.4) and Step 4.2 (Section 4.7.2).

4.5.3 Step 2.3: Determine Potential for Technology Integration

Purpose: The user needs to be aware of the potential to integrate technology into redesigned processes as this may affect the selection of BPR practices [Step 2.4.2 (Section 4.5.4.2)] and the redesign of these processes which occurs in Step 2.4 (Section 4.5.4). This step considers the potential for technology integration in order to aid the identification and selection of technology in Phase 3 (Section 4.6) and Phase 4 (Section 4.7). Should the user not require any implementation of technology (and therefore only desires to improve business processes in general), the user may continue to Step 2.4 (Section 4.5.4) without performing this step.

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: This step requires that the user assesses the information derived in Phase 1 (Section 4.4). This information includes, among others: IT knowledge, capabilities, education and training [Step 1.2 (Section 4.4.2)]; support for technological innovation [Step 1.2 (Section 4.4.2)]; preferred warehouse process flows and system requirements [Step 1.3 (Section 4.4.3)]; warehouse dimensions, degree of mechanisation and automation, electric fields and magnetic fields or Electromagnetic Interference (EMI), and existing IT infrastructure [Step 1.4 (Section 4.4.4)]; and equipment used for inventory handling, WMS and storage systems [Step 1.5 (Section 4.4.5)]. Before the applicable BPR best practices can be allocated to the selected processes for redesign, the user needs to consider the potential to integrate technology into redesigned processes (as proposed by Attaran (2004) in Section 2.3.5).

The user needs to consider the:

- amount of space that is available for technology implementations;
- capacity for training regarding any new technology;
- level of support (from various stakeholders) there will be for technology implementations;
- ease of integrating technology into the preferred process flows and requirements;
- degree of existing automation and mechanisation and how this may affect future technology integration;
- interference (such as EMI) present that may affect technologies such as RFID systems; and
- various systems available.

The actual technology aspects such as desired operational characteristics are considered only in Phase 3 (Section 4.6), and Phase 2 is reiterated if the redesigned processes are not aligned to desired technology aspects.

Outputs: Understanding of potential to integrate technology successfully into the existing environment; information from this step is required in Step 2.4 (Section 4.5.4), Step 3.2 (Section 4.6.2) and Step 4.2 (Section 4.7.2).

4.5.4 Step 2.4: Redesign or Reengineer

Purpose: This step aims to redesign existing processes using information derived from the previous steps.

Inputs: Warehouse design decision levels and warehouse considerations discussed in Section 2.2.5.2; aspects from Section 2.2.5.3; BPRD best practices from Section 2.3.4; foundation principles from Section 2.3.1; MCDM models mentioned by Campos and De Almeida (2015) for best practices from Section 2.3.4; awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); elements of existing business processes and those required for new processes from Step 2.2 (Section 4.5.2); understanding of potential for technology integration from Step 2.3 (Section 4.5.3); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: The following sub-steps are to be followed:

1. for all processes selected in Step 1.3 (Section 4.4.3), consider *each* of these processes according to the subsequent sub-steps below;
2. consider the existing process elements identified in Step 1.3 (Section 4.4.3);
3. consider the process elements required (based on the existing processes) and available for the new processes identified in Step 2.2 (Section 4.5.2);
4. be cognisant of the AIM strategy and the relevant considerations in Step 2.1 (Section 4.5.1);
5. be cognisant of the potential for technology integration (contextual aspects) as in Step 2.3 (Section 4.5.3);
6. consider legal and environmental issues relevant to the process;
7. select the appropriate BPR best practices as in Step 2.4.2 (Section 4.5.4.2); and
8. plan modifications (including new layouts and operational flows) of existing process by considering design aspects in Step 2.4.1 (Section 4.5.4.1) and applying the best practices selected in Step 2.4.2 (Section 4.5.4.2).

Outputs: Redesigned business processes; information from this step is utilised in Step 3.3 (Section 4.6.3), Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9).

4.5.4.1 Step 2.4.1 Consider Warehouse and Storeroom Design

Section 2.2.5.2 describes the three levels (*strategic*, *tactical* and *operational*) involved with warehouse design. The entire BPR initiative itself occurs on the strategic level, but the steps within are mostly concerned with the tactical and operational levels. The user should consider the level at which decisions occur and how these decisions affect the organisation. An important decision factor is the cost of processes and this cost should be minimised when possible. Figure 2.12 in Section 2.2.5.2 illustrates the typical distribution of costs associated with warehouse processes. Order-picking is one of the largest costs regarding processes and this is an important focus area in the redesign. Additionally, Table 2.6 in Section 2.2.5.2 displays the various design and operation considerations when redesigning warehouse or storeroom environments.

As mentioned in Section 2.2.5.3, warehouse design should be based on interrelationships between warehouse processes and space requirements while the warehouse operations focus on resource utilisation and customer satisfaction. Gould (2013) states that the primary objective is to minimise both the total distance travelled during the processing of a typical order and the total cost. The following items, mentioned in Section 2.2.5.3, are important to consider:

- equipment utilisation;
- space utilisation;
- labour utilisation;
- accessibility to inventory; and
- protection of inventory.

The following sub-steps (from Section 2.2.5.3) aim to reduce total process flow:

- design for as few movements of flow between consecutive points as possible;
- provide materials, information and people as required to facilitate processes and eliminate unnecessary steps; and
- combine flows and operations by planning the handling of materials, information and people to be integrated into processing steps.

As explained in Section 2.2.5.3, a U-shaped layout is the most popular and effective layout of warehouse activities for material handling process flows (Gould, 2013). Blomqvist (2010) highlights that this layout allows for fast-moving items to be placed closer than the slow-moving items, thereby supporting class-based storage. Therefore, the user should attempt to design processes in U-shaped layouts when possible if no better layouts are applicable.

Additionally, the user should consider issues mentioned in Section 2.2.5.4 such as the existence of squirrel stores and implement stricter policies regarding order-picking and monitoring of spare parts. Du Toit and Houston (2013) argue that it is vital to know what inventory is owned at any given time before inventory levels can be reduced. This includes knowledge of the location and quantity of all spare parts. Therefore, the organisation may wish to implement traceability technology [discussed in Chapter 3 and considered in Phase 3 (Section 4.6)] to track or trace spare parts. Storerooms should also be maintained as assets would be on-site. Therefore, motors and gearboxes in storage should be maintained and lubricated (including being turned over regularly) despite the lack of usage of these motors and gearboxes. This may require storerooms to have a designated maintenance zone.

4.5.4.2 Step 2.4.2 Select Appropriate BPR Best Practices

Taking cognisance of the elements of the business process [identified in Step 2.2 (Section 4.5.2)], the process points to be improved (identified in Step 1.3 (Section 4.4.3) of Phase 1) and the previous steps in this phase, consider and select the most appropriate BPR best practices (explained in Section 2.3.4) or principles (mentioned in Section 2.3.1) to apply to the process. Twenty-nine different BPR best practices have been described in Section 2.3.4. This is one of the most difficult steps requiring the most effort from the user. The user should consider utilising one of the MCDM models available [such as those mentioned by Campos and De Almeida (2015)] to aid selection of the most appropriate best practices.

Every spare parts storeroom is designed differently and functions differently. As a result, the application of these BPR principles depends on the specific site. It is the user's responsibility to assess the existing business processes, determine the amount of effort required and allowed, and then decide which BPR best practices are most applicable. Table 2.7 provides a summary of the typical effects of the 29 BPR best practices on cost, time, quality and flexibility of the processes. However, it is important to remember that combinations of BPR best practices may negate the effects of each of the best practices in isolation. For instance, *task elimination* may reduce the process time, but applying *control addition* or *knock-out* to the same process will either reduce the amount of reduction of the overall process time or increase it.

4.6 Phase 3: Asset Traceability Technology

This phase considers technology aspects. Should the user not require any implementation of new technology (and therefore only desires to improve business processes in general), the user may continue to Step 4.2 (Section 4.7.2) without performing Step 3.1 through to Step 4.1. There are two pertinent considerations regarding asset traceability technology selection. Firstly, the types of technology (such as barcode technology, RFID technology or GPS technology) need to be considered. Thereafter, the various brands, models and variations associated with each specific type of technology needs to be investigated and appropriate combinations selected for implementation. Phase 4: Decision-Making (Section 4.7) aids with the selection of the appropriate technology to use for the specific environment and to achieve desired objectives.

4.6.1 Step 3.1: Identify Available Traceability Technologies

Purpose: This step aims to identify different types of AIDC technologies and involves the consideration of specific brands and models per type of technology.

Inputs: Available AIDC technology systems; new information from Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: The user needs to:

1. consider the different types of AIDC technology solutions (discussed in Chapter 3) such as barcode technology (Section 3.3), RFID technology (Section 3.4), GPS technology (Section 3.5) or hybrid solutions; and
2. investigate the technology systems available within each type of technology, such as the specific brands and models accessible for the particular type of technology.

Outputs: Identification of traceability technology systems that can potentially be integrated into organisation; information from this step is required in Step 3.2 (Section 4.6.2), Step 3.3 (Section 4.6.3), Step 4.1 (Section 4.7.1), Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9).

4.6.2 Step 3.2: Assess Important Technology Characteristics

Purpose: The technology aspects or characteristics relating to the systems identified in Step 3.1 (Section 4.6.1) need to be identified and assessed such that the systems can be evaluated against one another in Phase 4 (Section 4.7).

Inputs: Understanding of potential for technology integration from Step 2.3 (Section 4.5.3); available AIDC technology systems from Step 3.1 (Section 4.6.1); new information from Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: This step involves the consideration of various important characteristics of the technologies identified in Step 3.1 (Section 4.6.1). The sub-steps include:

1. consider the information obtained in Step 2.3 (Section 4.5.3) in Phase 2;

2. identify relevant characteristics (such as the criteria described in Section 3.2 and Section 3.7, including cost, accuracy, complexity, interference susceptibility, and security and privacy) of the technologies that may influence the success of implementation;
3. review the differences between these characteristics for the available technologies identified in Step 3.1 (Section 4.6.1); and
4. consider legal and environmental issues relating to the technologies and the environments in which they will operate.

Outputs: Identification and assessment of various characteristics [used as criteria in Phase 4 (Section 4.7)] of the previously identified traceability technology systems; information from this step is required in Step 3.3 (Section 4.6.3), Step 4.1 (Section 4.7.1), Step 4.2 (Section 4.7.2) and Phase 6 (Section 4.9).

4.6.3 Step 3.3: Align BPR and Technology Aspects

Purpose: It is important to align both the BPR aspects and the potential technology aspects to ensure compatibility for the overall solution.

Inputs: AIM strategy from Step 2.1 (Section 4.5.1); redesigned processes from Step 2.4 (Section 4.5.4); available AIDC technology systems from Step 3.1 (Section 4.6.1); various technology characteristics from Step 3.2 (Section 4.6.2); new information from Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: The following sub-steps attempt to guide the alignment:

1. take cognisance of BPR selections or options proposed in Phase 2 (Section 4.5) together with technology considerations assessed in Phase 3 (Section 4.6);
2. reiterate Phase 2 and Phase 3 as required to ensure alignment of most suitable BPR principles for the technological environment under consideration; and
3. proceed to Phase 4 (Section 4.7) once redesigned processes are aligned appropriately to technology aspects.

Outputs: Alignment of BPR aspects to potential technology aspects; information from this step is utilised in Step 4.1 (Section 4.7.1) and Step 4.2 (Section 4.7.2), as well as Phase 2 [Step 2.1 (Section 4.5.1) to Step 2.4 (Section 4.5.4)] during iteration process.

4.7 Phase 4: Decision-Making

The organisation may have a predisposition towards a specific type of technology or feel confident enough regarding choice of technology without a supporting tool. In this case, the managers can select the relevant technology and proceed to Step 4.2 (Section 4.7.2) without utilising the AHP. However, Phase 4 incorporates the AHP to support the appropriate decision-making regarding technology selection. The AHP is selected as the Multi-criteria Decision-Making (MCDM) tool for its ease of understanding, ease of use, minimal historical data requirements and ability to handle subjective criteria. The following steps guide the user through the decision-making process:

4.7.1 Step 4.1: Technology Selection: AHP

Purpose: As aforementioned, should it be possible or desired to select the appropriate technology without utilisation of the AHP; then the user may proceed to Step 4.2 (Section 4.7.2). However, should it become too complex to assess which technology is suitable for the organisational context or if too many criteria are used, then the AHP (described in detail in Section 2.4) can be used to support the decision-making process.

Inputs: AHP steps from Section 2.4.2 and example from Section 2.4.4; available AIDC technology systems from Step 3.1 (Section 4.6.1) and their various technology characteristics from Step 3.2 (Section 4.6.2) after being aligned in Step 3.3 (Section 4.6.3); new information from Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: This step of Phase 4 provides the AHP steps described in Section 2.4 to support the selection of technology. Saaty and Vargas (2012) discuss the AHP in detail and provide additional considerations regarding structuring the AHP. An example utilising the AHP, and which is related to traceability technology, has been provided in Section 2.4.4. Furthermore, software programs, such as *Expert Choice*, enable the user to structure and resolve problems using the AHP (Saaty and Vargas, 2012). The calculations in the steps can also be set up in a Microsoft Excel spreadsheet (as was performed for this study) that quickly calculates the necessary values. The following steps (discussed in detail in Section 2.4.2) should be performed:

1. deconstruct the problem into a hierarchy of objective, criteria (such as cost, range, etc.), sub-criteria (if required) and alternatives (such as barcode, RFID or GPS technologies) through a top-down approach (as illustrated in Figure 4.2) as described in *Step 1* in Section 2.4.2;
2. evaluate each criterion, then sub-criteria and finally alternatives using qualitative scale through pairwise comparisons based on each relevant

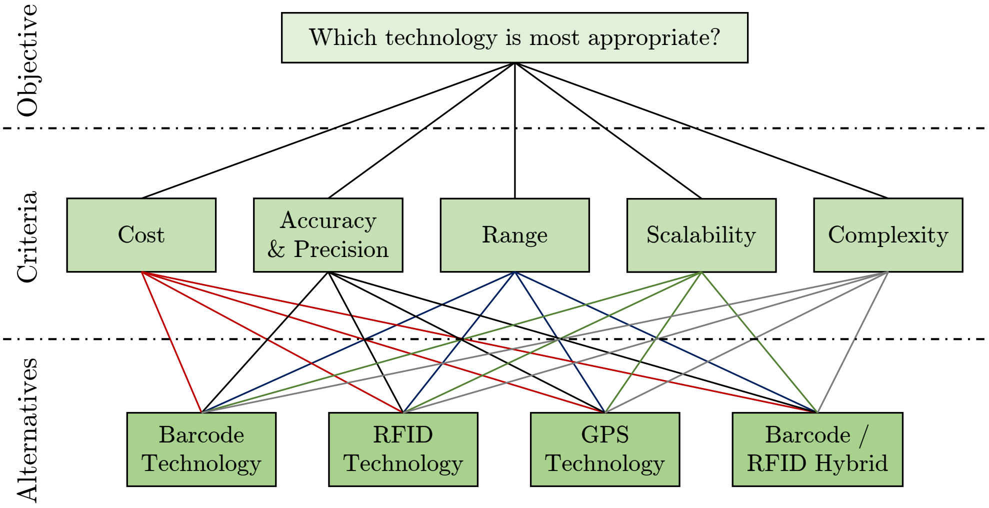


Figure 4.2: AHP hierarchical structure for technology selection

node before branching (such as relevant criterion). This is *Step 2* in Section 2.4.2. For instance, decide if barcode technology will be more expensive than RFID technology (with cost as the relevant criterion). Table 2.11 illustrates an example of comparing criteria;

3. create comparison matrices (as shown in Equation 2.4.1) using data obtained from pairwise comparisons as explained in *Step 3* in Section 2.4.2. First, a comparison matrix containing the data relating to criteria comparisons will be established. Thereafter, comparison matrices for sub-criteria per criterion will be created. Finally, comparison matrices for alternatives based on each sub-criterion will be generated;

4. calculate the steady-state eigenvectors (priority vectors) by squaring and normalising the comparison matrices (using Eigenvector Method) as discussed in *Step 4* in Section 2.4.2;

5. evaluate the consistency of matrices by calculating the Consistency Ratio (CR) as in *Step 5* in Section 2.4.2, reevaluating expert comparison judgements if $CR > 0.1$; and

6. determine the product of the priority matrices (ratings of alternatives) and the weights of the criteria to obtain the final decision priority values for all alternatives (*Step 6* in Section 2.4.2). The largest final decision priority value indicates the most appropriate technology to select.

Outputs: Identification of most appropriate technology system based on identified characteristics (criteria); information in this step is utilised in Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2) and Step 5.3 (Section 4.8.3).

4.7.2 Step 4.2: Assess Results and Reiterate

Purpose: Once a specific technology has been selected, the user is required to determine whether the overall BPR solution is suitable and, more specifically, whether the traceability technology is suitable for the overall BPR solution.

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; AIM strategy from Step 2.1 (Section 4.5.1); elements of existing business processes and those required for new processes from Step 2.2 (Section 4.5.2); understanding of potential for technology integration from Step 2.3 (Section 4.5.3); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) out of the available AIDC technology systems from Step 3.1 (Section 4.6.1) and their various technology characteristics from Step 3.2 (Section 4.6.2) after being aligned in Step 3.3 (Section 4.6.3).

Sequence & considerations: The evaluation of the suitability of the BPR solution is performed by:

1. performing a feasibility study, a cost-benefit analysis and/or a Return on Investment (ROI) analysis [various authors discuss these analyses related to technology implementations, including Dutta, Lee and Whang (2007), Doerr, Gates and Mutty (2006), Roulstone and Phillips (2007) and Keen (2011)];

2. assessing the appropriateness of the technology solution based on feasibility, practicality and viability with regards to the redesigned processes [from Phase 2 (Section 4.5)];

3. selecting the next best technology solution (or repeating Step 4.1 (Section 4.7.1) if necessary) if the initial solution is not appropriate; and

4. repeating the steps from Phase 2 through to Phase 4, accommodating new information, if no reasonably appropriate technology solution is available for the redesigned processes, otherwise proceed to Phase 5 (Section 4.8).

Outputs: Confirmation or reiteration of previous steps such that the appropriate solution is possible; information from this step is utilised in Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9), as well as Phase 2 (Section 4.5), Phase 3 (Section 4.6) and Step 4.1 (Section 4.7.1) when iteration is required.

4.8 Phase 5: Implement

After the processes have been redesigned [in Phase 2 (Section 4.5)] and the appropriate technology selected [in Phase 4 (Section 4.7)], the complete solution is ready for implementation. This first requires an action plan to coordinate the implementation efforts. Thereafter, a pilot study is executed (if required) and then the full-scale implementation proceeds. This phase correlates with *Stage 2* of the Change Management stream (Section 4.3.2).

4.8.1 Step 5.1: Establish BPR Action Plan

Purpose: The BPR action plan coordinates the implementation of the solution.

Inputs: Awareness of the organisational environment [from Step 1.2 (Section 4.4.2)]; existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2).

Sequence & considerations: The sub-steps require the user to:

1. establish both long-term and short-term objectives of the solution (considering aspects from Phase 1 (Section 4.4) such as business objectives);
2. determine roles and procedures for implementation;
3. identify suppliers and vendors of necessary components such as technology systems;
4. establish schedule and budget for implementation efforts;
5. perform risk assessment of initiative, assessing impact of actions on people, jobs, existing technology, existing structures, methods and processes;
6. evaluate any legal and environmental issues relevant to implementation;
7. determine Key Performance Indicators (KPIs) that can quantify the improvement of implementation efforts; and
8. execute a pilot study [as in Step 5.2 (Section 4.8.2)].

Outputs: Action plan that guides the BPR implementation; information from this step is utilised in Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9).

4.8.2 Step 5.2: Execute BPR Pilot

Purpose: The pilot study indicates whether the technology solution is viable for the specific environment and whether the existing process (selected for the pilot) has been improved.

Inputs: Existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1).

Sequence & considerations: This step involves a pilot study where an existing process is redesigned [as in Phase 2 (Section 4.5)] and the selected technology system [obtained from Phase 4 (Section 4.7)] is integrated into this process. The following sub-steps are to be followed:

1. identify a process [from selected processes in Step 1.3 (Section 4.4.3)] to use for pilot;
2. order the necessary components (such as the RFID system) for the small-scale pilot study;
3. rearrange or structure the process according to designs in Step 2.4 (Section 4.5.4);
4. integrate technology [selected in Phase 4 (Section 4.7)] into the process;
5. allow the process and systems to operate for a reasonable time period; and
6. review the pilot study [including an assessment of KPIs determined in Step 5.1 (Section 4.8.1)] to identify strengths and weaknesses.

Upon a successful pilot study, the actual large-scale or full-scale system can be implemented as in Step 5.3 (Section 4.8.3).

Outputs: Viability of solution and confirmation for further implementation; information from this step is utilised in Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9).

4.8.3 Step 5.3: Execute BPR Action Plan

Purpose: This step implements the proposed solution according to the plan developed in Step 5.1 (Section 4.8.1).

Inputs: Existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1); results from pilot in Step 5.2 (Section 4.8.3).

Sequence & considerations: This step executes the BPR action plan in Step 5.1 (Section 4.8.1) by:

1. considering the selected processes [from Step 1.3 (Section 4.4.3)] and the redesigns of these processes [Step 2.4 (Section 4.5.4)];
2. reviewing the BPR action plan in Step 5.1 (Section 4.8.1);
3. ordering the necessary components for the initiative as planned in Step 5.1 (Section 4.8.1), including technology systems required [the technology has been selected in Phase 4 (Section 4.7)];
4. ensuring management visibility;
5. rearranging or structuring the existing processes according to designs in Step 2.4 (Section 4.5.4);
6. integrating technology [selected in Phase 4 (Section 4.7)] into the process;
7. updating employees of progress regarding implementation efforts;
8. allowing processes and technology systems to operate for a reasonable time period; and
9. evaluating the actual milestones and achievements of implementation with planned objectives, schedule and budget [in Step 5.1 (Section 4.8.1)].

Outputs: Full-scale implementation; information and actions from this step are utilised in Phase 6 (Section 4.9).

4.9 Phase 6: Monitor and Evaluate

Purpose: Evaluation of the BPR initiative over the long-term is required to determine the success of the project and continuous improvement is also required.

Inputs: Existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); redesigned processes from Step 2.4 (Section 4.5.4); technology aspects from Phase 3 (Section 4.6); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1); results from pilot in Step 5.2 (Section 4.8.2); full-scale implementation in Step 5.3 (Section 4.8.3).

Sequence & considerations: This phase comprises an assessment of how the redesigned processes perform relative to the previously existing processes and how successfully the technology has been integrated into the processes. Key Performance Indicators (KPIs) that were determined in Step 5.1 (Section 4.8.3) need to be monitored to assess the improvement in operations. This phase also includes continuous improvement to the overall SPM environment. The changes that have been implemented are incorporated into the organisational strategy, policies, plans and identity. The new procedures are standardised, employees retrained as required and unforeseen issues addressed. Both the short-term and long-term results of the BPR initiative need to be evaluated against the initial problems identified in Phase 1 (Section 4.4). The entire BPR stream (Section 4.2) also reiterates for future BPR initiatives and continuous improvement efforts. This phase correlates with *Stage 3* of the Change Management stream (Section 4.3.3).

Outputs: Assessment of success of BPR initiative and continuous improvement to solution.

4.10 Chapter Summary

This chapter discusses the development of a framework for the BPR of processes within the SPM environment while considering Change Management aspects, and that supports the selection of traceability technology (barcode technology, RFID technology, GPS technology or a hybrid system), by utilising the AHP, for integration within the SPM environment. The proposed framework is based on the extensive and comprehensive literature review presented in Chapter 2 and Chapter 3. The framework consists of two primary elements (referred to as streams), namely the *Business Process Reengineering (BPR) stream* that encompasses the phases of BPR and the *Change Management stream* that flows parallel to the BPR stream.

The proposed framework is intended to serve as a guide and, therefore, it should be generic, holistic, objective- or outcome-oriented, practical and structured. The Change Management stream consists of three stages, namely *Stage 1: Unfreeze (Existing) State*, *Stage 2: Change State (Transition)* and *Stage 3: Refreeze (New) State.* The BPR stream consists of six phases, namely

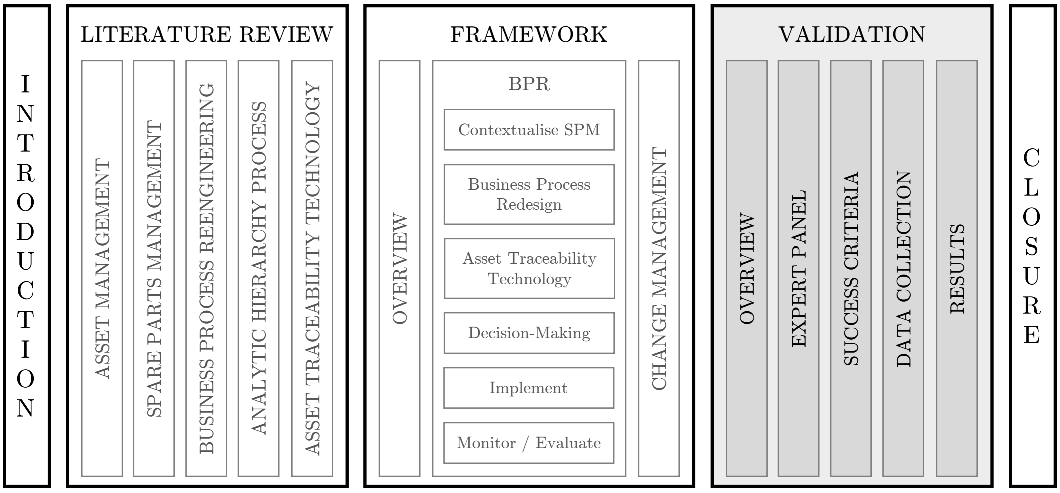
Phase 1: Contextualise SPM, *Phase 2: Business Process Redesign*, *Phase 3: Asset Traceability Technology*, *Phase 4: Decision-Making*, *Phase 5: Implement* and *Phase 6: Monitor and Evaluate*. Within each phase in the BPR stream of the framework are multiple steps (each of which is divided into four sections, namely *Purpose*, *Inputs*, *Sequence & considerations* and *Outputs*) that the user should perform sequentially to address various issues. The steps of the framework follow a logical progression and they are sequentially numbered according to the manner that they should be performed. These steps (and their respective sub-steps) are generic. They should, therefore, be modified and applied as required by the specific area of application.

The next chapter discusses the validation of the proposed framework.

Chapter 5

Validation of Framework

This chapter addresses the validity of the proposed framework (from Chapter 4) through face validation using semi-structured interviews containing both open-ended questions (predominant) and closed-ended questions. The methodology of the validation, particularly relating to the expert panel, the defined success criteria and the collection of data, is explained. Thereafter, the review of the proposed framework by the expert panel is discussed according to each success criterion. This is followed by a discussion of the validity of the framework based on the results of the review. The chapter concludes with a description of changes made to the framework based on improvements proposed during the review.



5.1 Overview

Chapter 4 proposes a framework that serves as a stepwise guide for the BPR of spare parts processes while considering elements of Change Management, and that supports the selection (through use of the AHP) of asset traceability technology for integration within the SPM environment. Chapter 5 addresses the validation of this proposed framework. Carson (1986), as cited by Robinson (1997), states that *validation* is "the process of ensuring that the model is sufficiently accurate for the purpose at hand". Validation is typically performed for models, but may be extended to frameworks (as in this study) to confirm that the framework is acceptable or accurate for the context for which it was designed.

As mentioned in Section 1.5, the validation of a study such as this one should ideally attempt to quantify the success of following the proposed framework through actual implementation. However, the scope and duration of the study, in addition to the costs involved and the unavailability of suitable sites to perform such an implementation, deter such a validation. This study rather follows a *qualitative* research approach for validation whereby the framework is evaluated according to certain success criteria (*Perceived Usefulness*, *Perceived Ease of Use*, *Understandability* and the achievement of various framework attributes including *adaptability* and *comprehensiveness*, among others) through face validation (involving semi-structured interviews) with an expert panel. The expert panel consisted of seven participants actively involved in Spare Parts Management (SPM) at three mining organisations (and that have varying degrees of experience related to BPR and traceability technology).

The aim of the validation is to determine the ability of the framework to achieve its intended functions. This includes the assessment of the potential of the framework as a stepwise guide for the BPR of spare parts processes while considering Change Management elements, and a guide that supports the selection (through use of the AHP) of asset traceability technology. The ability of the framework to achieve the desired attributes (discussed in Section 4.1.1) is also evaluated. Furthermore, *strengths* and *weaknesses* of the framework are identified and certain *improvements* recommended by the expert panel.

5.2 Methodology

Section 1.5 describes the research design and methodology of the study. The *qualitative research methodology* was followed to validate the study. More specifically, face validation through semi-structured interviews was used as the method of validation.

Holden (2010, p. 637) defines face validity as "the degree to which test respondents view the content of a test and its items as [appropriate, sensible or] relevant to the context in which the test is being administered". In a similar vein, Sargent (2005) states that face validity concerns obtaining responses from individuals that are knowledgeable about the system, environment or concepts (for which the model or framework was designed to represent or address) in order to determine whether the model (and its behaviour) or framework is reasonable. According to Borenstein (1998), the primary objective of face validation is to ensure, in a timely and cost-effective manner, that the perception of a problem held by the framework developer is consistent with the perception held by the potential user of the framework.

Some authors have expressed concerns of face validation being a weak form of validation (Drost, 2011). However, a number of authors have used or discussed face validation in their research, including Gibson and Strong (2002), Beecham, Hall, Britton, Cottee and Rainer (2005), Fisher, Binenbaum, Tapino and Volpe (2006), Ayodeji, Schijven, Jakimowicz and Greve (2007), Klügl (2008), Seixas-Mikelus, Kesavadas, Srimathveeravalli, Chandrasekhar, Wilding and Guru (2010) and Jooste (2014).

A form of snowball sampling was performed to a certain extent in order to identify suitable participants. A letter requesting for participation in the study (and stipulating the requirements) was sent to managers at four organisations. These managers participated in the study, if suitable for the study themselves, and/or referred the author to employees within their organisations that fulfil the criteria for validation. Seven of the ten suitable candidates (from three of the four organisations contacted) eventually participated in the study. Section 5.2.1 discusses the expert panel. Participants were informed that they were not obliged to answer questions and may withdraw from the study at any point. Participants are also made anonymous in the study (except for the description of their job titles and relevant experience).

The questions of the interview are based on evaluating the framework according to certain success criteria. These success criteria are discussed in Section 5.2.2. Furthermore, the questions aim to determine strengths and weaknesses of the framework in addition to improvements that can be made to it. The manner in which the data is collected is described in detail in Section 5.2.3.

Participants were asked to indicate whether they have had experience with or been involved in: (i) BPR initiatives, (ii) implementations of any forms of technology systems, and (iii) traceability technology systems. This is performed to assess the amount of weight each participant's response may hold regarding issues related to each of these three topics. Since the framework attempts to be a guide for the BPR of spare parts processes as well as a guide to support the selection of traceability technology, it is important to ascertain which participants have experience with each of these aspects. Table 5.1 in Section 5.2.1 indicates the relevant experience of the participants.

5.2.1 Expert Panel

The study is validated through face validation (involving semi-structured interviews) with an expert panel. Lauesen and Vinter (2001) recommend that the expert panel consists of participants from different backgrounds and industries. Participants in the study were required to be involved in SPM and/or have significant experience with traceability technology. Ten suitable participants (that vary in terms of number of years of experience in their respective fields, job title, organisation, location and previous industry experience) were contacted of which seven were willing to participate in the study.

The seven participants that form the expert panel are each employed by Anglo American, ArcelorMittal South Africa or Tronox (at South African divisions). One of the participants was employed at Glencore (a producer and marketer of metals, minerals, energy products and agricultural products) before recently transferring to one the organisations listed. Participants also have previous experience at other companies, such as Barloworld Logistics (a company focused on smart supply chain solutions) and Afrox (a company specialising in gases and welding products), and industries such as the banking sector and consultation services. The majority of these organisations are capital-intensive (particularly the mining organisations) which is the focus area of the study. Participants are highly experienced and have been exposed to different environments and industries. Therefore, they are in a position to evaluate the framework for its intended purposes.

Anglo American is a global and diversified mining business that mines, produces and markets various minerals and precious materials including iron ore, manganese, coal, copper, nickel, niobium, phosphates, platinum and diamonds. The organisation's mining operations, growth projects and exploration and marketing activities extend across Australia, Asia, Europe, South America, Southern Africa and North America (Anglo American, 2015). The headquarters of Anglo American are based in London (United Kingdom). According to Anglo American (2015), the company employs 148,000 people worldwide and had an annual group revenue of $31 billion in 2014.

ArcelorMittal South Africa, part of the ArcelorMittal Group, is the largest steel producer in Africa and supplies more than 60% of the steel used in South Africa (ArcelorMittal South Africa, 2015). According to ArcelorMittal South Africa (2015), the typical annual production capacity is seven million tonnes of liquid steel. The ArcelorMittal Group is ranked as the world's largest steel producer and employs 232,000 employees worldwide (ArcelorMittal South Africa, 2015). The group has an industrial presence in 60 countries across Africa, Asia, Europe, North America and South America. ArcelorMittal South Africa has its headquarters in Vanderbijlpark (Gauteng, South Africa). The company had a revenue of R34 billion in 2014 (ArcelorMittal South Africa, 2015).

Tronox is a global organisation in the mining, production and marketing of inorganic minerals and chemicals, particularly those related to titanium dioxide (TiO_2) and alkali chemicals. The organisation operates at more than 20 locations around the world including in Australia, the Netherlands, South Africa and the United States of America (Tronox Limited, 2015). According to Tronox Limited (2015), the company has a diverse global workforce of 4,400 employees and had an annual sales figure of approximately $1.7 billion in 2014.

The study obtained responses (available in Appendix C) from seven participants (six of whom are involved in SPM at least to some extent) employed by the aforementioned companies. The participants include:

- a *Head of Inventory and Procurement (HoIP)*: four years of experience in procurement and an additional two years of experience specifically in inventory management;
- a *Head (Group Manager) of Physical Supply Chain (HoPSC)* based in London and Ireland: one year of experience in current role and 16 years of experience in supply chain and logistics;
- a *Head of Reco (HoR)* for reconditioned spares: 40 years of experience in both engineering and supply chain;
- a *Materials Manager (MM)*: 30 years of experience in inventory supply chain of mining operations including ten years of experience as manager;
- a *Regional Principal for Physical Supply Chain (RPPSC)* – previously Projects Director within supply chain: 15 years of experience, including two years as Projects Director, more than ten years of experience in Integrated Business Planning and only three weeks of experience as Regional Principal (as at the date of the interview);
- a *Senior Engineer (SE)* – previously System Analyst: no experience in SPM, five years of experience as Senior Engineer (involving Process Modelling), three years of experience as System Analyst, 10+ years of experience in Change Management (completing Master's related to technology acceptance) and two years of experience related to traceability technology systems; and
- a *Warehouse Coordinator (WC)*: 20 years of experience in inventory management.

The job titles of the participants have been coded as indicated in parentheses (for instance, HoIP is the Head of Inventory and Procurement). This is to ensure brevity of the recorded responses and analysis thereof. Table 5.1 indicates the relevant experience of the participants for this study. Examples of specific projects (relating to BPR, technology system implementations and/or traceability technology systems) that each participant has been involved in are available in Appendix C. It should be noted that the majority of participants that have had experience with traceability technology systems have only been exposed to barcode technology systems. SE has been involved in various traceability systems including barcode, RFID and GPS technology. However, SE has no experience in SPM (only involved in the maintenance side of assets). HoPSC indicated experience with GPS and sensor systems and RPPSC has considered RFID applications before.

Table 5.1: Relevant experience of participants forming expert panel

Participant	Experience Related to			Total Years in Field
	BPR Initiatives	**Technology System Initiatives**	**Traceability Technology Systems**	
HoIP	Yes	Yes	Yes	6
HoPSC	Yes	Yes	Yes	16
HoR	No*	No*	No	40
MM	Yes	Yes	No	30
RPPSC	Yes	Yes	Yes	15
SE	Yes	Yes	Yes	10
WC	Yes	Yes	Yes	20

**HoR has been involved in process improvement (but not for SPM); has also been affected by technology system changeovers, but not involved in the actual implementation.*

The subsequent subsection provides and discusses the success criteria upon which the framework is validated.

5.2.2 Success Criteria

The success criteria for the validation of the framework in this study are based upon the criteria established by Davis (1989) and Beecham *et al.* (2005). Davis (1989) proposed the now popular Technology Acceptance Model (TAM) which attempts to predict attitudes and in turn influence the intended use of a technology. Some of the criteria proposed by Beecham *et al.* (2005) are addressed as the achievement of framework attributes, such as *generic and adaptable* which corresponds to *tailorable* in the paper by Beecham *et al.* (2005). Additionally, participants are asked to state the strengths and weaknesses of the framework to improve it further.

Davis (1989) investigated two measures, namely *Perceived Usefulness* and *Perceived Ease of Use*, for predicting user acceptance of information technology. Although the studies performed by Davis (1989) focused on information technology, the author is of the opinion that the same measures are applicable to any system or guide in general. Therefore, the proposed framework is assessed based on these two criteria (*Perceived Usefulness* and *Perceived Ease of Use*) in addition to *Understandability* and the achievement of the desired framework attributes described in Section 4.1.1. Various questions posed to the participants of this study relate to more than one of the criteria established.

Davis (1989) defines *Perceived Usefulness* (the first criterion of success) as "the degree to which a person believes that using a particular system would enhance his or her job performance". In the context of this study, the system is considered to be the proposed framework. Furthermore, Davis (1989) asserts that a system that is perceived to be very useful is one for which the user believes in the "existence of a positive use-performance relationship". This implies that users will only perceive the framework to be useful if it provides value to the user. Hence, if the framework is perceived to be useful by potential users, then there is a greater likelihood of users actually using or desiring to use the framework. As a result, it is important to ascertain the potential that the framework has, according to the user, in fulfilling its intended functions. The study poses various questions (keywords include: *useful*, *potential* and *utilise*) to participants that aim to determine their impression of the usefulness of the framework.

Although a user may find an application useful, if the application is too difficult to use then the user will view the benefits as being outweighed by the effort to use the application (Davis, 1989). Therefore, the perceived ease of use needs to be determined. Davis (1989) defines *Perceived Ease of Use* (the second criterion of success) as "the degree to which a person believes that using a particular system would be free of effort". Davis (1989) claims that, for all else being equal, an application that is perceived to be easier to use than another application is more likely to be accepted by users. The framework, thus, needs to be comprehensive, but without being too complex or difficult to use. However, Davis (1989) reports that, for the studies performed to identify measures that can be used to predict user acceptance of information technology, *Perceived Usefulness* had a significantly greater correlation than *Perceived*

Ease of Use with usage behaviour. Keywords in questions posed to participants in order to determine *Perceived Ease of Use* include *too complex* and *information-overload.*

The third success criterion is *Understandability.* The framework should be easily understood and well-defined with clear explanations of the more complex aspects described. The desired *Structured and objective- or outcome-oriented*, *Holistic and comprehensive* and *Practical* framework attributes contribute to the understandability of the framework. There should be a logical flow and structured breakdown of steps to enhance understandability. Keywords in the questions posed include *ease of understanding*, *too complex*, *information-overload* and *step logic.*

Finally, the achievement of desired framework attributes (as described in Section 4.1.1) is assessed (the fourth criterion of success). There are four attribute categories to be assessed, namely (i) *Generic and adaptable*, (ii) *Holistic and comprehensive*, (iii) *Structured and objective- or outcome-oriented* and (iv) *Practical.* Section 5.2.3 discusses the method of collecting data from participants.

5.2.3 Data Collection

As aforementioned, the study is validated through face validation (involving semi-structured interviews) with an expert panel. Sturges and Hanrahan (2004) state that face-to-face interviewing is the method of validation typically used by qualitative researchers when conducting semi-structured in-depth interviews. Similarly, DiCicco-Bloom and Crabtree (2006) assert that semi-structured in-depth interviews are the most widely used interviewing format for qualitative research and they state that this type of interview is “generally organised around a set of predetermined open-ended questions, with other questions emerging from the dialogue between interviewer and interviewee/s”. Adams, McIlvain, Lacy, Magsi, Crabtree, Yenny and Sitorius (2002) mention that semi-structured interviews are typically the sole data source for qualitative research projects, which is the case for this study.

Participants that accepted the request to participate in the study were sent the document provided in Appendix B a week before their respective interviews. The document describes the context of the problem and, thereafter, the proposed framework of this study. It concludes with open-ended questions and closed-ended questions regarding the framework that are asked during the interviews. Participants were interviewed and asked these questions in order to validate the framework developed in this study. Before participants answered any questions, they were asked if their responses may be recorded via voice recorder in order to facilitate the response-recording process. Participants were assured that their participation in the study would remain anonymous (besides the identification of their job titles and experience). The responses from participants have been included in Appendix C.

As explained by Welman, Kruger and Mitchell (2005), the open-ended questions allow the participants to provide answers without being influenced unduly by the interviewer or questionnaire, and the verbatim responses may provide information that would not have been obtainable using closed-ended questions. In contrast, closed-questions provide a clearer indication of overall impression ratings of certain criteria and result in easier comparisons between participants. The interview schedule attempted to provide as much opportunity as possible for interviewees to offer additional comments and explain their opinions, but included the closed-ended questions for structural assessment of the framework. Additionally, individual semi-structured interviews were favoured over focus groups, as focus groups often inhibit responses from participants due to the participants feeling intimidated by the presence of other respondents (Welman *et al.*, 2005; DiCicco-Bloom and Crabtree, 2006).

The choice of the most appropriate ordinal point scale to use in questionnaires and surveys has been debated for decades (Garland, 1991; El Emam and Birk, 2000; Dyba, 2000; Beecham *et al.*, 2005; Taylor-Powell, 2008). Most researchers agree that a point scale should not have more than seven points (Taylor-Powell, 2008). The greatest dispute regarding the number of points to use relates to the choice between a four-point scale and a five-point scale. El Emam and Birk (2000) used a four-point scale in their validation. Alternatively, Dyba (2000) considers the different measurement scales and concludes that a five-point scale is the most reliable measure.

Some authors argue that a four-point scale forces the respondent to forgo a neutral position which is undesirable [as it may frustrate the respondent (Taylor-Powell, 2008)]. In contrast, a five-point scale may result in the respondent selecting too readily a neutral stance for the questions posed (Taylor-Powell, 2008; Garland, 1991). This is undesirable when the researcher desires to know in which direction the neutral respondents are inclined. The five-point scale has been selected for this study to allow for a neutral stance and to avoid a bias towards the positive end of the scale [as mentioned by Garland (1991)].

Taylor-Powell (2008), an evaluation specialist, provides advice regarding wording for rating scales. In particular, one of the most important considerations regarding the scale to use is that it should be balanced with an equal number of positive and negative categories. Therefore, the study uses *Very Poor*, *Poor*, *Fair*, *Good* and *Very Good* as graduation points for closed-ended questions. Additionally, Taylor-Powell (2008) states that the order of choices, such as the five graduation points selected for this study, should remain the same throughout the questionnaire. She also highlights that numerical values may confuse respondents or create unintended meaning and, therefore, can be removed from the scale.

The responses from participants are discussed in Section 5.3.

5.3 Results

Section 5.2.2 discusses the success criteria that are used to validate the proposed framework. The success criteria are *Perceived Usefulness, Perceived Ease of Use, Understandability* and *Achievement of Desired Framework Attributes* which includes four attribute categories, namely *Generic and adaptable*, *Holistic and comprehensive*, *Structured and objective- or outcome-oriented* and *Practical*. This section discusses the responses from participants and how they relate to the defined success criteria. To reiterate, the seven participants each have a different job title as mentioned in Section 5.2.1 which is represented by a code for brevity as follows:

- *Head of Inventory and Procurement*: HoIP;
- *Head of Physical Supply Chain*: HoPSC;
- *Head of Reco (reconditioned spares)*: HoR;
- *Materials Manager*: MM;
- *Regional Principal for Physical Supply Chain*: RPPSC;
- *Senior Engineer*: SE; and
- *Warehouse Coordinator*: WC.

The responses from participants for each question of the Validation Questionnaire (available in Appendix B) are contained within Appendix C. The *Head of Inventory and Procurement* (HoIP) invited the *Warehouse Coordinator* (WC) to join the interview, as the WC had more experience and could provide responses from a more technical background. The responses from both these participants were recorded together during a single interview and are reported together in Appendix C. The subsequent subsections discuss the responses from participants per success criterion defined in Section 5.2.2.

5.3.1 Perceived Usefulness

The *Perceived Ease of Use* (discussed in Section 5.3.2) and the *Understandability* (addressed in Section 5.3.3) of the framework affect substantially the *Perceived Usefulness* of the framework. Other factors such as the *step logic* (mentioned within the *Structured* attribute category of Section 5.3.4) also contribute to the usefulness of the framework, but to a lesser degree.

All of the participants considered the framework to be a *useful guide*. In particular, one of the participants (SE) stated that the framework would be "valuable". However, another participant (MM) indicated his concern that many existing systems are available to manage inventory (including tools within Enterprise Asset Management (EAM) and Enterprise Resource Planning (ERP) packages such as *SAP*, *Ellipse* and *MIMS*) and whether an organisation would want additional systems to be implemented (especially considering the costs involved). In contrast, SE stated that there may be modules in systems such as SAP, but few people actually use them (and hence the framework is helpful). The proposed framework follows a structured approach and considers various aspects with the necessary reiteration of sections to ensure that the solution is well integrated. Therefore, the framework is useful despite other systems being available since it relies on proven BPR principles and follows steps that previous system implementations may not have considered. It also addresses Change Management which other system implementations may not consider. SE further stated that Step 3.3 (aligning the process redesign and technology aspects) was an important part of the framework and that this step "will become more and more important as technology plays a larger part in everything that [organisations] do".

One participant (HoIP) in particular believed that using the framework would have increased the success probability of a previous barcode implementation that had failed somewhat at the organisation (the systems are currently not being utilised). MM also claimed that the results of such an initiative should be successful if the initiative is followed as stipulated in the framework. Another participant (HoPSC) stated, "putting the systems before the processes is obviously a bad idea and that did happen in some previous work I was involved in. Particularly for technology companies who think everything revolves around a system; that's a pitfall. So I think the way you prioritise the process over the technology is a fundamental benefit". RPPSC emphasised the value in taking the user through the steps one would follow to ensure that the user is aware of what to expect and how to approach the project and task at hand.

Participants were asked their opinion regarding the *potential* of the framework as (i) a guide to the BPR of spare parts processes, and (ii) a guide to support the selection of traceability technology for integration within the SPM environment. All of the participants expressed that the framework has significant potential as a guide for BPR. One participant (WC) stated that "it's a good guide for any process, but more for warehousing: definitely". Another participant (MM), however, believed that the framework may be too complicated and that it contains too much information (particularly for employees on the shop floor). In contrast, RPPSC stated that the framework is “fairly high-level” and that it could be expanded to another level such that it provides more guidance to the users. HoPSC highlighted that a “scoping and objectives” section, which aligns the objectives of the BPR initiative and the stakeholders in the project, was missing. Although SE had no experience in SPM, he considered the framework to be helpful, especially for its ability to provide structure to the process of the initiative which is often lacking (organisations tend to initiate projects without the proper process structure and contextualisation required before implementation).

Regarding the potential of the framework as a guide for the selection of traceability technology for integration within SPM, five of the seven participants (HoIP, WC, HoPSC, MM and SE) believed the framework had potential. HoIP stated that organisations sometimes try to fit business processes around technology and that she believed this was not the ideal approach. She considered the fact that the business process redesign is addressed before technology aspects (and then both are aligned) to be beneficial. As aforementioned, HoPSC made a similar comment, regarding this to be a “fundamental benefit”. SE also stated that Step 3.3 (the alignment of business process redesign to technology aspects) is very important. Furthermore, HoIP believed that the success factor of a technology implementation would be higher if a guide such as the framework was utilised properly, as many systems are “half-implemented” and not thought through properly from the beginning (considering the whole context). WC stated that the framework would guide the process, allowing the user to track progress based on phases. In addition, he mentions that implementations require a champion to manage the process.

One participant (HoR) felt that the framework would possibly not have much potential specifically for his Reco (reconditioned spare parts) department, but that it may have potential for other parts. HoR indicated the desire for traceability of reconditioned spare parts and believed that the framework would have potential as a guide for the selection of traceability technology for integration if the technology could track, or at least trace, the movements of reconditioned parts.

Another participant (RPPSC) was hesitant to rate the potential of the framework as a guide for the selection of traceability technology, as he believed there are many factors to consider. RPPSC highlighted that the user needs to know the technology very well, processes need to be well-defined particularly regarding RFID, and the user needs to be aware of the costs and the application of the technology in harsh environments (such as in mining industries). He further insisted that any framework that is comprehensive is beneficial and that it “is important to put something in place”. Similarly, HoPSC stated that the framework has “some good steps in terms of finding the technology” and reported that selecting and integrating the appropriate technology is typically not performed particularly well in organisations.

All of the participants indicated that they would *utilise* the framework if they were to improve spare parts processes and/or to select and integrate traceability technology into the SPM environment. One participant (HoPSC) considered the framework to be “a valid way of doing it” and beneficial in terms of the structure it provides, although he highlighted that large companies typically have their own internal frameworks (despite his lack of encountering such frameworks in his current organisation). Another participant (RPPSC) observed that the framework “marries a lot of different aspects that are probably done in isolation” and, therefore, definitely helps the user. RPPSC further emphasised that the framework will have significant value if there are clear decision-making matrices across multi-disciplinary or multi-departmental areas that describe the responsibilities of different parties.

5.3.2 Perceived Ease of Use

Various factors affect *ease of use* including the comprehensiveness and the *ease of understanding* of the framework. One of the desired framework attribute categories is “*Holistic and comprehensive*”. Therefore, this aspect is discussed in Section 5.3.4. The *Understandability* of the framework is considered in Section 5.3.3.

One important aspect affecting the *ease of use* is whether the framework is too complex or includes too much information such that information-overload is experienced. This aspect also affects significantly the Understandability (discussed in Section 5.3.3) of the framework. Additionally, the structure of the framework affects the impression of complexity and information-overload. One of the desired attribute categories of the framework is that it should be structured and objective- or outcome-oriented. This is considered in Section 5.3.4.

Four of the seven participants (HoIP & WC, HoPSC and SE; HoIP and WC both agreed on the same rating) rated the ability of the framework to consider various relevant aspects without becoming too complex or resulting in information-overload as *Good*. One participant (HoR) rated it as *Very Good* and another (MM) rated it as *Fair*. The seventh participant (RPPSC) abstained from rating this aspect, as he believed the framework would first need to be applied in order to prove its effectiveness before this could be rated. The participant that rated *Fair* stated that the framework may have too much information and be too complicated for employees on the shop floor. However, HoPSC stated that “with the structure... and the steps that you go through, it looks manageable to someone that they’re [sic] not going to get overloaded with information at the start". Similarly, SE stated that the framework "actually reduces complexity".

5.3.3 Understandability

The majority of participants considered the framework to be easily understandable. Four of the seven participants (HoIP & WC, HoPSC and RPPSC; HoIP and WC both agreed on the same rating) rated the *ease of understanding* of the framework as *Good*, one participant (HoR) rated it as *Very Good* and the other two participants (MM and SE) rated it as *Fair*. One participant (HoPSC) stated, "It's quite intuitive. Just a few things like the acronyms, AHP, would obviously not necessarily be known by the lay-user, but ultimately the structure makes sense". All acronyms and important concepts used in the framework are explained in text within the thesis (in the framework itself or the literature review), and acronyms and abbreviations are expanded in the nomenclature. Other participants (HoR and RPPSC) highlighted that they found the framework to be logical, straightforward and very chronological. MM, who considered it to be *Fair*, stated elsewhere that too much information may have been provided in the framework (particularly for shop floor level employees).

As mentioned in Section 5.3.2, the complexity and amount of information contained within the framework affects the *Understandability* of the framework. The structure of the framework also affects the impression of complexity and information-overload of the framework. The *structure* of the framework is assessed in Section 5.3.4.

Five of the seven participants (HoIP & WC, HoPSC, HoR and SE; HoIP and WC both agreed on the same rating) considered the *step logic* to be *Very Good* and two participants (MM and RPPSC) rated it as *Good*. HoPSC responded that the framework "goes through the right process" and RPPSC considered it to be fairly straightforward. SE states that it is "easy to understand the flow" of the framework.

5.3.4 Achievement of Desired Framework Attributes

As discussed in Section 4.1.1, the proposed framework is to be (i) *Generic and adaptable*, (ii) *Holistic and comprehensive*, (iii) *Structured and objective- or outcome-oriented*, and (iv) *Practical*. This subsection discusses the ability of the framework to achieve these desired attributes.

Generic and adaptable: Three of the seven participants (HoIP & WC and HoR; HoIP and WC both agreed on the same rating) rated the *flexibility and* *adaptability* of the framework as *Very Good* and highlighted the ability to apply the framework to other processes (not only within the SPM environment). Two participants (MM and SE) considered the *flexibility and adaptability* to be *Good*. The other two participants (HoPSC and RPPSC) rated it as *Fair*. HoPSC stated that the framework was missing a "scoping and objectives" section that defines the scope and objectives of the project, indicates relationships (who is involved and how much responsibility, accountability and authority or influence the stakeholders have) and considers organisational politics, in addition to convincing the relevant stakeholders of the importance of the project. RPPSC believed that, as long as the area of application related to AM or SPM, the framework is "fairly robust and fairly generic". SE emphasised that the *flexibility and adaptability* is considered *Good* only if the entire framework is used without steps being removed, as removing steps would inhibit the process (each step lays the foundation for the subsequent steps).

The majority of participants considered the framework to be *generic and adaptable*. One participant believed the framework required an additional section concerning "scoping and objectives" and the other believed that it is generic as long as the area of application is related to AM or SPM. Therefore, it is reasonable to assert that the framework satisfies the generic and adaptable attribute (at least for SPM environments) to an acceptable degree.

Holistic and comprehensive: It is important for the framework to address relevant aspects and describe them as extensively as possible, but without becoming too complex or containing too much information. As mentioned in Section 5.3.2, the majority of participants considered the framework to be able to consider various aspects without becoming complex or contain too much information. However, one participant believed that it may contain too much information or be too complex.

Six of the seven participants (HoIP & WC, HoR, MM, RPPSC and SE; HoIP and WC both agreed on the same rating) rated the *comprehensiveness* of the framework as *Very Good* while one participant (HoPSC) rated it as *Good*. One of the participants (MM) reiterated that the framework may be "too comprehensive". However, another participant (HoPSC) considered the framework's comprehensiveness as one of its strengths, stating that "it has a good way of trying to bring in all of the available aspects... and then having a broad, open mind in terms of bringing in technologies". Similarly, RPPSC claimed that users may be able to list a few of the steps without a framework, but that the real value of the framework derives from its comprehensiveness. SE stated that the framework "covers everything... [i]ncluding the change management part which is very nice. Similar frameworks would ignore it most of the times". HoIP mentioned that the framework provides a guideline to ensure that the entire process is thought through properly and believed that the points within the framework are broad such that the framework can accommodate various potential aspects.

The majority of participants, therefore, consider the framework to be very comprehensive (and holistic), thus, it is reasonable to conclude that the framework succeeds (to a significant degree) at being comprehensive without providing too much information or becoming too complex.

Structured and objective- or outcome-oriented: The framework is structured into stages, phases and steps that are contained within the phases. These steps contain sub-steps and considerations that the user should perform or of which the user needs to be aware. As described in Section 4.1.2, each step is divided into a *Purpose* section, an *Inputs* section, a *Sequence & considerations* section and an *Outputs* section.

Participants described the framework as “intuitive”, “logical”, “chronological”, “structured” and “straightforward”. HoPSC stated that, although lay-users may not be aware of certain acronyms, “ultimately the structure makes sense”. He further highlighted that the framework “has the right scope: starts off broad, but it’s got a good way of narrowing down to a decision in a very *structured* way”. HoPSC, however, felt that a “scoping and objectives” section is missing from the framework. Another participant (SE) stated that the framework provides structure to the whole process of redesigning processes and integrating technology.

Furthermore, as aforementioned, five participants (HoIP & WC, HoPSC, HoR and SE) considered the *step logic* to be *Very Good* and two participants (MM and RPPSC) rated it as *Good*. Therefore, the framework satisfies the structured and objective- or outcome-oriented attribute, although an additional “scoping and objectives” section should be provided before or within the contextualisation phase (Phase 1) of the framework.

Practical: The *Practical* attribute is assessed using the *Perceived Usefulness* criterion (discussed in Section 5.3.1). To reiterate, all of the participants considered the framework to be a *useful guide*. One of the participants (MM) indicated his concern that there are many existing systems available to manage inventory and whether an organisation would want additional systems to be implemented (especially considering the costs involved). In contrast, another participant (SE) argued that most people do not use the modules available in systems such as SAP that can manage inventory or other aspects, despite the existence of such modules. HoIP believed that using the framework would have increased the success probability of a previous barcode implementation that had failed somewhat at the organisation (the systems are currently not being utilised). Similarly, MM stated that the results of such an initiative should be successful if the initiative is followed as stipulated in the framework. Furthermore, as discussed in Section 5.3.1, all of the participants indicated that they would *utilise* the framework if they were to improve spare parts processes and/or select and integrate traceability technology into the SPM environment.

5.3.5 Additional Feedback

Additional feedback from participants included the *strengths* and *weaknesses* of the framework, besides the improvements that can be incorporated into the framework. Many of these have already been mentioned, but will briefly be reiterated. Participants emphasised the following aspects to be *strengths*:

- structure and logic of the framework;
- comprehensiveness of the framework;
- ability to provide a guideline that helps to address current gaps (by identifying typical areas of weakness on which to focus and thereafter providing what needs to be in place) and that ensures that the whole process is thought through properly;
- contextualisation phase (Phase 1) where various aspects are analysed and considered before commencing the redesign, selection of technology or implementation;
- consideration of business process redesign before technology aspects and then aligning the redesigned processes to the technology aspects (in Step 3.3 of the framework);
- scope of first beginning broad and then narrowing down in a structured manner, particularly regarding decision-making; and
- circular nature (iterative process) of framework such that it includes a check of whether initial assumptions (from contextualisation in Phase 1) are still applicable or valid before reiteration of the entire process.

Participants highlighted the following aspects to be *weaknesses*:

- lack of a "scoping and objectives" section that describes the scope of the project, defines relationships (who is involved and how much responsibility, accountability and authority or influence they have) and considers organisational politics, in addition to convincing the relevant people of the importance of the project;
- cost significantly determines the feasibility and whether such an initiative would be performed;

- people may lose their jobs after such an initiative or with new technology that streamlines processes;
- too complicated and complex for employees on the shop floor level; and
- lack of detail regarding Change Management.

The following improvements were suggested, many deriving from the weaknesses already provided:

- addition of clear decision-making matrices across multi-disciplinary or multi-departmental areas that describe the responsibilities of different parties such that they can be related to the redesigned business processes (suggested by RPPSC);
- Change Management section should be expanded and should promote the involvement of the shop floor employees (suggested by HoPSC and SE);
- addition of the "scoping and objectives" section mentioned (suggested by HoPSC); and
- inventory management methodology (suggested by MM): more extensive discussion on how to categorise spare parts, particularly to distinguish them from other materials, and how to manage specific metal spare parts.

MM alleged that squirrel stores are always a problem and reported that they can accumulate to millions of rands in a company if they are not managed properly. In one year, the company performed a redundancy exercise and wrote off five million rand of redundant stock which employees had requested, but never used. Additionally, salvage yards at mining organisations are typically not managed by any particular technology systems. MM also indicated that automated stock-counting should be emphasised, as this is often performed manually despite the modern era.

RPPSC asserted that an organisation needs to have a certain maturity level before asset traceability technology can be implemented. In certain cases, systems guide processes (as opposed to processes determining which systems should be used) and, as a result, the organisation should be aware of available systems and what is to be achieved. The business processes and the technology systems need to be integrated and Step 3.3 of the framework attempts to address this. Additionally, HoPSC insisted that if the right department in an organisation is involved in the governance structure regarding an implementation then many potential organisational issues are resolved upfront.

HoIP and WC highlighted a pitfall regarding a previous barcode technology implementation at the company at which they are employed. The servers were outdated (lack of maturity) and could not support the new technology. As a result, the technology was not utilised (at least not to its full potential). HoIP stated that a "technology solution can look favourable, but there's just so much to consider when you select a specific technology". Similarly, HoR stated that one needs to view the whole process in its entirety and not only focus on a part of it. He believed that the barcode technology implementation at the company was not successful due to only a part of the process being considered.

SE described how interference affected the implementation of RFID and GPS technologies at the organisation at which he is employed and he emphasised the importance of considering this for any technology implementations. He described an RFID implementation where RFID tags were attached to the various parts on a certain machine such that a database could be created which displayed the parts and the amount of usage related to each part. This was used for preventative maintenance. When a part was installed or removed, the part would be selected on the handheld RFID reader and the date selected. However, SE explained that there were two reasons (deriving from one cause) for the system not being successful. The first reason was the unreliable communication of the handheld reader with network access points (in order to communicate with the server) and the second reason was the difficulty in reliably scanning the tags which were attached directly on the metal parts (and which had to be scanned at close range). Both reasons stemmed from the harsh environment and the interference associated with it. Additionally, SE stated that the company did not follow a framework similar to the one proposed.

Despite the failure of the previous barcode implementation, HoIP observed that her organisation could use technology more effectively to obtain an advantage in accuracy and efficiency. WC stated that the organisation would use the technology to streamline business processes such as stock-counting and the issue and receipts of parts. However, he was concerned that new technology may reduce the need for certain employees involved in the tasks and, as a result, people may lose their jobs. He mentioned that it is possible, though, for these employees to be reassigned to other tasks or areas.

WC and HoR also raised concerns over the cost of technology involved in such an initiative. However, WC (and HoIP) also believed that cost would not be considered a weakness if the technology was implemented correctly and utilised effectively. HoIP specifically referred to the cost of implementing SAP at their organisation and how the system could be utilised more effectively. SE stated that one needs to consider how such a framework would integrate with existing systems such as SAP.

In terms of other issues typically experienced at mining organisations, HoR highlighted that motors and gearboxes in storage are rarely turned over in order to keep them lubricated. This affects the condition of the spare parts. Regarding reconditioned spare parts, he raised the issue of parts not being taken from storage according to a First-In-First-Out (FIFO) basis. Instead, the most recently repaired part tends to be taken out of storage first. This may result in obsolescence, as described in Section 2.2.5.4. Moreover, equipment is not traced, so it is not possible to know where a specific motor is being used (equipment is not linked to a specific position in the plant).

Finally, MM described automated warehouses and believed that the technology used in them could also be considered in the framework. These warehouses use automated material handling equipment for storage and retrieval of parts. The equipment typically handles smaller items instead of heavy machinery parts.

5.4 Discussion

According to the ratings provided by the expert panel, the framework excelled at being *comprehensive* (six participants rated *Very Good* and one as *Good*) and logical (five participants rated the *step logic* as *Very Good* and two as *Good*). The framework performed well in the other ratings as well, but to a lesser extent. For instance, the ability of the framework to consider various relevant aspects without becoming too complex or resulting in information-overload was rated by one participant as *Very Good*, by four participants as *Good* and by one participant as *Fair* (with the seventh participant abstaining from rating). However, one participant warned that the framework may be too complex or contain too much information which would result in shop floor employees not being able to easily follow it.

Additionally, three participants rated the *flexibility and adaptability* of the framework as *Very Good*, two participants as *Good* and the other two participants as *Fair*. The *ease of understanding* of the framework was rated by one participant as *Very Good*, by four participants as *Good* and by the two other participants as *Fair*. Although these categories are rated lower than *comprehensiveness* and *step logic*, they remain reasonably positively rated. Furthermore, participants discussed the issues that resulted in their lower ratings for these categories and these issues have been highlighted in Section 5.3.

Overall, participants generally considered the framework to be *useful*, *easy to use*, *understandable*, *generic and adaptable*, *holistic and comprehensive*, *structured and objective- or outcome-oriented* and *practical*. They also considered the framework to have potential as both a guide for BPR and a guide to support the selection of traceability technology for integration within SPM. Therefore, the framework is deemed to satisfy the achievement of its defined outcomes. Furthermore, two of the improvements to the framework, proposed by participants, are addressed in the subsequent section.

5.5 Proposed Changes to Framework

Various improvements to the framework were suggested by participants during the validation process. These proposed improvements have been discussed in previous chapters and are summarised in Section 5.3.5. The most relevant and important changes suggested are addressed in this section.

A *Scoping* section should be added to the framework, as this relates to the contextualisation of the scenario (prior to Phase 1: Contextualise SPM). It is an important point of departure for BPR. The *Scoping* section that should be added relates to the entire BPR initiative and not merely the implementation phase (Phase 5). The scope needs to be defined in order to focus efforts and determine the objectives of the change initiative. The company needs to know whether the initiative is aimed at (i) expanding capacity to cope with the growth of the business, (ii) adopting best business practices and new technologies to improve the efficiency of operations and, thereby, remain competitive, or (iii) a reason they deem worthy of change. The Change Management section should also be expanded upon in the framework since more than one participant considered this valuable and it is one of the focus areas in the research.

The suggestion for an inventory management methodology is not included, as parts of this have been discussed in Section 2.2 (characteristics and classification of spare parts, demand forecasting and inventory warehousing). Further expansion of this in the framework is considered beyond the scope of the study. A participant also believed that clear decision-making matrices could be established to describe the responsibilities of different parties during the BPR initiative such that they can be related back to redesigned business processes. This is not addressed since matrices such as these would vary considerably among organisations, depending on the processes involved, the organisational structures, the resources available and the level of planning coordination. It is, instead, assumed that organisations can establish these matrices themselves based on their specific scenarios and in the same manner in which they manage other projects. Furthermore, this is considered to be an aspect of Project Management which is not, as a subject area, in the scope of the study. However, it is mentioned in the framework that the organisations should assign roles and responsibilities for the BPR initiative. These issues, which are not addressed, can be considered future areas of improvement to the framework.

Section 5.5.1 provides the necessary literature review for recommended changes (following the evaluation by the expert panel) made to the BPR stream (specifi-

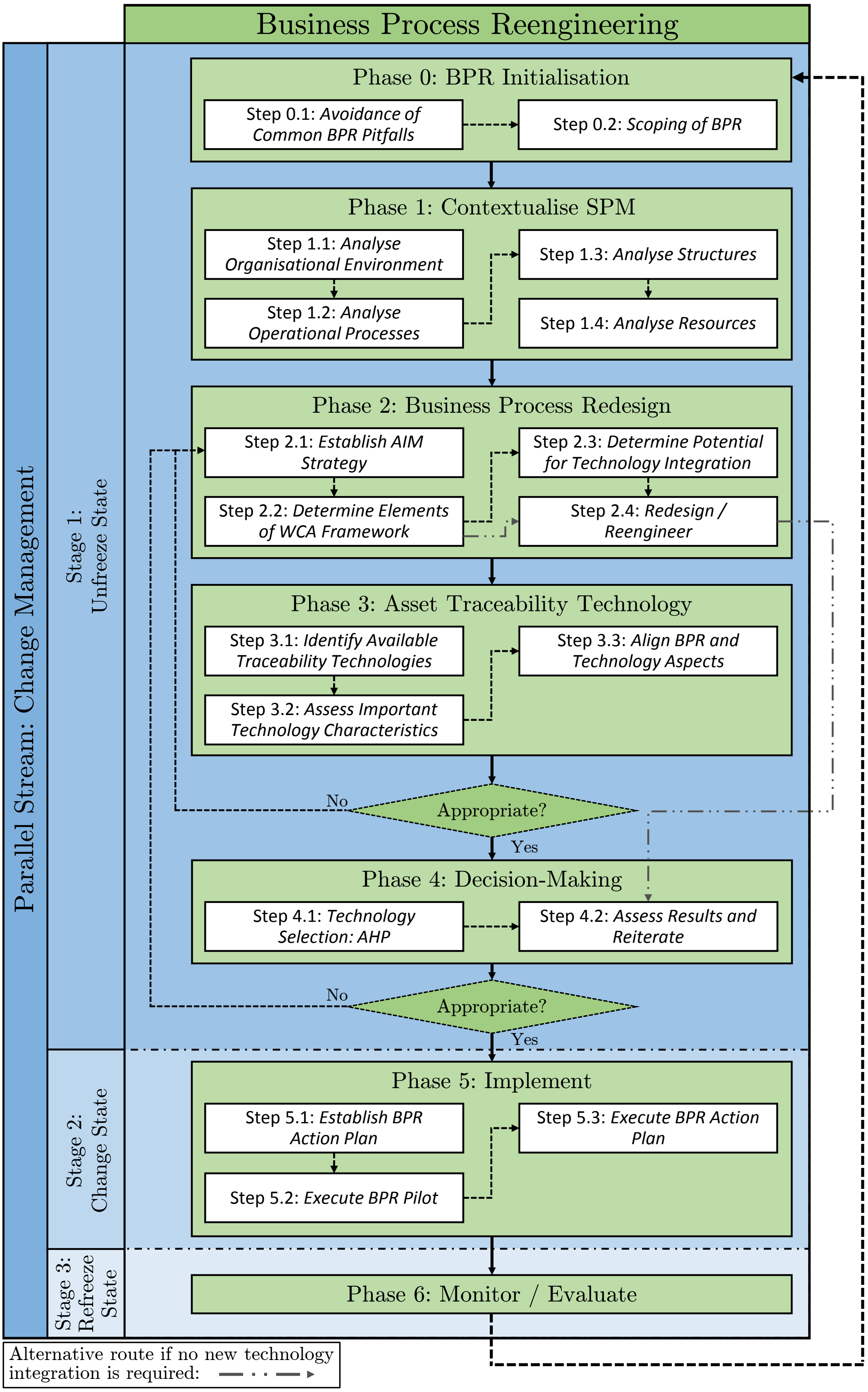


Figure 5.1: Revised framework outline

cally regarding the new *Scoping* section). These changes to the BPR stream are described in Section 5.5.3. The literature review for the expansion of Change Management is available in Section 5.5.2 while the changes to the Change Management stream are discussed in Section 5.5.5. Figure 5.1 illustrates the revised framework outline.

5.5.1 Literature on BPR Scope

Hagel (1993) emphasises the importance of the management team obtaining consensus on the amount of radical change desired. Hagel (1993) asserts that people resist change due to the change process being difficult, threatening and involving significant risk. Additionally, Hagel (1993) believes that the organisation's efforts need to be focused effectively in order to achieve large-scale benefits. Therefore, the extent of the application of a BPR initiative needs to be defined carefully such that it is clear to everyone involved. Levene and Braganza (1996) explain two dimensions of this extent of application as:

- *breadth*: the span of change that includes the number of functions which are integrated to form the process [such as whether the change applies only across work processes, business processes, supply chains or holistic networks (Evans, Mason-Jones and Towill, 1999)]; and
- *depth*: the degree of change in terms of how radical the BPR initiative is, involving six variables: roles and responsibilities; measurements and incentives; organisational structure; IT; shared values; and workforce skills.

Evans *et al.* (1999) define a third dimension referred to as *width* which concerns the various types of flow to be included, such as product flows, information flows, capacity flows and cash flows. Evans *et al.* (1999) describe the three dimensions for Business Systems Engineering of which BPR is considered a subset or strand. Furthermore, Evans *et al.* (1999) consider the scope of a project to comprise of these three dimensions. Figure 5.2 illustrates the dimensions of application of BPR.

It is important to have a sufficient breadth, as the likelihood of (i) improvements permeating through the business, and (ii) finding and substantially improving process interface activities increases as the breadth enlarges (Evans *et al.*, 1999). Evans *et al.* (1999) further state that a narrow vision and insufficient drive from top management can cause a BPR initiative to fail. The typical reasons for failure to achieve significant business change, as a result of lack of breadth, depth and width in application, are tabulated in Table 5.2.

Khan (2006) highlights that managing the scope of a project, within any industry, is one of the most important aspects of Project Management. Fur-

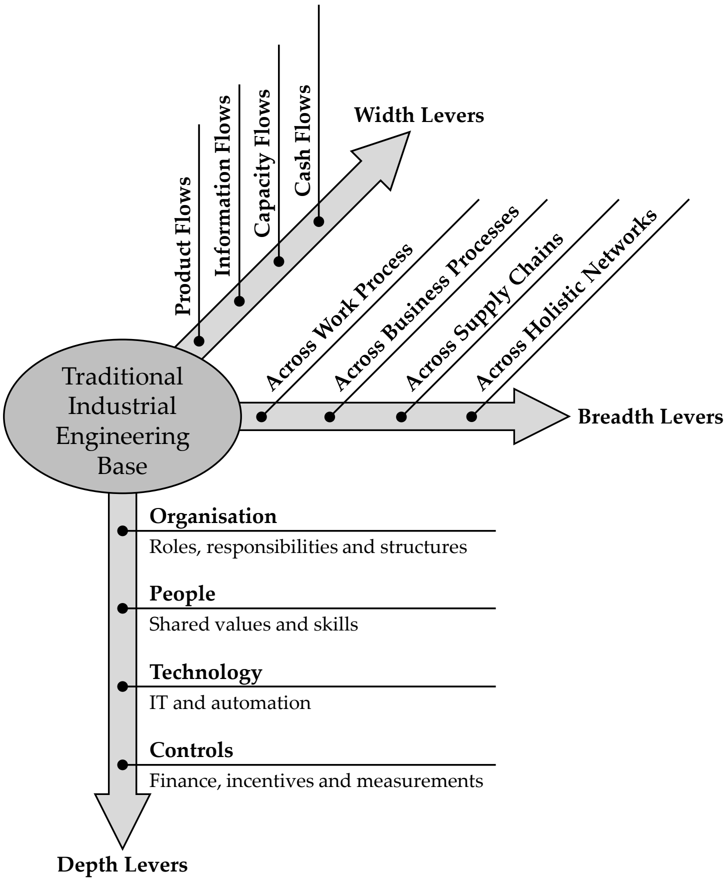


Figure 5.2: Sphere of BPR application
Adapted from Evans *et al.* (1999)

thermore, the scope is managed throughout the execution of the project (as opposed to only in the initial stages). Effective Project Scope Management (PSM) ensures the successful management of other important Project Management factors such as time, cost and quality (Khan, 2006). PSM consists of project initiation, scope planning, scope definition, scope verification and scope change control which are subsequently described.

Project Initiation: A project is initiated subject to feasibility criteria. First, a Project Manager is assigned to the project. Thereafter, a project feasibility analysis is performed which aids with defining the scope boundaries. This analysis consists of technical, economic and financial aspects. Khan (2006) points out that the technical analysis includes an assessment of the available technological capabilities, the competency of management and operations teams and the availability of structures. The economic analysis evaluates the potential Return on Investment (ROI) for the project. The financial assessment identifies the availability of funds and the cost of borrowing capital. Once the high-level analyses have been performed, management can decide whether

Table 5.2: Typical reasons for BPR initiative failure due to lack of dimension

Dimension	**Reason for Failure**
Depth	Internal conflicts Inappropriate technology Failure to create appropriate culture Inconsistent internal measures of performance
Breadth	Conflicts between external stakeholders Misalignment at interfaces Distortion of information No common objective across entire chain
Width	Lack of information transparency throughout chain Failure to synchronise material, information and capacity flows Too much emphasis on products and not enough on capacity Delayed and erratic cash flows

Adapted from Evans et al. *(1999)*

to proceed with the initiative or not.

Scope Planning: The Work Breakdown Structure (WBS), a hierarchical breakdown of the project into its constituent elements, is at the core of PSM (Khan, 2006). A detailed WBS has more levels than a less detailed WBS and allows for more accurate management of a project. However, it also requires more resources to collect and compile the necessary information. Scope planning involves developing a summary and intermediate level WBS of the project (Khan, 2006). A comprehensive WBS is not performed at this stage. The project is divided into deliverable-oriented constituent parts and these are presented in a hierarchy form to create the WBS.

Scope Definition: Dumont, Gibson Jr and Fish (1997, p. 55) describe project scope definition as "the process by which projects are defined and prepared for execution". The WBS is expanded by the Project Manager and the project team to include details on the work package level (Khan, 2006). Khan (2006) indicates that two types of emergency funds are allocated to the project, namely *management reserves* (for unforeseen changes to project scope) and *contingency funds* (for expected additional work that cannot be quantified accurately).

Scope Verification: Scope verification is intricately linked to project scope planning and project scope definition. It provides a feedback loop to verify the progress related to scoping, particularly regarding deliverables. Earned value management may be performed to measure the progress of the project (Khan, 2006). This is simply a technique of comparing actual work completed to the work that was scheduled to be complete at that given time. The same approach is performed regarding project cost. This is often referred to as an Earned Value Analysis (EVA).

Scope Change Control: The change in scope of a project is inevitable (Khan, 2006). According to Khan (2006), scope creep describes any uncontrolled changes in scope. This needs to be managed and controlled by establishing an effective scope change control mechanism. This includes evaluating the impact of scope change on cost, schedule and quality.

5.5.2 Further Literature on Change Management

According to Kerzner (2013), people tend to resist change both when they are content with their current environment and when they are discontent with it. People will not resist change when (i) they believe that the change is possible and (ii) they believe that they will somehow benefit from the change (Kerzner, 2013). Section 2.1.7.1 describes a few causes of resistance. Kerzner (2013) further divides the causes of individual resistance into four categories, namely potential changes in work habits, potential changes in the social groups, embedded fears and potential changes in the wage and salary administration. Moreover, Section 2.1.7.3 mentioned approaches to address resistance. Kerzner (2013) asserts that the best approach for change is to develop a shared understanding with employees by:

1. explaining the rationale for the change and encouraging feedback;
2. explaining the desired outcomes;
3. championing the change process;
4. empowering the appropriate individuals by allowing them to make decisions regarding changes; and
5. investing in training required to facilitate the changes.

The causes of and approaches for overcoming resistance related to *social groups*, *work habits*, *embedded fears*, and *wage and salary management* are displayed in Table 5.3, Table 5.4, Table 5.5 and Table 5.6, respectively.

Table 5.3: Causes of and approaches for resistance: social groups

Causes of Resistance	**Approaches for Resistance**
- Unknown new relationships - Multiple bosses - Multiple temporary assignments - Severing of established ties	- Maintain existing relationship - Avoid cultural shock - Determine and abide by an acceptable pace for rate of change

Adapted from Kerzner (2013)

Table 5.4: Causes of and approaches for resistance: work habits

Causes of Resistance	**Approaches for Resistance**
- New guidelines or processes - Need to share "power" information with others - Potential creation of a fragmented work environment - Need to forfeit established patterns (and learn new skills) - Change in comfort zones	- Order mandatory conformance from higher management levels - Create new comfort zones at an acceptable pace - Identify and explain tangible/ intangible benefits

Adapted from Kerzner (2013)

Table 5.5: Causes of and approaches for resistance: embedded fears

Causes of Resistance	**Approaches for Resistance**
- Fear of failure - Fear of termination - Fear or dislike of additional workload - Fear or dislike of uncertainty - Fear of embarrassment - Fear of an "us/them" organisation	- Explain the benefits of change to the workforce - Display willingness to recognise and admit mistakes - Display willingness to be involved - Transform unknowns into opportunities - Share information

Adapted from Kerzner (2013)

Table 5.6: Causes of and approaches for resistance: wage/salary management

Causes of Resistance	Approaches for Resistance
- Changes in authority and power - Lack of recognition after the changes - Unknown rewards and punishment - Inadequate review of personal performance - Multiple bosses	- Link incentives to change - Identify future advancement opportunities/career paths

Adapted from Kerzner (2013)

Section 5.5.6 addresses the changes made to the framework with regards to Change Management. The change relates to the reference to the Technology Acceptance Model (TAM).

5.5.3 Changes to BPR Stream

This section describes the changes that are to be made to the BPR stream. Prior to *Phase 1: Contextualise SPM* (Section 4.4) of the framework, a new *Phase 0: BPR Initialisation* is created. Aspects of scoping (which is an iterative process) are considered in Phase 1 and, therefore, Phase 0 initiates the project scoping process instead of defining the entire scope for the BPR initiative. *Step 1.1: Avoidance of Common BPR Pitfalls* (Section 4.4.1) is moved within Phase 0 and renamed *Step 0.1: Avoidance of Common BPR Pitfalls*. Step 1.2, Step 1.3, Step 1.4 and Step 1.5 are renamed to Step 1.1, Step 1.2, Step 1.3 and Step 1.4, respectively. The *Outputs* section of the newly named Step 0.1 changes from "User may proceed to Step 1.2" to "User may proceed to Step 0.2". Thereafter, a new step is created, after Step 0.1, titled *Step 0.2: Scoping of BPR*. The contents of this step are provided in Section 5.5.4 assuming the framework has been modified as stated. The *Inputs* of the newly named Step 1.1 changes from "Awareness of BPR pitfalls from Step 1.1" to "Awareness of BPR pitfalls from Step 0.1; definition of scope and objectives of BPR initiative from Step 0.2". All other references (from steps further on in the framework) to the change steps update in step numbering and section referencing accordingly. The reiteration loop in Figure 4.1 flows from Phase 6 to Phase 0 instead of to Phase 1.

5.5.4 Step 0.2: Scoping of BPR

Purpose: The user needs to define the scope and objectives of the BPR initiative in order to focus effort and resources. This step requires the user to define the scope before proceeding to the next step.

Inputs: Awareness of common BPR pitfalls from Step 0.1; knowledge of workflows, processes, supply chains and other forms of flow at the company; understanding of organisational and process boundaries; understanding of organisational strategy.

Sequence & considerations: It is important for the user to perform the following sub-steps:

1. establish a BPR project team that will carry out or significantly support the initiative and assign a project manager or team leader;
2. identify the primary objective of the initiative, for example, (i) expanding capacity to cope with the growth of the business, or (ii) adopting best business practices and new technologies to improve the efficiency of operations and, thereby, remain competitive;
3. determine realistic objectives of the BPR initiative (including both planning and implementation) necessary to attain the primary objective;
4. define the scope of the initiative, deciding on the breadth, depth and width (as described in Section 5.5.1) — this includes being aware of the potential *reasons for failure*, tabulated in Table 5.2, in which a lack of breadth, depth or width may result;
5. determine which departments and individuals will be responsible for and involved in the various areas and phases of the initiative (such as planning, managing, implementing and monitoring); and
6. review the scoping process, described in Section 5.5.1, which is addressed further in Phase 1.

Outputs: Defined scope and objectives of the BPR initiative. User may proceed to Step 1.1 in Phase 1.

5.5.5 Changes to Change Management Stream

Participants requested that the Change Management section (Section 2.1.7) be expanded. Two of the most important, useful and practical aspects in the Change Management section to understand are the causes of resistance and the approaches to address resistance. Therefore, these aspects are expanded upon in Section 5.5.2. The Change Management steps in the framework regarding these aspects, however, remain unchanged. They refer to the Change Management section (Section 2.1.7) which should incorporate the information provided in this section. The only change made to the structure of the Change Management stream in the framework is discussed in Section 5.5.6.

5.5.6 Changes to Stage 1: Unfreeze (Existing) State

The Technology Acceptance Model (TAM), proposed by Davis (1989), is a popular and successful model to predict the success or likelihood of adoption of a technology. TAM represents a Change Management model. The criteria from TAM has been addressed in the validation of the framework (Section 5.2.2). Use of TAM should be incorporated into Stage 1 of the Change Management stream of the framework to aid the user of the framework to determine the potential for technology acceptance. The steps are displayed below with the previous and subsequent items (with relevant numbering) to indicate the position in Stage 1 of the framework:

4. listen to and consider opinions, hesitations and concerns regarding change efforts (this may involve satisfaction surveys or questionnaires);
5. attempt to predict attitudes towards technology adoption by utilising the Technology Acceptance Model (TAM) proposed by Davis (1989) — the same success criteria utilised in the validation of the framework (Section 5.2.2) can be used for predicting technology acceptance; and
6. motivate staff for change implementation.

The subsequent section summarises this chapter which relates to the validation of the framework.

5.6 Chapter Summary

Chapter 5 addresses the validity of the proposed framework (from Chapter 4) through face validation using semi-structured interviews containing both open-ended questions (predominant) and closed-ended questions. The chapter begins with an overview of the validation of the study. Thereafter, the methodology followed for validation is described. In particular, the expert panel that assessed the framework is described, the success criteria against which the framework is evaluated are defined and the method of collecting data is explained. The review of the proposed framework by the expert panel is discussed according to each success criterion. Finally, the chapter concludes with a discussion of the validity of the framework based on the results of the review.

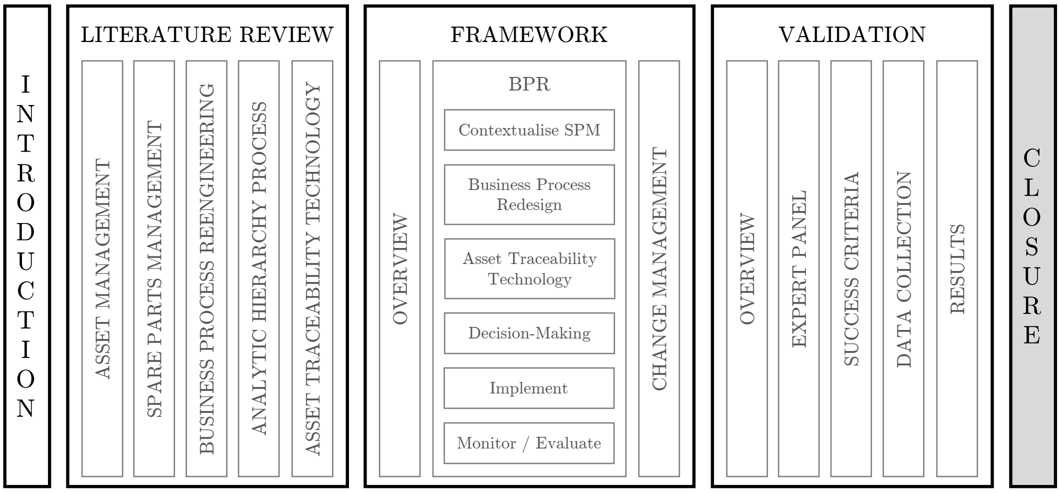
According to the responses from the expert panel, the framework satisfies the achievement of the desired framework attributes, namely (i) *Generic and adaptable*, (ii) *Holistic and comprehensive*, (iii) *Structured and objective- or outcome-oriented* and (iv) *Practical*. In addition, the expert panel perceived the framework to be *useful*, *easy to use* and *understandable*. Therefore, the framework satisfies the achievement of the defined success criteria and, hence, the research objective (defined in Section 1.3) regarding the validation of the framework has been attained. However, recommendations were proposed to further improve the framework, including the addition of a “scoping and objectives” section and the expansion of the Change Management element in the framework. The requested changes deemed necessary and within the scope of the study (the “scoping and objectives” section and the expansion of Change Management) are addressed.

The following chapter concludes the study.

Chapter 6

Closure

This chapter concludes the study by concisely summarising the research and answering the central research question mentioned in Chapter 1. The chapter begins with an overview of the study, after which the conclusion of the study is provided. Thereafter, the limitations imposed on the research are highlighted. Finally, recommendations for future research related to the study are proposed.



6.1 Overview

The study originates from an opportunity identified for improving processes within Spare Parts Management (SPM), particularly through the utilisation of asset traceability technology. The study proposes a framework that (i) guides the Business Process Reengineering (BPR) of processes within SPM while considering elements of Change Management, and (ii) guides the selection [through use of the Analytic Hierarchy Process (AHP)] of traceability technology for integration within SPM at capital-intensive organisations. The study consists of six chapters: an introduction; a literature review of AM, SPM, BPR and the AHP (the first part of the literature review); an overview of asset traceability technology (which is a continuation of the literature review); a proposed framework; a validation of the framework; and a conclusion. This section aims to provide a brief overview of the content of the study.

Chapter 1 introduces the study to the reader with a brief background on AM and spare parts, particularly the need for improved SPM within capital-intensive industries. Thereafter, the study briefly mentions each aspect that is considered in the study to address the problem (or rather opportunity) identified. Following from this, the research question is provided, in addition to the null hypothesis for the study which is reiterated below:

> $\boldsymbol{H_0}$ **:** *It is not possible to develop a framework that guides the BPR of processes within SPM while considering elements of Change Management, and that supports the selection (through use of the AHP) of traceability technology for integration within SPM, to improve current practices within the SPM environment at organisations within capital-intensive industries.*

The objectives, the delimitations and the research objectives of the study are also defined, and the research methodology and design described.

Chapter 2 begins with a thorough discussion of *AM*, including a discussion of two important series of documents: PAS 55 and ISO 55000. Change Management, which is an essential aspect for implementations, is also discussed. Thereafter, *SPM*, which is a subset of AM, is addressed. The characteristics of spare parts and how they differ from that of general inventory are indicated; the classification criteria and classification techniques for spare parts are discussed; and demand forecasting for spare parts is explained. The SPM section concludes with inventory warehousing management. Various aspects and principles (including 29 best practices) of *BPR* are described in order to support the proposed framework. These include criteria for selecting processes to redesign, the role of IT in BPR and typical barriers to effective implementation of BPR. The *AHP* is also explained in detail, as this is to be used as an aid for decision-making, specifically for the selection of asset traceability technology.

Chapter 3 provides an overview of asset traceability technologies (specifically barcode, RFID and GPS technologies) and describes certain characteristics of each technology.

Chapter 4 discusses the development of the proposed framework which is based on the literature review. The framework consists of two primary elements (referred to as streams), namely the *Business Process Reengineering (BPR) stream* that encompasses six phases of BPR and the *Change Management stream*, consisting of three stages, that flows parallel to the BPR stream. The proposed framework is to serve as a guide and, therefore, attempts to be generic, holistic, objective- or outcome-oriented, practical and structured.

The proposed framework is validated through face validation with a panel of experts involved in and familiar with SPM and asset traceability technology. The validation is addressed in Chapter 5 where the methodology (particularly regarding the expert panel, defined success criteria and data collection) and results are discussed. Additionally, changes are made to the framework based on feedback from participants in the study. The following section concludes the study, after which limitations imposed on the study are highlighted and recommendations for future research made.

6.2 Conclusions

Cavalieri *et al.* (2008) report that few companies actually adopt proper structural, factual and quantitative approaches to manage spare parts despite the relatively vast body of literature on spare parts (although this is primarily focused on demand forecasting and stock levels). Thus, Bacchetti and Saccani (2012) highlight the need for integrated approaches to manage spare parts as well as supplement theoretical models with practical guidelines in order to bridge the gap between research and practice. This study proposes a framework that serves as a comprehensive, structured guide to improve processes within SPM (through BPR) and to facilitate the selection of asset traceability technology for integration within SPM in an attempt to improve current practices within SPM.

A framework has been developed in the study that guides the BPR of processes within SPM while considering elements of Change Management, and that supports the selection (through use of the AHP) of traceability technology for integration within SPM at organisations within capital-intensive industries. Therefore, the objective of the study regarding such a framework (defined in Section 1.3) has been attained [primarily through Chapter 4].

According to the responses from the expert panel, the proposed framework satisfies the achievement of the desired attributes, namely (i) *Generic and adaptable*, (ii) *Holistic and comprehensive*, (iii) *Structured and objective- or outcome-oriented* and (iv) *Practical.* In addition, the expert panel perceived the framework to be *useful*, *easy to use* and *understandable.* The framework, therefore, satisfies the achievement of the defined success criteria. Hence, the research objective (defined in Section 1.3) regarding the validation of the framework through face validation has been achieved [through Chapter 5]. However, recommendations were proposed to further improve the framework, including the addition of a "scoping and objectives" section and the expansion of the Change Management element in the framework. These were addressed briefly and the relevant changes were made to the framework. Proposed improvements that are considered to be areas for future research are also discussed in Section 6.4.

Furthermore, the following additional objectives stated in Section 1.3 have been attained:

1. To master the fundamental principles of AM and, more specifically within AM, SPM [addressed in Chapter 2].
2. To acquire sufficient knowledge of the fundamental principles of Change Management necessary to facilitate an implementation project or BPR initiative [addressed in Chapter 2].
3. To master the fields of BPR [addressed in Chapter 2] and asset traceability technologies [addressed in Chapter 3], as well as the AHP which will support decision-making [addressed in Chapter 2].

Considering the responses from the expert panel, it is plausible that the proposed framework would be able to improve current practices within the SPM environment at organisations within capital-intensive industries. The null hypothesis of this study is, therefore, rejected since the expert panel considered the framework to be satisfactory in achieving its outcomes. This study also contributes towards bridging the gap between research and practice regarding SPM.

Although the objectives of the study have been successfully achieved, certain limitations influenced the manner in which the study was conducted. These limitations are discussed in Section 6.3. Finally, as an opportunity to improve on the study, recommendations for future research are suggested in Section 6.4.

6.3 Limitations of the Study

Every study has certain limitations that impact on the results and/or the manner in which it is conducted. It is important to identify the limitations of a study in order to understand what may have affected the results and the method of conducting the study, how it may have affected the study and in which ways the study could have been conducted differently. The study, particularly the proposed framework, was or is constrained by the following limitations:

- The framework, although a somewhat generic stepwise guide, involves various aspects and each aspect cannot be considered in depth within the framework itself. However, it is assumed that the user is capable of performing these additional steps through the manner in which they are accustomed (such as internal policies) or by researching the necessary steps.

- The primary fields of study for the framework include AM, SPM, BPR, asset traceability technology, AHP and Change Management. However, other fields or domains, such as Project Management and Contract Management, would typically be involved in a BPR initiative. These fields have not been considered in this framework except where applicable to the fields of study.

- The framework does not consider rotable spare parts separately, but instead, focuses on SPM in general.

- With regard to the selection of traceability technology using AHP, the method does not automatically exclude options (alternatives) that are beyond specifications listed by the user. Instead, it assesses the options based on importance per criterion allocated by user. This implies that the method attempts to select the most appropriate technology solution, but the user still needs to verify whether the solution is viable (within specifications).

- The AHP is capable of processing subjective criteria, but it also relies on expert judgement. The appropriate traceability technology solution selected is dependent on the knowledge, experience and careful consideration of the user.

- The AHP is time-consuming and would be more beneficial with an associated software package that can support the process of selecting the most appropriate technology solution.

- The framework refers to a cost-benefit analysis and a Return on Investment (ROI) analysis and provides references to books and papers that discuss these analyses. These are, however, not discussed exhaustively within this framework. Despite this, the framework includes a partial evaluation utilising the AHP which is based on prioritised criteria to support the selection of technology.

- The validation of the study only included face validation (instead of a more quantitative method). This is primarily due to the scope and duration of the study, costs involved and the unavailability of suitable sites to implement a solution according to the framework. This lack of field testing of the framework is considered a limitation despite the extensive use of expert panels to validate research within the academic community.

- Seven participants were interviewed to validate the study. This small sample size limited the total experience of the sample and restricted feedback regarding recommendations and suggested areas for improvement. A larger number of participants, including more participants that are experts of traceability technology, would have contributed more towards the credibility of the study. Additionally, surveys could have been utilised that can be analysed statistically. This would have provided a more quantitative, and therefore objective, approach to the research.

The subsequent section provides recommendations for future research related to this study.

6.4 Recommendations for Future Research

Areas for future research were identified during the course of this research study, either arising from limitations imposed on the study or due to the opportunity for improvement. This section provides the following recommendations for future research that may improve or contribute to the research:

- A stronger focus can be placed on SPM, particularly regarding the actual application of the framework within the SPM environment and how process within SPM can be altered. Furthermore, this focus can include an extensive guide for the implementation of traceability technology within the SPM environment.

- More appropriate or improved Multi-criteria Decision-Making (MCDM) methods may be employed instead of the AHP for selection of traceability technology.

- MCDM methods can be employed to identify business processes to redesign and select the most appropriate BPR best practices to apply in the redesign phase.

- Software packages can be developed or integrated into the model for (i) the selection of traceability technologies and (ii) guiding the overall BPR process.

- The BPR framework can be expanded upon with supporting guides for various aspects such as designing spare parts storerooms, performing feasibility studies, installing traceability technologies and executing both the pilot test and full-scale implementation.

- Hassan *et al.* (2015) list a cost-benefit analysis or ROI analysis to be one of the most difficult problems in selecting an AIDC technology (traceability technology). The framework utilises the AHP which is based on prioritised criteria to support selection of this technology, but it does not exhaustively discuss a cost-benefit analysis or ROI analysis. The framework, instead, refers to books and papers that discuss these analyses. Further research would extend the framework by providing these analyses for both the selection of technology and the overall BPR implementation.

- The framework can incorporate an approach that attempts to determine the level of maturity at which a company is. The viability of technology integration can be evaluated based upon this. A participant of the study highlighted the importance of ascertaining the level of maturity before implementing technology.

- Other parallel streams, such as Project Management, can be incorporated into the framework, although this may reduce the readability and usability of the framework.

- The framework can include clear decision-making matrices across multidisciplinary or multi-departmental areas that describe the responsibilities of different parties, such that they can be related to the redesigned business processes.

- An inventory management methodology can be addressed, including an extensive discussion on how to distinguish spare parts from other materials, and how to manage specific metal spare parts.

The recommendations for further research listed above are propositions to advance the research conducted.

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Appendices

Appendix A

Guide Tables for Framework

The proposed framework in Chapter 4 consists of phases and within each phase are multiple steps. Each step is structured into *Purpose*, *Inputs*, *Sequence & considerations* and *Outputs* sections. The *Inputs* section indicates the information or knowledge required (from outside the framework or from other steps of the framework) for the specific step to be performed. In contrast, the *Outputs* section lists the relevant outputs of the specific step that are used in other steps of the framework. This section provides a summary of the inputs (tabulated in Table A.1) and outputs (tabulated in Table A.2) of all the steps of the framework.

Table A.1: Inputs required for each step of framework

Step	Step Description	Inputs
1.1	Avoidance of Common BPR Pitfalls	Knowledge of the definition and concept of BPR.
1.2	Analyse Organisational Environment	Awareness of BPR pitfalls from Step 1.1 (Section 4.4.1)
1.3	Analyse Operational Processes	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; criteria, provided in Section 2.3.3, for selecting processes to improve; understanding of the Work-Centred Analysis (WCA) process described in Step 2.2 (Section 4.5.2)
1.4	Analyse Structures	Understanding of various part classifications described in Section 2.2.3; understanding of organisation's preferred method of part classification; awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; consideration of existing processes from Step 1.3 (Section 4.4.3)
1.5	Analyse Resources	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; understanding of types of WMS discussed in Section 2.2.5.5; processes under examination [selected from Step 1.3 (Section 4.4.3)]
2.1	Establish AIM Strategy	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations
2.2	Determine Elements of WCA Framework	Existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations
2.3	Determine Potential for Technology Integration	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations

2.4	Redesign / Reengineer	Warehouse design decision levels and warehouse considerations discussed in Section 2.2.5.2; aspects from Section 2.2.5.3; BPRD best practices from Section 2.3.4; foundation principles from Section 2.3.1; MCDM models mentioned by Campos and De Almeida (2015) for best practices from Section 2.3.4; awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; existing business processes identified for redesign in Step 1.3 (Section 4.4.3); existing structures from Step 1.4 (Section 4.4.4); existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); elements of existing business processes and those required for new processes from Step 2.2 (Section 4.5.2); understanding of potential for technology integration from Step 2.3 (Section 4.5.3); new information from Step 3.3 (Section 4.6.3) and Step 4.2 (Section 4.7.2) during iterations
3.1	Identify Available Traceability Technologies	Available AIDC technology systems; new information from Step 4.2 (Section 4.7.2) during iterations
3.2	Assess Important Technology Characteristics	Understanding of potential for technology integration from Step 2.3 (Section 4.5.3); available AIDC technology systems from Step 3.1 (Section 4.6.1); new information from Step 4.2 (Section 4.7.2) during iterations
3.3	Align BPR and Technology Aspects	AIM strategy from Step 2.1 (Section 4.5.1); redesigned processes from Step 2.4 (Section 4.5.4); available AIDC technology systems from Step 3.1 (Section 4.6.1); various technology characteristics from Step 3.2 (Section 4.6.2); new information from Step 4.2 (Section 4.7.2) during iterations
4.1	Technology Selection: AHP	AHP steps from Section 2.4.2 and example from Section 2.4.4; available AIDC technology systems from Step 3.1 (Section 4.6.1) and their various technology characteristics from Step 3.2 (Section 4.6.2) after being aligned in Step 3.3 (Section 4.6.3); new information from Step 4.2 (Section 4.7.2) during iterations
4.2	Assess Results and Reiterate	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; AIM strategy from Step 2.1 (Section 4.5.1); elements of existing business processes and those required for new processes from Step 2.2 (Section 4.5.2); understanding of potential for technology integration from Step 2.3 (Section 4.5.3); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) out of the available AIDC technology systems from Step 3.1 (Section 4.6.1) and their various technology characteristics from Step 3.2 (Section 4.6.2) after being aligned in Step 3.3 (Section 4.6.3)
5.1	Establish BPR Action Plan	Awareness of organisational environment [from Step 1.2 (Section 4.4.2)]; existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2)

5.2	Execute Pilot	Existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1)
5.3	Execute BPR Action Plan	Existing resources from Step 1.5 (Section 4.4.5); redesigned processes from Step 2.4 (Section 4.5.4); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1); results from pilot in Step 5.2 (Section 4.8.3)
Phase 6	Monitor / Evaluate	Existing resources from Step 1.5 (Section 4.4.5); AIM strategy from Step 2.1 (Section 4.5.1); redesigned processes from Step 2.4 (Section 4.5.4); technology aspects from Phase 3 (Section 4.6); most appropriate technology from Step 4.1 (Section 4.7.1) after being confirmed for suitability in Step 4.2 (Section 4.7.2); action plan from Step 5.1 (Section 4.8.1); results from pilot in Step 5.2 (Section 4.8.2); full-scale implementation in Step 5.3 (Section 4.8.3)

Table A.2: Outputs obtained from each step of framework

Step	Step Description	Outputs
1.1	Avoidance of Common BPR Pitfalls	Awareness of pitfalls before undergoing subsequent steps in framework. User may proceed to Step 1.2 (Section 4.4.2)
1.2	Analyse Organisational Environment	Understanding of the organisational environment including: the business objectives to which SPM objectives should be aligned, the support available to ensure success of a BPR initiative and the problems, needs and requirements experienced in the warehouse / storerooms; this contextualises Step 1.3 (Section 4.4.3), Step 1.4 (Section 4.4.2) and Step 1.5 (Section 4.4.5), as well as the BPR initiative in general; information from this step is required in Step 2.1 (Section 4.5.1), Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 4.2 (Section 4.7.2) and Step 5.1 (Section 4.8.1)
1.3	Analyse Operational Processes	Identification of existing processes to be improved and evaluation of process elements both required primarily for Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3) and Step 2.4 (Section 4.5.4), as well as for reference in Step 1.5
1.4	Analyse Structures	Understanding of existing structures (such as infrastructure) available to support or be utilised in BPR initiative; information from this step is required primarily in Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3) and Step 2.4 (Section 4.5.4)
1.5	Analyse Resources	Indication of resources that should be incorporated into redesigned processes, that may be available for utilisation during BPR initiative and that may be available for utilisation elsewhere after BPR initiative; information from this step is required primarily in Step 2.2 (Section 4.5.2), Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9)
2.1	Establish AIM Strategy	Establishment of AIM strategy that indicates the management of data and affects selection of technology as well as redesign of processes; information from this step is required in Step 2.3 (Section 4.5.3), Step 2.4 (Section 4.5.4), Step 3.3 (Section 4.6.3), Step 4.2 (Section 4.7.2) and Phase 6 (Section 4.9)
2.2	Determine Elements of WCA Framework	Allocation / recognition of elements for each process; information from this step is required primarily in Step 1.3 (Section 4.4.3), Step 2.4 (Section 4.5.4) and Step 4.2 (Section 4.7.2)
2.3	Determine Potential for Technology Integration	Understanding of potential to integrate technology successfully into the existing environment; information from this step is required in Step 2.4 (Section 4.5.4), Step 3.2 (Section 4.6.2) and Step 4.2 (Section 4.7.2)

2.4	Redesign / Reengineer	Redesigned business processes; information from this step is utilised in Step 3.3 (Section 4.6.3), Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9)
3.1	Identify Available Traceability Technologies	Identification of traceability technology systems that can potentially be integrated into organisation; information from this step is required in Step 3.2 (Section 4.6.2), Step 3.3 (Section 4.6.3), Step 4.1 (Section 4.7.1), Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9)
3.2	Assess Important Technology Characteristics	Identification and assessment of various characteristics [used as criteria in Phase 4 (Section 4.7)] of the previously identified traceability technology systems; information from this step is required in Step 3.3 (Section 4.6.3), Step 4.1 (Section 4.7.1), Step 4.2 (Section 4.7.2) and Phase 6 (Section 4.9)
3.3	Align BPR and Technology Aspects	Alignment of BPR aspects to potential technology aspects; information from this step is utilised in Step 4.1 (Section 4.7.1) and Step 4.2 (Section 4.7.2), as well as Phase 2 [Step 2.1 (Section 4.5.1) to Step 2.4 (Section 4.5.4)] during iteration process
4.1	Technology Selection: AHP	Identification of most appropriate technology system based on identified characteristics (criteria); information in this step is utilised in Step 4.2 (Section 4.7.2), Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2) and Step 5.3 (Section 4.8.3)
4.2	Assess Results and Reiterate	Confirmation or reiteration of previous steps such that appropriate solution is possible; information from this step is utilised in Step 5.1 (Section 4.8.1), Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9), as well as Phase 2 (Section 4.5), Phase 3 (Section 4.6) and Step 4.1 (Section 4.7.1) when iteration is required
5.1	Establish BPR Action Plan	Action plan that guides the BPR implementation; information from this step is utilised in Step 5.2 (Section 4.8.2), Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9)
5.2	Execute Pilot	Viability of solution and confirmation for further implementation; information from this step is utilised in Step 5.3 (Section 4.8.3) and Phase 6 (Section 4.9)
5.3	Execute BPR Action Plan	Full-scale implementation; information and actions from this step are utilised in Phase 6 (Section 4.9)
Phase 6	Monitor / Evaluate	Assessment of success of BPR initiative and continuous improvement to solution

Appendix B

Validation Questionnaire

A BUSINESS PROCESS REENGINEERING FRAMEWORK
USING THE ANALYTIC HIERARCHY PROCESS TO SELECT
A TRACEABILITY TECHNOLOGY FOR SPARE PARTS
MANAGEMENT IN CAPITAL-INTENSIVE INDUSTRIES

MENG (ENGINEERING MANAGEMENT)
October 2015

Student: Jared FLYNN	*Supervisors:* Prof. P.J. VLOK Dr J.L. JOOSTE

INTRODUCTION

Background

- BEng (Mechanical), Stellenbosch University
- MEng (Engineering Management), Stellenbosch University
- Member of Asset Care Research Group (ACRG), Stellenbosch University

Purpose of Interview: Validation of research for Master's thesis

IMPORTANT INFORMATION

- Participation in this interview is completely voluntary. Participants are allowed to withdraw at any time and are not obligated to answer any of the questions posed.

- This interview will be conducted in a confidential manner. Participants will be made anonymous in the study (not identifiable except by job title and experience).
- The supervisors of this study are:
  - Prof. P.J. Vlok (email: pjvlok@sun.ac.za)
  - Dr J.L. Jooste (email: wyhan@sun.ac.za)
- Please feel free to ask any questions regarding the study or this interview.

Research Context and Problem

There has recently been a strong emphasis on the field of Asset Management (AM) to realise value from assets. A subset of AM is Spare Parts Management (SPM). The three primary drivers of business performance in general are people, information and technology. Organisations have become increasingly cooperative with each other and within their own structures; sharing equipment, resources and having spare parts (such as rotable spare parts) repaired. Hence, it is difficult, especially in large organisations, to manage the exact location of spares, tools and people. Researchers argue that it is critical to know the location of assets in order to effectively manage the assets. They assert that providing *relevant, timely and useful location information* to the persons and systems responsible for managing asset-intensive business processes provides a number of significant benefits. Among these benefits are: timely and informed decision-making based on real-time information, decrease in information-related errors, reduction in costs associated with searching for misplaced or lost assets, and the improvement of overall productivity and throughput. Often the value of an asset itself is not as important as the costs involved with the misplacement or loss of the asset. It is therefore important to know:

1. Where assets are at any given moment in time;
2. Where assets were last identified; and
3. How many of the particular assets are present in the given location.

Technology integration allows for real-time information and integrates various fields, processes and applications into one manageable package. A 2004 survey (performed by the Aberdeen Group) of 233 companies in a broad variety of industries indicated that 50% of the companies have manual AM processes. This suggests that there is still the potential to minimise errors and improve productivity through automation of AM processes. However, it is important to realise that IT and computer systems are merely tools to aid with managing information and activities. The onus is on the organisation to have necessary Asset Management principles already in place for these tools to be effective.

Studies from the early 2000s indicate that after-sales services and sales of spare parts account for approximately 25% of the revenues and 40% to 50% of the profits in manufacturing and engineering-driven organisations. The successful management of *Maintenance, Repair and Operations (MRO)* materials, which include spare parts, is vital in capital-intensive organisations. The majority of the literature regarding SPM focuses on demand forecasting (especially intermittent demand), the classification of spare parts and various inventory stock policies. However, the tracking of spare parts and the ideal layout and design of spare parts processes are not as well researched. Additionally, there is a substantial discrepancy between theory and application concerning inventory concepts in manufacturing or engineering-driven organisations. Integrated approaches to manage spare parts, as well as to supplement theoretical models with practical guidelines, are required in order to bridge the gap between research and practice.

PROPOSED FRAMEWORK OUTLINE

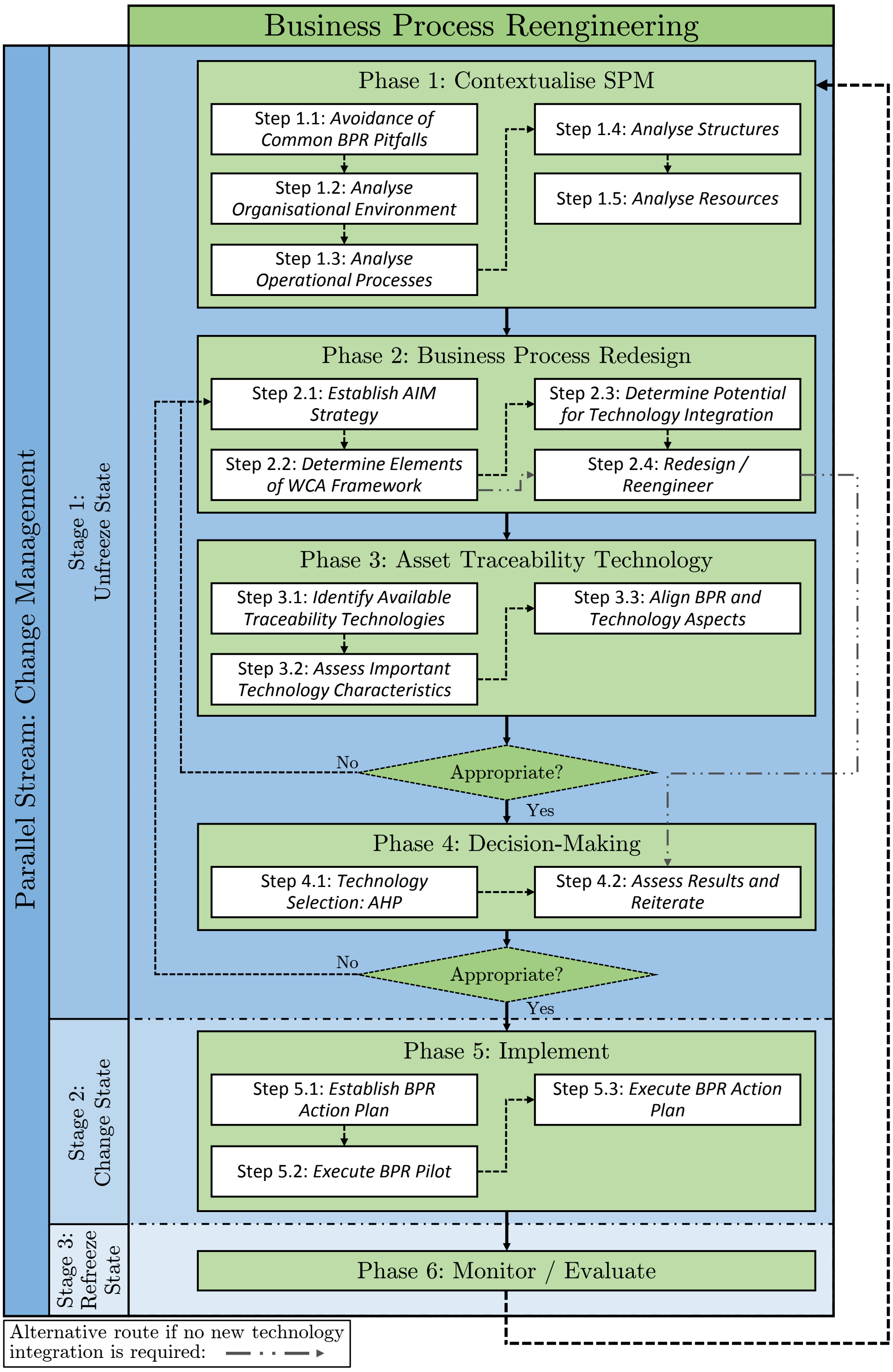


Figure B.1: Proposed framework outline

Framework Description

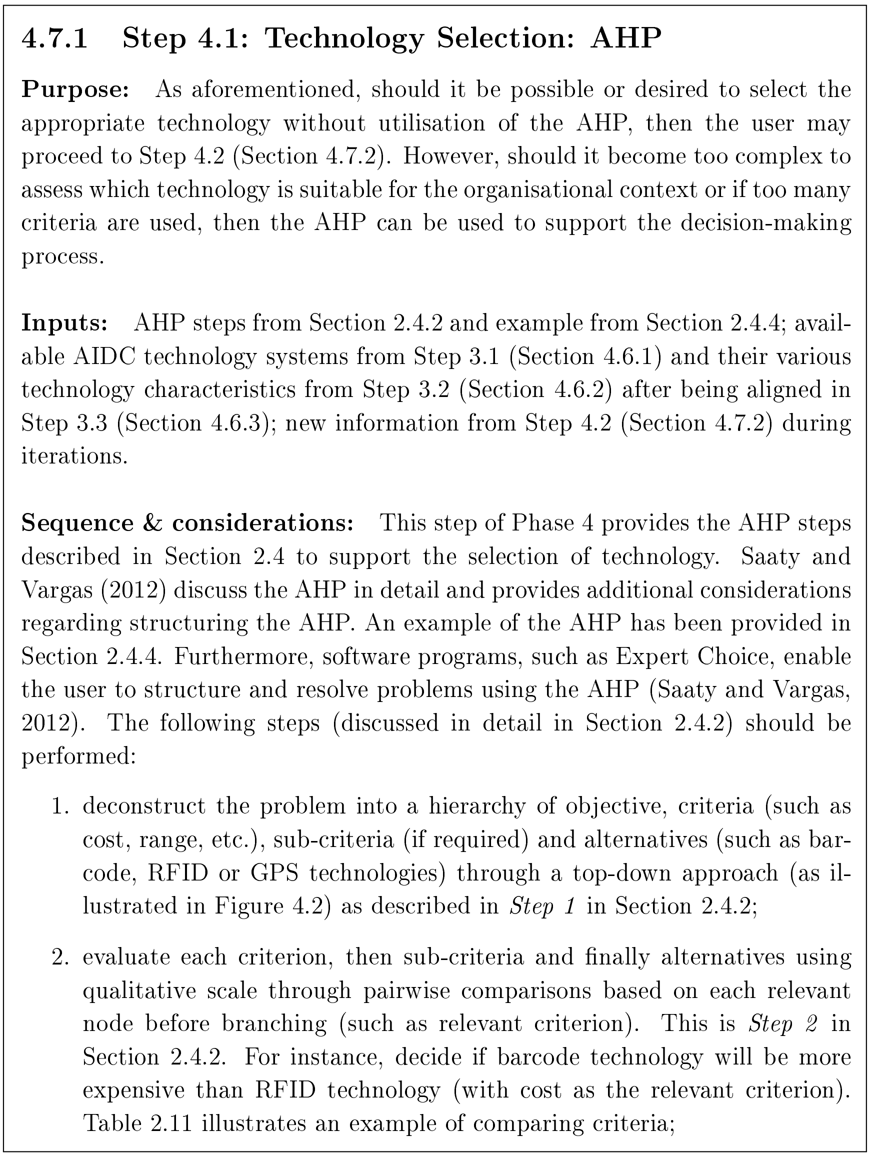
The framework serves as a guide for the Business Process Reengineering of processes within the Spare Parts Management environment and supports the selection (through use of the Analytic Hierarchy Process which is a Multi-criteria Decision-Making method) of traceability technology (barcode technology, RFID technology, GPS technology or a hybrid system) for integration within the SPM environment. The framework consists of two primary elements (referred to as streams), namely the *Business Process Reengineering (BPR) stream* that encompasses the phases of BPR and the *Change Management stream* that flows parallel to the BPR stream.

The Change Management stream considers aspects of Change Management following the Plan-Do-Check-Act (PDCA) cycle and supports the BPR initiative by describing: (i) the *unfreezing* of the existing state (including addressing resistance to change, motivating change and including all parties within discussions), (ii) the *transition* stage (involving, among others, the establishment of objectives, roles and procedures, risk assessments and actual implementation) and (iii) the *refreezing* of changes (involving the standardisation of changes, retraining of employees and continuous improvement).

Within each phase in the BPR stream are multiple steps (each of which is divided into four sections, namely *Purpose*, *Inputs*, *Sequence & considerations* and *Outputs*) that the user should perform to address various issues. These steps (and their respective sub-steps) are generic and should be modified and applied as required by the specific area of application. Figure B.2 illustrates the partial layout of a typical step in the framework. The BPR initiative begins with Phase 1: Contextualise SPM.

Phase 1: Contextualise SPM

Phase 1 involves the assessment of the existing state-of-being of the organisation, specifically with regards to SPM. The first step (Step 1.1) highlights various BPR principles and attempts to protect the user from common BPR pitfalls. It is important to be aware of the mistakes typically made when undergoing a BPR initiative. Thereafter, Step 1.2 concerns the analysis of the organisational environment including understanding the organisational strategy. This is important to develop a holistic solution that aligns to the organisational strategy and plans. Step 1.3 involves the analysis of existing operational processes (including identifying problem areas and decomposing processes into *customers*, *products*, *the business process*, *participants*, *information* and *technology*) which lays the foundation for Phase 2: Business Process Redesign. Existing structures are analysed in Step 1.4 in order to evaluate at a later stage as to which potential solutions are viable. Phase 1 concludes with



4.7.1 Step 4.1: Technology Selection: AHP

Purpose: As aforementioned, should it be possible or desired to select the appropriate technology without utilisation of the AHP, then the user may proceed to Step 4.2 (Section 4.7.2). However, should it become too complex to assess which technology is suitable for the organisational context or if too many criteria are used, then the AHP can be used to support the decision-making process.

Inputs: AHP steps from Section 2.4.2 and example from Section 2.4.4; available AIDC technology systems from Step 3.1 (Section 4.6.1) and their various technology characteristics from Step 3.2 (Section 4.6.2) after being aligned in Step 3.3 (Section 4.6.3); new information from Step 4.2 (Section 4.7.2) during iterations.

Sequence & considerations: This step of Phase 4 provides the AHP steps described in Section 2.4 to support the selection of technology. Saaty and Vargas (2012) discuss the AHP in detail and provides additional considerations regarding structuring the AHP. An example of the AHP has been provided in Section 2.4.4. Furthermore, software programs, such as Expert Choice, enable the user to structure and resolve problems using the AHP (Saaty and Vargas, 2012). The following steps (discussed in detail in Section 2.4.2) should be performed:

1. deconstruct the problem into a hierarchy of objective, criteria (such as cost, range, etc.), sub-criteria (if required) and alternatives (such as barcode, RFID or GPS technologies) through a top-down approach (as illustrated in Figure 4.2) as described in *Step 1* in Section 2.4.2;
2. evaluate each criterion, then sub-criteria and finally alternatives using qualitative scale through pairwise comparisons based on each relevant node before branching (such as relevant criterion). This is *Step 2* in Section 2.4.2. For instance, decide if barcode technology will be more expensive than RFID technology (with cost as the relevant criterion). Table 2.11 illustrates an example of comparing criteria;

Figure B.2: Example of part of a step in the framework

Step 1.5: an analysis of existing resources (including labour) that can be used in the BPR initiative and that should or can be incorporated into redesigned processes. This phase and the next three phases correlate with the unfreezing stage (Stage 1) of Change Management.

PHASE 2: BUSINESS PROCESS REDESIGN

Phase 2 involves the redesign of processes related to spare parts that have been selected for redesign in Phase 1. Step 2.1 involves the establishment of an Asset Information Management (AIM) strategy. This step is necessary to define the manner in which information should be collected and processed. It aids with the identification and selection of technology used within SPM in the organisation. Step 2.2 determines the Work-Centred Analysis Framework elements (*customers*, *products*, *the business process*, *participants*, *information* and *technology*) of processes for redesign. Step 2.3 determines the potential to integrate technology into redesigned processes. This is particularly important for the selection and integration of traceability technology which occurs later. However, if no new technology is to be integrated into the SPM environment, then the user may skip Step 2.3. The phase concludes with Step 2.4 which describes the redesign of the selected processes by providing BPR principles, referring to 29 BPR best practices (including *task elimination*, *resequencing*, *control addition* and *technology integration*, among others) and describing aspects of warehouse / storeroom design and issues such as squirrel stores.

Phase 3: Asset Traceability Technology

Phase 3 considers the aspects relating to traceability technology (barcode technology, RFID technology, GPS or a hybrid system). This entire phase can be skipped if no new technology integration is required (existing business processes are only redesigned). Step 3.1 requires that the user identify available traceability technology systems by considering these technologies and investigating systems available for each kind of technology. Step 3.2 involves an assessment of the important characteristics (such as cost, accuracy, complexity, interference susceptibility, range, etc.) of the technology systems identified in Step 3.1. The environmental and legal aspects are also to be considered in this step. Step 3.3 attempts to align the BPR solutions derived from Phase 2 to the technology aspects considered in this phase (Phase 3).

Phase 4: Decision-Making

Phase 4 concerns the decision-making related to technology selection and assesses the feasibility and viability of solutions. Step 4.1 utilises the Analytic Hierarchy Process (AHP) to facilitate the selection of a traceability technology system. The AHP was selected for its ease of understanding, ease of use, minimal historical data requirements and ability to handle subjective criteria. Various criteria and potential alternatives are identified by the user and then the steps of the AHP are followed to determine the most appropriate technology solution. Figure B.3 illustrates the hierarchical structure used in the AHP. Step 4.2 determines whether the technology solution obtained in Step 4.1 and BPR solution overall are suitable by performing a feasibility study, a ROI analysis and / or a cost-benefit analysis. This step also reiterates Step 4.1 if another technology solution is required or Phase 2 through to Phase 4 if no appropriate technology solution is available.

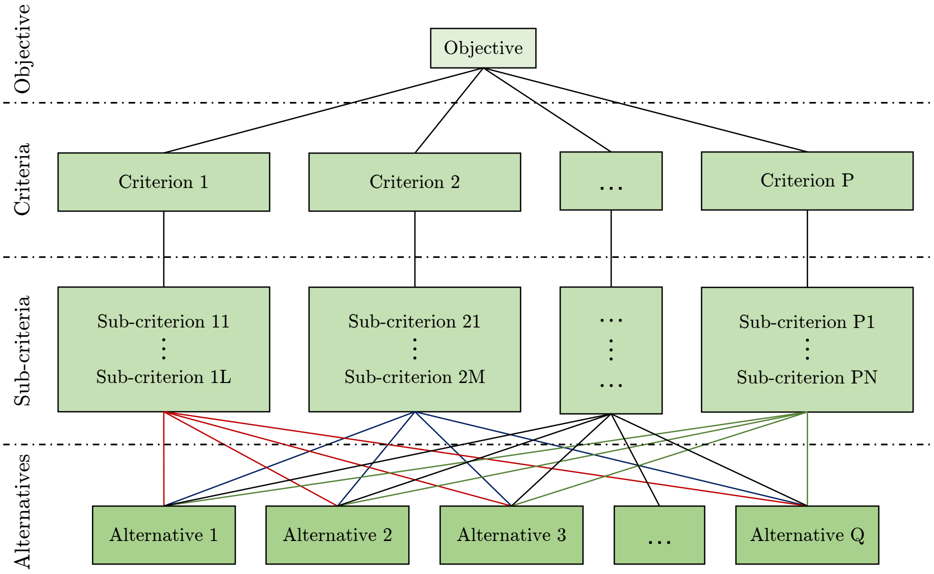


Figure B.3: Hierarchical structure used in the AHP

Phase 5: Implement

The *Implement* phase and the *Monitor / Evaluate* phase are not the core focus of the framework, but are briefly addressed for completeness. Phase 5 provides brief guidance regarding establishing a BPR action plan (Step 5.1) that is used to execute the BPR implementation (Step 5.3). However, before executing the BPR action plan, Step 5.2 describes the execution of a BPR pilot study. This phase correlates with the transition stage (Stage 2) of Change Management.

Phase 6: Monitor / Evaluate

Phase 6 evaluates the BPR initiative over the long-term in order to determine the success of the project and continuous improvement occurs throughout the long-term. This phase discusses the monitoring of KPIs to assess the improvements made, if any. The procedures are also standardised in this phase. This phase correlates with the refreezing stage (Stage 3) of Change Management.

Framework Validation

Problem to be addressed: The focus in Spare Parts Management (SPM) is typically on forecasting and stock levels, but the processes within SPM can be improved through Business Process Reengineering and / or the integration of traceability technology (barcode technology, RFID technology, GPS technology or a hybrid system) into SPM. A framework would be required to support such a BPR initiative and / or to aid selection of traceability technology for the environment.

Questions

1. Have you *ever been involved* in a Business Process Reengineering (BPR) initiative, i.e. systematically redesigning and / or changing processes?
   Yes ☐ No ☐

2. In your opinion, would a framework such as the one proposed in this study have been a *useful guide* (in any possible way) for you or your fellow team members when you were involved in the BPR initiative or if you had been involved in such an initiative? If not, please substantiate as to why you do not believe so.

3. Have you *ever had any experience* with initiatives to implement *any form of technology systems* (SAP, Ellipse, RFID technology, barcode technology, etc.) within your field?
   Yes ☐ No ☐

4. Have you *ever had any experience* with *traceability technology* systems (RFID technology, barcode technology, GPS) within your field?
   Yes ☐ No ☐

5. Considering the research methodology that was followed, what is your opinion on the *potential* of the proposed framework as:

   a) a guide to the Business Process Reengineering of spare parts processes, and

b) a guide to support the selection and integration of traceability technology into the Spare Parts Management environment?

6. In your opinion, what are the *strengths* of the proposed framework and methodology that was followed?

7. In your opinion, what are the *weaknesses* of the proposed framework and methodology that was followed?

8. Please comment on the following structural aspects of the proposed framework:

   - How would you rate the *ease of understanding* of the framework?
     Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐

   - How would you rate the ability of the framework to *consider various relevant aspects without becoming too complex or resulting in information-overload*?
     Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐

   - How would you rate the *flexibility / adaptability* of the framework (ability to apply relevant steps to different environments in different organisations)?
     Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐

   - How would you rate the *comprehensiveness* of the framework (referring to many or most of the relevant aspects)?
     Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐

- What is your impression of the *step logic* of the framework?
  Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐

9. In your opinion, what *improvements* can be made to the proposed framework?

10. Would you *utilise the framework* if you were to improve spare parts processes and / or integrate traceability technology into the SPM environment? If not, please substantiate as to why you would not.

11. Do you have any additional comments?

Appendix C

Responses from Participants

The participants that formed the expert panel in this study have different job titles as mentioned in Section 5.2.1 of Chapter 5. Each job title is represented by an acronym or abbreviation for briefness as follows:

- *Head of Inventory and Procurement*: HoIP;
- *Head of Physical Supply Chain*: HoPSC;
- *Head of Reco (reconditioned spares)*: HoR;
- *Materials Manager*: MM;
- *Regional Principal for Physical Supply Chain*: RPPSC;
- *Senior Engineer*: SE; and
- *Warehouse Coordinator*: WC.

The responses from participants for each question of the Validation Questionnaire (available in Appendix B) are recorded below. The *Head of Inventory and Procurement* (HoIP) invited the *Warehouse Coordinator* (WC) to join the interview, as the Warehouse Coordinator has more experience and can provide responses from a more technical background. The responses from both these participants were recorded together during a single interview and are reported together below.

Questions and Responses

1. Have you *ever been involved* in a Business Process Reengineering (BPR) initiative, i.e. systematically redesigning and / or changing processes?

   HoIP & WC:
   Yes ☒ No ☐

HoIP: *"[WC] has just been involved in a whole role redesign process... on the systems side... who can execute which functions to ensure that there is segregation of duties... [I have been involved more with regards to] the overseeing capacity; not in terms of the direct implementation."*

HoPSC:
Yes ☒ No ☐
"[Many projects, but one in particular:] Nokia... converging their supply chain to a vendor-managed inventory model which involved a huge amount of processing systems changes... [when asked if any guide or framework was used:] worked on a Nokia-based methodology, change management methodology... I wouldn't say I'm too familiar academically with BPR formats or templates, but I've been through several kinds of projects that could be classed as BPR."

HoR:
Yes ☐ No ☒
"Not this type of thing [sic]... I haven't been involved in [BPR of spare parts processes]... I was involved in other processes... There is a lot of other stuff [sic] we have improved over the years, but not spare parts." [However, I have been involved in setting up the Reco (reconditioned spares) department].

MM:
Yes ☒ No ☐
"We have done that numerous times throughout my career."

RPPSC:
Yes ☒ No ☐
"... implemented supply chain planning processes. I redesigned the banks' business processes. I did several supply chain planning implementations, both systems and in terms of operational functions at various companies."

SE:
Yes ☒ No ☐
"On a small-scale. I'm a modelling specialist; what we do is we look at the process and we see: these are the inputs, these are the outputs, this is what's happening in between and what if we change the inputs? Or this is the output we like, how should we change the inputs? But it's on a very small-scale; it's not a physical business process redesign. [When asked to clarify:] For example... I change the business process, because I add more of one raw material than another raw material. In that way, I do change the business process. But the physical process of taking the steel from here to there rather, is not part of my job spec."

2. In your opinion, would a framework such as the one proposed in this study have been a *useful guide* (in any possible way) for you or your fellow team members when you were involved in the BPR initiative or if you had been involved in such an initiative? If not, please substantiate as to why you do not believe so.

   WC: *"It would work, definitely."*
   HoIP: *"It would have been much more successful [referring to previous basic barcode implementation that failed]."*

   HoPSC: *"Yeah, I think so. I mean you touched on a keypoint there: putting the systems before the processes is obviously a bad idea and that did happen in some previous work I was involved in. Particularly for technology companies who think everything revolves around a system; that's a pitfall. So I think the way you prioritise the process over the technology is a fundamental benefit."*

   HoR: *"Yes, definitely."*

   MM: *"There're plenty of systems and tools available to the market to manage inventory... we went through three changes: first of all MIMS and then Ellipse and then later SAP... and all those systems have got the tools in themselves... some companies waste money, in my opinion, and we did that in the past... do we actually want a number of systems to use at that stage?.. because you always have the human factor... the human still drives it... but yes... this [referring to the framework] is quite flexible [and useful despite other systems being available to aid the process]."*

   RPPSC: *"Absolutely, I think it's important to take them through the steps that you are going to go through so they know what to expect and how to approach the task and project ahead."*

   SE: *"I think it definitely would... It provides some structure to the whole process. What I like about it is Step 3.3 where you align the Business Process Redesign and the technology aspects. My feeling is that that step will become more and more important as technology plays a larger part in everything that we do."*

3. Have you *ever had any experience* with initiatives to implement *any form of technology systems* (SAP, Ellipse, RFID technology, barcode technology, etc.) within your field?

HoIP & WC:
Yes ☒ No ☐
WC: *"The transfer from Ellipse to SAP, so ja."*
HoIP: *"And obviously also this barcode technology that we haven't implemented successfully."*

HoPSC:
Yes ☒ No ☐
"Examples in the past would've been Warehouse Management Systems in particular, inventory visibility and tracing systems and currently we're implementing an inventory optimisation system."

HoR:
Yes ☐ No ☒
"We all were [sic] involved in SAP... we were on Ellipse and then we went over to SAP, but I was not really involved [in the implementation]."

MM:
Yes ☒ No ☐
"First manual, then MIMS, then Ellipse and then... SAP."

RPPSC:
Yes ☒ No ☐
"I've implemented SAP ATO [Advanced Training Optimisation], as well as Barloworld logistics software called Optimizer at several clients... part of ERP conversions... So yeah, I'm pretty familiar with that."

SE:
Yes ☒ No ☐
"RFID and SAP [as well as barcode technology and GPS]."

4. Have you *ever had any experience* with *traceability technology* systems (RFID technology, barcode technology, GPS) within your field?

HoIP & WC:
Yes ☒ No ☐
WC: *"A couple years back we went to [a nearby mining organisation] to see how feasible it is for [the participant's organisation] to implement [barcode technology] on our side as well. So that's where we started with the barcoding system, but the full coding system... also the costs involved, doesn't [sic] justify what we want to do with it... It wasn't feasible at that stage so it was put on hold up until we started with these bin labels and we started [thinking]: why don't we implement the barcoding system as*

well or start with it?" [No experience with RFID or GPS (besides private one used for navigation)].

HoPSC:
Yes ☒ No ☐
"[When asked if the tracing systems mentioned were barcode-based:] The tracing was more on a track-and-trace system around shipments; not around particular products... But I was involved in barcode scanning implementations at a warehouse level. I have been involved in quite a few traceability-type programs, but they were related to the shipment, not to the product... [Example] putting a device in an ocean freight container to track a shipment with GPS and also measure its environmental characteristics like temperature and humidity controls."

HoR:
Yes ☐ No ☒

MM:
Yes ☐ No ☒
"We had a look at it some time ago, but I have no experience implementing it or using it for that matter."

RPPSC:
Yes ☒ No ☐
"Actually recently, yes. [When asked which one specifically:] Barcodes... RFID was a bit too tedious at that point and the technology wasn't really robust enough for the application; although I did consider it."

SE:
Yes ☒ No ☐
"The RFID one [described in additional comments section]. We also tried GPS in another part of the plant, but we have the same problem with interference [as with the RFID implementation discussed in additional comments section] with the coordinates that we get are not accurate enough. [They tried to track industrial ladles that holds iron, slag or steel]."

5. Considering the research methodology that was followed, what is your opinion on the *potential* of the proposed framework as:
   a) a guide to the Business Process Reengineering of spare parts processes, and

WC: *"Obviously it's a good guide, for any process for that matter, but more for warehousing: definitely. I mean if we can use that, by all means. You cover all your bases I think."*

HoPSC: *"I think it is good. One thing I'm missing which may have come in in previous pieces I haven't read [referring to the literature review], is an upfront statement or alignment of objectives, you know, what the end-goal is. The framework has some good work on contextualising SPM, but to what purpose? The scoping and objective setting is something I miss... simply the step, if you are to use this framework in a wide degree of contexts, that [defines the] scoping and objectives... what part of SPM... You could almost have a Phase 0 to do that piece. You may have multiple stakeholders who need to be involved in this and there needs to be some alignment on that before you study something."*

HoR: *"Well, I think there is a good opportunity... I don't have anything to do with inventory stock-keeping / warehousing stuff [sic] like that... but from Reco [reconditioned spares] side, I would especially like something like traceability... I want to see what went out and what comes back... what went to the plant, and where it was used and stuff [sic] like that... So if an electronic system can be helpful with that then I'm certain it will [have potential]."*

MM: *"One thing we must steer away from is to get too complicated... on its face for inventory management — if you follow that, you've got a win-win situation... So I say yes, it's great, but it could be a bit too much info [sic] in it itself... it's not that easy to read; it's slightly complicated so people on the floor might battle to understand what exactly it is you're trying to work with."*

RPPSC: *"It's good, it's fairly high-level. So I think it does give you the steps you need to go through, but you can maybe break it down to another level to give more guidance to people that are going to execute the project... I would be cautious to impose a specific framework that's not generic enough... I've seen other frameworks like SCOR [Supply Chain Operations Reference-model]... and that's a bit too rigid. So it needs to be very comprehensive and... it needs to be mutually exclusive and collectively exhaustive... needs to be very simple and then the complexity can be disaggregated into the breakdown structure."*

SE: *"It's not my area so I can't really comment, but from what I see, I think it will be helpful... It adds structure to the process... In our case anyway, most times it's not well managed. We have maybe* *a module in SAP, but there's only a small amount [sic] of people that use it."*

b) a guide to support the selection and integration of traceability technology into the Spare Parts Management environment?

WC: *"Most definitely, because it's in phases... you can track it as you progress on your process."*
HoIP: *"I think often you get technology that sort of drives how you have to engineer your business process; where in this case you actually decide what is your business process and then you select technology that fits your business process... We sometimes do things the other way around and then we try to fit our business around the technology and that's not the ideal way to go about it... Sometimes you see elements in the technology that can help you improve the way that you currently do stuff [sic], but I think if you try and put your business into someone else's technology, you're forcing it and you lose a lot of the good stuff [sic] you've got."*
WC: *"When we went to go visit [the nearby mining organisation that implemented barcode technology] for the barcoding system, it was implemented, but... it wasn't working for them. Well, of course, they didn't use it effectively... and part of it works and part of it don't [sic]... If it's implemented correctly, definitely, it will be an advantage for a company."*
HoIP: *"...these things are sometimes implemented haphazardly without taking the whole context into account."*
WC: *"...Ja, and this is where this framework will help you and guide you actually too... it should work, ja."*
HoIP: *"If this is done properly, the success factor will be higher... So you are finding with us, you are finding at [another organisation] and you are finding at [the nearby mining organisation], these systems are half-implemented and not working, because they weren't thought out properly from the start."*
WC: *"And something like [the framework] would definitely guide you through: have you covered all your bases."*
HoIP: *"You need the guideline, because people obviously skip the steps."*
WC: *"And obviously you need a champion to manage it and to go through with it until it's finished."*

HoPSC: *"I think it's good; I'm not familiar enough with the AHP, but it sounds like it could be something that is quite useful... Like I said, you have put the business piece first, you've then got some* *good steps in terms of finding the technology and, admittedly, it is not something that in organisations is done particularly well. So yeah, I think it's useful."*

HoR: *"I don't think it will have a very big influence on Reco [reconditioned spares]... I'm not saying there won't be any potential; there will be some advantages... but I don't think there will be a lot of potential... I think for other parts, non-Reco stuff [sic]... I think there is potential for that."*

MM: *"It is certainly worth exploring... and even implement it. I wish we had systems in place at [the organisation], but unfortunately it was always thrown out because of the costs involved."*

RPPSC: *"That's difficult, because there are many facts to consider. You need to know the technology very well, your processes need to be very well-defined. Especially with RFID, it needs to be powerful; you have to define what to switch on and what to switch off and how the data interacts... becomes very intense, so you need to know exactly what you want and how you want to implement it. That's one part of it, the second part is the cost of the technology and application. So if it is going to be in the mining environment... it needs to be very robust... it's often a very harsh environment... steel affects the effectiveness of that RFID... Any framework that is comprehensive is good, but just to say this framework is going to work, I can't say. It is important to put something in place, but you need to have a comprehensive framework and I think there are not a lot of companies that have really gone to the* n^{th} *degree to define that decision-making process properly."*

SE: *"I think... Step 3.3 is a big part of that... I think it's very important and it would be very helpful."*

6. In your opinion, what are the *strengths* of the proposed framework and methodology that was followed?

   HoIP: *"I think we already sort of covered that... it gives you a guideline to ensure that the whole process is thought through properly before you implement; also the point I made that you consider your business process design first before you consider the... available technologies so you don't try to make your business fit a prescribed technology."*

   HoPSC: *"It's comprehensive... you talk about organisational environment, processes, etc. so it has a good way of trying to bring in all of* *the available aspects, processes and then having a broad, open mind in terms of bringing in technologies and then a good way of zeroing down into the actual selection of what's going to work... It has the right scope: starts off broad, but it's got a good way of narrowing down to a decision in a very structured way. It appears to be academically supported by the use of the AHP methodology and your research of BPR. It's circular as well; it's an iterative process so once you go through it and implement, then within a certain timeframe you'll need to go back to reassess if the assumptions behind that contextualisation are still in place."*

HoR: *"The steps have a proper structure and it's logical. It follows a logical process."*

MM: *"If it's followed through as it's set up here, it's certainly safe to say the results should be successful."*

RPPSC: *"The strength is to give decision-makers and people that need to address a lack of asset management a guide to address their current gaps... and what process to go through. They can probably put a couple of steps down, but where the value is going to come in is the framework is comprehensive. And it is going to highlight [typical] areas of weakness, where to focus on and define stage gauge properly and maturity models of what needs to be in place to go to the next level."*

SE: *"It adds structure. It takes you from a start point: what I like about it is in Phase 1 you analyse everything first instead of just starting and then realising, as we did, in [Phase 3 or Phase 4] that the technology is not adequate."*

7. In your opinion, what are the *weaknesses* of the proposed framework and methodology that was followed?

WC: *"Is [sic] there any weaknesses?"*
HoIP: *"I haven't discovered any."*
WC: *"Cost... when you implement a high profile, whether it's barcoding or whatever [sic], it's going to cost big companies x amount of money so obviously cost... I wouldn't call it a weakness, if it's an investment in something that can work... For me, [the framework] is very well thought through... I would've said people [losing their jobs], but you can use them somewhere else."*

HoPSC: *"I'm missing that scoping and objectives piece and, related to that, you might want to consider relationships within an organisation...*

you're going to have stakeholder parts of the organisation who have more or less involvement, but may consider themselves to have more stake in it than they actually do... so organisational politics and managing those... there's going to be a need for alignment on who's involved and for whose benefit it ultimately is."

HoR: *"Not really, I think this is well done and if you do it properly like the whole thing [sic] says you should do it, then it's excellent." [Perhaps the fact that for Reco itself, it's not that value-creating].*

MM: *"It's too complicated [especially for people on the shop floor]."*

RPPSC: *"I haven't studied [the framework extensively enough], but if it is not comprehensive and lacks a certain level of detail that whoever is going to use it is not going to see and therefore make you fail."*

SE: *"[Participant mentions that he is currently doing a Master's in Change Management, specifically regarding technology acceptance:] I see the huge part [Change Management] plays in trying to roll out new technology... Maybe for SPM, if you decide to use technology then that's also something to incorporate into the framework. It is there... I just feel the influence of it is bigger than you expect... [More elements of Change Management addressing how the implementation will be managed are desired]."*

8. Please comment on the following structural aspects of the proposed framework:

   - How would you rate the *ease of understanding* of the framework?

     HoIP & WC:
     Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐

     HoPSC:
     Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
     "It's quite intuitive. Just a few things like the acronyms, AHP, would obviously not necessarily be known by the lay-user, but ultimately the structure makes sense."

     HoR:
     Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
     "It seems logical to me; I think it's quite easy [to understand]."

     MM:
     Very Poor ☐ Poor ☐ Fair ☒ Good ☐ Very Good ☐

RPPSC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
"I think it's very chronological. It's obviously attached various aspects about the process. I think it's very straightforward."

SE:
Very Poor ☐ Poor ☐ Fair ☒ Good ☐ Very Good ☐

- How would you rate the ability of the framework to *consider various relevant aspects without becoming too complex or resulting in information-overload*?

HoIP & WC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐

HoPSC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
"I think with the structure you've taken and the steps that you go through, it looks manageable to someone that they're [sic] not going to get overloaded with information at the start. There's a process to go through to keep everyone up to speed on it, so yeah, good."

HoR:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

MM:
Very Poor ☐ Poor ☐ Fair ☒ Good ☐ Very Good ☐
"Simply for the reason that I mentioned [too much information and too complicated for people on the shop floor]."

RPPSC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐
"[Participant did not want to select an option:] I think it would have to prove itself so it needs to be applied. So I am reluctant to say it's effective without being proven."

SE:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
"I like the framework because it actually reduces complexity."

- How would you rate the *flexibility / adaptability* of the framework (ability to apply relevant steps to different environments in different organisations)?

HoIP & WC:

Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
HoIP: *"You can apply this process to a lot of things... or... in terms of technology implementation in any area, not just for spare parts."*

HoPSC:
Very Poor ☐ Poor ☐ Fair ☒ Good ☐ Very Good ☐
"The scoping and objectives piece... without that, it kind of looks like the framework jumps in... as if everyone knows the objective and scope and just goes for it... it's part of the change management as well... You need quite a bit of work to get people on board to have that flexibility and adaptability in place."

HoR:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

MM:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐

RPPSC:
Very Poor ☐ Poor ☐ Fair ☒ Good ☐ Very Good ☐
"That's relative. As long as it's with regards to asset management or parts management or a MRO environment, I think it's fairly generic... It's fairly robust and fairly generic."

SE:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
"But only if the entire framework is used and not just certain parts of it [each phase builds on the next; gives implementation "route"; removing steps would inhibit the process]."

- How would you rate the *comprehensiveness* of the framework (referring to many or most of the relevant aspects)?

HoIP & WC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

HoPSC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
"One of its strengths is it's quite comprehensive."

HoR:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
"This has been so extensive, it has got [sic] to be very good... It's obviously been well thought through."

MM:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
"Very comprehensive document... I would say very good, but as I mentioned, it might be too comprehensive."

RPPSC:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

SE:
Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
"It covers everything I can think of. Including the change management part which is very nice. Similar frameworks would ignore it most of the times."

- What is your impression of the *step logic* of the framework?

  HoIP & WC:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

  HoPSC:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
  "It goes through the right process."

  HoR:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒

  MM:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐

  RPPSC:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☒ Very Good ☐
  "It's fairly straightforward."

  SE:
  Very Poor ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☒
  "Easy to understand the flow."

9. In your opinion, what *improvements* can be made to the proposed framework?

   HoIP: *"These points are quite broad so you can include quite a lot of things [sic]... one of our pitfalls on the barcoding was the whole issue of the server that collapsed [being outdated and not supporting the new technology]... Technology solution can look favourable, but there's just* *so much to consider when you select a specific technology." [Make sure other aspects, such as servers being able to support the technology, are taken into account].*

HoPSC: *"Nothing that I haven't mentioned before [scoping and objectives piece]... So just making sure that the organisational politics are taken into account in the change management [section]."*

HoR: *"My best answer would be nothing." [I can't answer this when you've researched it; I'm not in a position to tell you otherwise].*

MM: *"We have talked about that already, maybe it is in the rest of your documentation, but that is the inventory management methodology itself [discussed under additional comments]."*

RPPSC: *"What you need to consider is the change management aspect in terms of where responsibilities lie... Often you find that there needs to be proper responsibility and accountability matrices of who is responsible for what in the MRO environment. Often you need to define those responsibilities so that the resources know upfront what is going to be expected of them so they can execute the project and relate it to the business processes that have been redesigned. That also ties in with your maturity roadmap of business process redesign."*

SE: *"As discussed I would like to see more change management aspects. But that might just be a personal feeling and it depends largely on the environment of implementation I would think. [When asked about specific elements regarding Change Management that should be added:] Perhaps something that promotes involvement from the shop floor, but again it depends on the environment I would think."*

10. Would you *utilise the framework* if you were to improve spare parts processes and / or integrate traceability technology into the SPM environment? If not, please substantiate as to why you would not.

WC: *"Well, I would use it."*
HoIP: *"Ja, I think it's a good framework to use."*

HoPSC: *"Yes, I think it's definitely a valid way of doing it. The only thing with big companies: we tend to have our own internal framework... decision matrics... but in [the participant's organisation], I haven't really come across it so I think it's good to bring in that kind of structure and it would make sense to do so."*

HoR: *"Ja, I think I would."*

MM: *"Yes, I would."*

RPPSC: *"Ja, I definitely think it helps; what it does is it marries a lot of different aspects that are probably done in isolation. So potentialising is really looking at where you are and what your strategy is, and in business process redesign... someone goes and tells the guys [sic] what to do on an operational level and part of that is also your change management and if somebody goes and says: 'I like this system' and then they make a decision... and it often happens in isolation or it's not well-coordinated. What will also make this valuable is if there are clear decision-making matrices set up across multi-disciplinary or multi-departmental areas in an organisation... This is probably not going to be a single department's responsibility; there're going to be various parties involved like... your IT guys [sic], your engineering guys [sic], supply chain guys [sic], you have HR involved, you have management involved and everybody needs to have some form of input into this. I think this framework, if it includes that, will be powerful."*

SE: *"Yes."*

11. Do you have any additional comments?

HoIP: *"Our traceability technology knowledge is limited to barcoding at this stage so there isn't that much common knowledge on all the available traceability solutions in terms of the general public [referring to employees in industry as general public]... So if there are companies that have these solutions, they are not marketing it to us... I think we could use technology far better to our advantage in terms of accuracy and efficiency... [The framework] makes logical sense to me... it's a well-thought-out process... we try to relate it to our personal experience with the failure of implementing the barcode system so from that point of view we can understand where our weaknesses are, but we can't see weaknesses with your flow... we don't have two days to study the process to provide you with indepth feedback."*
WC: *"Everybody is looking at cost, but if you do your homework properly, I don't think it would be that costly."*
HoIP: *"Ja, I don't think the cost would be that excessive if you think of what we spent on SAP as a system and now we're actually not utilising the full benefit of it... Our system has the capability of incorporating the technology, but we're not [implementing it]."*
WC: *"[When asked by HoIP why they would implement better technol-*

ogy in their environment:] To streamline our business with regards to... especially stock-counting... If we implement barcoding, it will obviously streamline our stock-counts and the posting process in terms of receipts and issues... the system would be more accurate, because you do it there and then in terms of the scanning of the items. When you do stock-counting of issues or receipts, it's just a matter of scanning the item that you count... and download it into the system... Something like that would have its advantages and disadvantages in terms of resources. If you have barcoding, you need one or two persons [doing scanning and issues & receipts]... it will benefit the company with number of people employed, but on a more human side: [people may lose jobs]... You can use them elsewhere [though]."

WC: *"At the moment we are moving towards barcoding and there is some implementation in terms of the orders: they've already got the barcodes on them and we scan them and they pick up the order number and it's filed on the DMS system. It's on the orders, on the goods received notes, we've tried to do it on the reservations as well... It's already on the bin tags also, but we don't use it currently... So when we implement a barcoding system, we don't have to do that anymore, because it's already there."*

HoIP: *"This [referring to the framework] will take us through that thought process."*

WC: *"[When asked about the failed barcoding implementation:] We have a bin label machine and now we can't use it... because of the servers that need to be upgraded. I think it's working at [another site of the participant's organisation], but at [the participant's organisational site], we've done all those steps until we realised we can't use this printer at the moment because of the servers that need to be upgraded... They first need to upgrade the servers and then we can start using the label printer."*

HoPSC: *"The change management piece is there, but... it probably needs to be fleshed [sic] out more. You can probably put a lot of the comments I've made into that change management piece... It deserves a bit more detail on that so people are very clear... If you get the right department in an organisation in the governance structure then you avoid a lot of the politics and organisational issues a bit later on."*

HoR: *"To do something like this... any of these systems, will cost a lot of money... this won't be a cheap change for instance... Most of our stuff [sic] is manually done so it's quite accurate because it's manually done; you're not reliant on a machine... I don't think there are too many unnecessary steps involved [on the reco side] as well... [Ideally] the people that you have the interview with... should have a better understanding of this and maybe have more time to look at it and understand it... we*

haven't got time for this now [to study the framework extensively]."
"I think it's important before you do anything like this [the changing of processes and technology integration], that you need to have a process to follow and you look at that whole process from the beginning to end; what am I going to need to implement this. What they've done now [referring to a failed barcode implementation on site] is looked at a part of the whole implementation process."
"You should actually take first-in-first-out [when describing issues with repairable items: example of five motors in bin, end-user draws one from the bin, then another motor breaks in the plant and they repair it and put it back in the bin. Then another motor breaks and they take the newly repaired motor in the bin instead of the older ones]. [When asked about turning of motors in store:] We're supposed to do that. What we thought about is getting the end-users here every six months or three months to turn them over, but I don't think it's really being done. Also the gearboxes: part of the gearboxes will be in the oil and part of them will be out of the oil; it needs to be turned to pick up oil... Another problem is... they will take a motor to the plant and you will never know where that motor is being used so you can't really trace the motor... The equipment is not linked to a specific position in the plant."

MM: *"I would like to see more emphasis on the methodology of your inventory management... how to categorise... we should focus the principles and methodology on categorising maintenance spares, because it's not only maintenance spares in the warehouse... PPE, tea, coffee, milk, sugar, bolts and nuts and that kind of thing [sic]... stationery... all sorts of things that have nothing to do with production but are necessary for the mining environment and mine sites... So a methodology on how to categorise and how to treat [certain] metals."*
"[interesting point is] automated warehouses which makes use of automated materials equipment both for storage and retrieval... that is based on an inventory management system which you should first have in place... and then it has warehouse control systems looking at the management system... so your control system is an operational issue... [interviewer asked whether framework should include this technology:] no, what I am saying is that it's also available and I can see for your framework that that's also an option... and it's not for big maintenance spares... it's for the smaller maintenance bolts and nuts, even protective clothing..."
"emphasis can also be put on automated stock-counting... we're living in a modern world, but we're still using old-fashioned man-handling equipment and systems."
"you have salvage yards on your mines... and we have no systems there..."
"[squirrel stores] are always a problem and can add up to millions if you don't really keep your hand on it... this year alone, we went through a

redundancy exercise and we have already written off about five million rand of equipment [redundant stock] which people sometime in the past, made stock and never used it."

RPPSC: *"To do asset traceability technology, you have to be at a certain [maturity] level to implement it... asset traceability technology is probably a subset of the business process redesign, because you can't always let your process guide systems; sometimes your systems guide your process. You need to consider exactly where you want to go, then marry the two [systems and business processes]... [Considering the reiteration of Phase 2 and Phase 3 to align processes to the technology:] Then it's good."*

SE: *"Just that I think the framework will be valuable. The one thing that needs to be [considered] is how this will integrate with existing system for example SAP."*
"[Referring to RFID implementation at the organisation:] What we aimed to do was; we have all different segments in our car-busting machine and each segment's made up of different sub-parts... So there are rollers and things that keep everything together. They wanted to put RFID tags on each one of these segments or pieces of the segment so that we're able to build a database of each of these pieces of equipment... we would be able to know how many tonnes did each segment do [sic]. If we wanted to do preventative maintenance or something like that, we can use that... You use a handheld scanner so every time it's [the segment or piece] installed, you scan it... You would select that this is the install date and the name would already be prepopulated because it comes from the tag. When you take it out again, you would scan it and say it's been taken out. [When asked whether there were any problems with the system:] Ja... It's not working now... The main reasons why it didn't work was [sic]:... we had trouble with the access points... handheld scanner needed to be connected to the access points which in turn can talk to the server. But because of the environment, it was difficult to have access points all over the place to ensure the reliability of this handheld scanner... Sometimes we just couldn't get it to pick up a network that it can use to communicate with the server. The other technical problem we had is:... we put [the RFID tag] directly on the metal part of the segment or roll. You really had to go very close to the tag to scan it. Interference was definitely a problem, both with scanning the tag and also with getting access to the network to communicate with the server. [When asked if any framework or process was followed for implementation:] We didn't use a framework like the one that you propose."