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Improving Material Utilisation in E2E Upstream Supply Chain Operations: A Multiple Case Study

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Kayode Ashogbon

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ABBREVIATIONS

E2E	End-to-end
ERP	Enterprise Resource Planning
FMCG	Fast Moving Consumer Goods
IDOC	Information Document
IS	Information System
MBOM	Manufacturing Bill of Material
MES	Manufacturing Execution Systems
MU	Material Utilisation
PCA	Process Capability Analysis
PCI	Process Capability Indices
SAP	Super Absorbent Polymer
SCQM	Supply Chain Quality Management
SPC	Statistical Process Control
SWP	Standard Work Process
WMS	Warehouse Management System

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Abstract

The increasing cost of manufacturing and the constant need for organisations to remain competitive and profitable is garnering unprecedented attention of supply chain practitioners and academia. Several approaches are being employed in minimising raw material losses within supply chain network. The study of effective utilisation of raw materials are therefore of great importance to manufacturing organisations seeking to increase the efficiency of their operations while reducing material related losses. By improving the utilisation of raw material, huge cost savings is achievable within the supply chain operations that are focused on the radical reduction of raw material wastes during its transportation and transformation processes. This study makes uses a multiple case approach to investigate MU in the upstream supply chain operations, and utilises a mixed research method to explore the process approaches utilised by the case organisations in minimising MU losses and improving their manufacturing system.

Keywords: Material Utilisation; E2E Supply Chain; Process Capability; Process Improvement

1. INTRODUCTION

The cost of manufacturing is increasingly being researched. And with better approaches and scientific developments, there are significant innovations and advances in the field of supply chain management that has dramatically reduced manufacturing costs and improved raw material optimisation. However, despite these advances, a great opportunity lies in improving operational efficiency through a more sustainable approach to improving material utilisation (MU) in the supply chain operation when given a holistic consideration.

This study delves into the very heart of cost savings in the optimisation of raw material. By focusing on analysing the areas of losses, sustainable actions that necessitate positive changes are initiated, which could salvage the inherent losses in the end-to-end (E2E) supply chain processes. The result of the study will provide insight into recovering raw material losses within the supply chain, especially in the FMCG industries. It will be useful to researchers and supply chain practitioners by providing best-in-class solutions that are applicable to modern operations.

This chapter introduces this research study by discussing the case organisations, problem definition, provides the research background and justification, discuss the purpose statement, and research questions.

1.1. Case Organisations

Two case organisations are considered in this study, both of which are multinational FMCG top competitors that specialise in tissue-based baby disposable diaper brands. The expansion drives of these organisations resulted in establishing new manufacturing facilities in the Sub-Saharan Africa region in order to take advantage of available organic growth possibilities and the nascent economic development in other to meet the needs of the consumers with innovative products. This however necessitates the need to chart new supply chain network strategies that optimise the transformation of raw materials.

The study was carried out at the manufacturing facilities of the case organisations. Due to the pre-study non-disclosure of confidentiality agreements, their identity will not be disclosed in this study. However, in order to protect their identity and prevent the divulgence of important company data, for the sake of this study, they are named 'Case Alpha' and 'Case Beta'.

1.2. Problem Definition

Contrary to the expectation of attaining a vertical start-up operation, both case organisations struggle with operational inefficiencies within their supply chain operations, especially in the areas of raw material utilisation. High scrap levels that cost tens of thousands of euros were characteristic experiences during and after successful start-up of the production operations. Although the scrap levels reduced significantly during full mode operation owing to improved operational capabilities of personnel, efficient utilisation of raw materials during transformation to finished product did not. This however necessitated the need to deep-dive into the upstream E2E supply chain processes in order to discover and eliminate the inherent raw material losses. Without adequate attention to the MU efficiency, the impact of high material losses that could results to high cost of production is evident.

1.3. Background and Justification

Since the cost of raw materials enormously contributes a greater percentage to the overall cost of manufacturing of the case organisations, an increasing pressure from top management on the need to focus on improving the MU efficiency for the entire upstream supply chain is the driving force behind this study. This arises from the need to stay competitive and retain the brands' market leadership, and to further reduce the cost of production through the minimisation of losses along the value chain. Hence, it resulted in the need to place utmost attention on raw material optimisation along the E2E supply chain operations.

Without adequate attention on the utilisation efficiency of raw and pack materials, there is bound to be material losses within the supply chain which significantly results in high cost of manufacturing. On the contrary, tens of thousands of euros can be salvaged monthly which are normally lost during raw material transformation to finished product in the form of product scraps, material mishandling, process instability, etc.

This study aims to uncover these sources of losses within the supply chain processes and to proffer sustainable counteractions that resolve these problems in order to achieve breakthrough loss elimination.

1.4. Thesis Structure

As shown in the thesis structure in Figure 1, Chapter one of this thesis presents the introduction to the study while the underlying theoretical framework is presented in chapter two. Here, previously published and related studies are extensively consulted and used as theoretical foundations and basis for the study.

The subjects discussed in the literatures are carefully selected to support the research topic by providing a strong support for the stated research questions thereby putting the study in a proper theoretical context. The key themes discussed are those related to material utilisation efficiency, end-to-end supply chain perspective, the need for integrating information systems in supply chain management, themes from quality management and process capability analysis. Furthermore, the research methodology and the research design is presented in chapter three. It outlines the research strategy and procedures involved in data collection, and the method of data analysis employed in arriving at the study results. The findings and results of the empirical research are presented in chapter four. Trends and patterns obtained from the study of the case organisations forms the results hereto presented. Finally, the analysis of the empirical study is discussed in chapter five. The summary of the findings are discussed and recommendations are offered, with suggestions for future research studies.

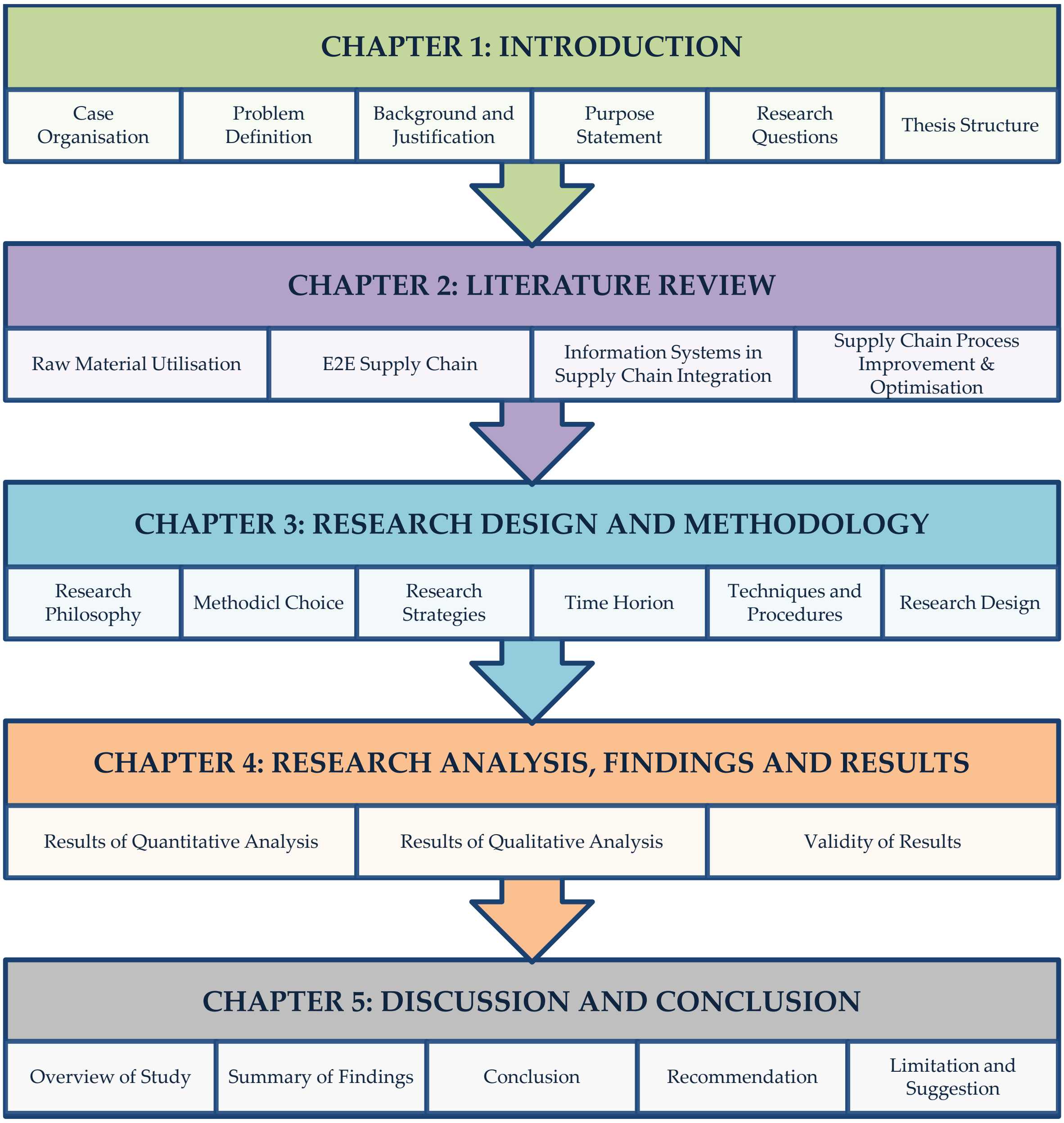


Figure 1. Thesis Structure

1.5. Research Questions

The journey to improving raw material utilisation within the supply chain can be analysed from several perspectives, one of which seeks to analyse material utilisation from the point of view of the converting machines. The study therefore takes on the approach of assessing the state of the converters' process stability with the aim of investigating potential gaps that may be inherent in the machine processes. This therefore leads to the first research question:

RQ1: What is the capability of the converting lines with respect to minimising material losses during raw material conversion to finished product?

Furthermore, while the gap from the above research question is determined, it is important to determine the overall key loss points in order to tackle the resulting issues. This provides an analytical E2E view of the of the loss areas which leads to the second research question:

RQ2: What are the key MU loss areas impacting operational productivity and efficiency?

As it is important to uncover the areas of material losses within the upstream supply chain by analysing the loss areas, solutions on the ways of improving material utilisation efficiency needs to be addressed so as to improve the overall productivity of the case organisations. This therefore leads to the third research question:

RQ3: What are the ways to improve material utilisation efficiency?

The above research questions are carefully formulated to achieve the research objectives and therefore guide the course of the study. Ranging between qualitative and quantitative data components, they are appropriate for this study because they achieve the goals and expectation of the case organisations and the researcher’s interest. Hence, it aims to utilise the mixed study method to understand the current situation and chart the path on how the study will provide suitable solutions that will resolve the current challenge.

1.6. Purpose Statement

The need for setting in motion the aim of the study to the readers earlier in the write-up is emphasised by Creswell (2009, p. 119) and referred to as the purpose statement. This is to clearly show the readers the intent and the objectives of the study. However, as it relates to a mixed method studies, the purpose statement must clearly express both the quantitative and qualitative aspects of the study, and the rationale for combining them (Creswell, 2009).

Creswell’s guideline (2009, p. 121) is used to formulate the purpose statement for this study:

> *The purpose of this concurrent mixed methods study is to investigate material utilisation losses in order to improve operational bottom line results. In this study, experimentation, statistical process control and process capability analysis will be used to optimise material usage and determine machine capability. At the same time, the critical analysis of the potential loss will be explored using observations from the project participants and teams at the research site. The reason for combining both quantitative and qualitative data is to achieve triangulation of both the quantitative and qualitative data components.*

The outcome of this study is a deep understanding of the impact of material losses on overall productivity of the supply chain. The study aims to advance the body of knowledge in supply chain research by providing empirical methods and techniques that works, and which are replicable to other related organisations with similar operations as the case organisations.

2. LITERATURE REVIEW

The tense global economic environment and the strong competition for market share is greatly impacting and shaping the corporate horizon both positively and negatively, while upsetting organisational competitiveness. The resulting effect is an increasing complexity and uncertainty of the corporate environment. Firms are left with no other option than either to innovate and remain competitive or fizzle into obscurity. This has led to the adoption of many different viable strategies that are capable of positively impacting an organisation's bottom line in order to remain profitable and competitive. One of such strategies is to improve the cost efficiency through effective usage of raw materials, leading to breakthrough cost savings.

Previous studies have approached the subject of material utilisation efficiency from the perspectives of sustainability of a firm's value chain, economic policies, energy savings and improvement, and production control (Table 1). However, little research has been able to effectively tackle the problem from an end-to-end viewpoint along the value chain of the supply chain operations.

Table 1. Overview of Previous Literature

Article Author(s)	**Theme**
Closs, Speier and Meacham (2011)	Sustainability of a firm's value chain in the environmental, educational, ethics and economical perspectives.
Söderholma and Tilton (2012)	The role of public policy in providing market incentives for an efficient use of materials.
Worrell, Faaij, Phylipsen and Blok (1995)	Technical and economical proposal on the assessment of potential energy savings and calculation for material efficiency improvement.
Lopez, Terry, Daniely, and Kalir (2005)	Achieving higher predictable utilisation by increasing the work in progress (WIP) velocity for tooling equipment.

The following sub-sections lays the underlying background of the study with the aim of providing an extensive look into the major themes, based on the research questions. Figure 2 is the main research focus that shows the relationship and the pictorial connectivity of the research themes.

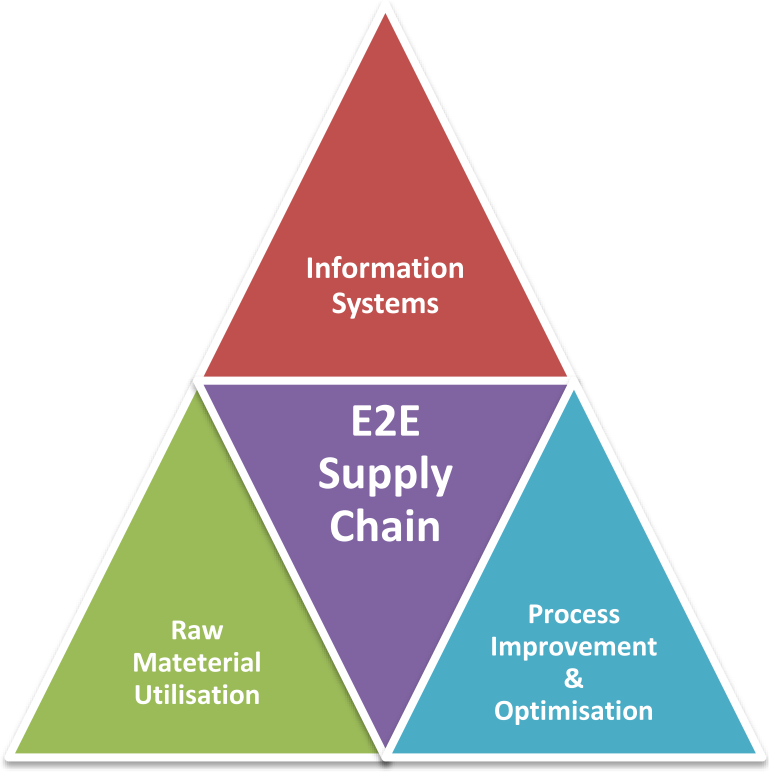


Figure 2. The Main Research Focus

2.1. Raw Material Utilisation

Attention to the effective utilisation of raw materials is highly important to manufacturing operations, considering the losses resulting from its inefficient use. The lean methodology advocates for the need to meet the customers' need while reducing wastes along the value chain, during raw material transformation and service delivery. It promotes the "systematic pursuit of perfect value through the elimination of waste in all aspects of the organisations business processes" (Bendell, 2006).

Today, there is an increasing need to reduce the cost of manufacturing. The result is the shifting of organisational strategies and perspective to lower the overall cost of production along the entire value chain. Interestingly, a huge opportunity that could deliver breakthrough savings lies in the reduction of the cost associated with material losses through an efficient utilisation of raw materials. A subsequent MU improvement will save an organisation cost that are normally lost, and will hereafter boost bottom-line profit (Chong, 2012). This can be achieved by improving the MU efficiency through an in-depth study of all raw materials transformed within the manufacturing operation.

According to Söderholm and Tilton (2012), the study of material utilisation discusses the level of efficiency at which raw materials are transformed during and along the manufacturing processes to finished products. It is 'the amount of primary material that is needed to fulfil a specific function', its improvement allows the fulfilment of the same function, but with a subsequent reduction in material usage (Kotzab, Seuring, Müller, & Reiner, 2006). A thorough look into the material flow lifecycle within the supply chain provides a holistic perspective of areas of improvement and it is important in improving MU efficiency. It is an input to achieving a systematic approach to unearthing intrinsic losses in the E2E supply chain, through a profound loss analysis. Wagner (2002) advocates that such a comprehensive investigation uncovers the potential savings, allows priorities to be set and hints on the right methods to mitigate such losses.

The idea behind MU efficiency stems from the principle of conservation of material within a system. The law of conservation of material according to Hopp & Spearman (2000) states that:

> *In a stable system, over the long run, the rate out of a system will equal the rate in, less any yield loss, plus any parts production in the system.*

The law of material conservation assumes that during the flow of materials within a system, there are process variability resulting in yield losses in the form of material loss and scraps. However, in an ideal system without such losses or variability in the process, the input should always equal the output. However in reality, there is nothing as an ideal system and hence the need for MU analysis.

Mentzer & Konrad (1991) gives the formula for efficiency and utilisation in equation 1 below.

$$\text{Efficiency (\%)} = \frac{Output}{Input} * 100\% \qquad \text{Utilisation} = \frac{\text{capacity used}}{\text{available capacity}} \qquad [1]$$

Utilisation is analogous to efficiency which puts into consideration the output versus input of the quantities. With respect to raw materials, a positive utilisation denotes that less materials are used during production when compared to the planned quantity from the product's BOM. On the other hand, a negative result denotes that more materials are used to accomplish the production of the product. While the latter suggests that the materials are wasted or lost during transformation, the former may suggest a better utilisation of material which may also be that quality formulation is lowered. The ultimate goal however is to ensure that customer target specifications are not compromised.

2.2. End-to-End Supply Chain

To succeed in completely reducing material related losses and improving MU efficiency, the focus must shift from the traditional view of just scouring the production operation alone which further increases the supply chain complexity, to a more rigorous and holistic end-to-end perspective of the supply chain. An

E2E supply chain perspective, on the other hand, increases visibility of the physicality of the material flow through the value chain. A detailed E2E loss analysis and elimination hence involves the whole supply chain and across all supporting functions. This will therefore require the mapping of the E2E material flow within the processes to further uncover intrinsic loss areas.

To begin with, it is important to define supply chain management in order to give a broader view into the subject matter. Although there is no singular universally acceptable definition, several authors have defined it differently. Table 2 illustrates the definition of supply chain. These definitions describe the E2E supply chain operations and are adopted in this literature because they identify the various entities, the key players and gives clarity to the subject matter.

Table 2. Illustrative definitions of E2E supply chain

S.no	SCM Definition	Author(s) & Year
1.	An integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers.	Beamon (1998)
2.	A supply chain is referred to as an integrated system which synchronises a series of inter-related business processes in order to: (1) acquire raw materials and parts; (2) transform these raw materials and parts into finished products; (3) add value to these products; (4) distribute and promote these products to either retailers of customers; (5) facilitate information exchange among various business entities (e.g. suppliers, manufactures, distributors, third-party logistics providers, and retailers).	Min & Zhou (2002)
3.	The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction.	Stocker & Boyer (2009)
4.	Supply chain management encompasses the entire value chain and addresses materials and supply management from the extraction of raw materials to its end of useful life.	Tan (2001)
5.	Supply chain management is the management of the interconnection of organisations which relate to each other through upstream and downstream linkages between the different processes that produce value in the form of products and services to the ultimate consumer.	Slack, Chambers, & Johnston (2010, p. 375)

Beamon's (1998) definition gives rise to the two main sub-processes of the supply chain namely: Production Planning and Inventory Control, and Distribution and Logistics Processes as illustrated in Figure 3.

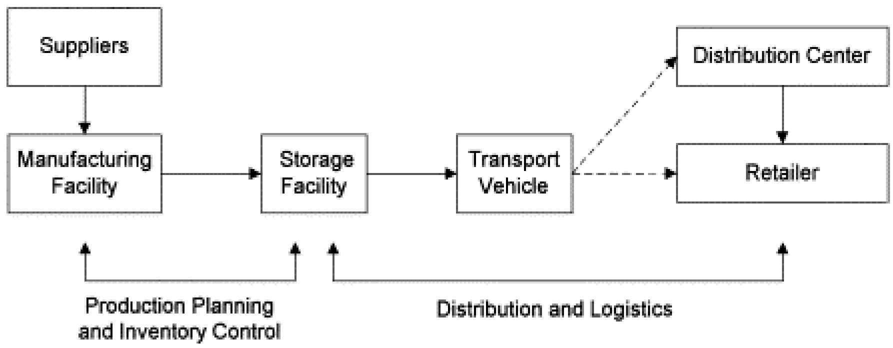


Figure 3. Supply chain components (Beamon, 1998)

Furthermore, Min and Zhou (2002) highlight the function of a supply chain from integrating the entire value chain of sourcing for raw materials, transformation into finished goods, and to its distribution to the end customers. They describe the three structures that form a supply chain network such as the supply chain partnership, vertical and horizontal structural dimensions, and the process links among supply chain partners.

Stock & Boyer (2009) gave an all encompassing definition with an extended look into the various entities of the supply chain and their functions with respect to material flow. In the bid to fully define a supply chain, they identified the main themes (activities, benefits and constituents) and subsequent sub-themes identified from various definitions of supply chain as shown in Figure 4.

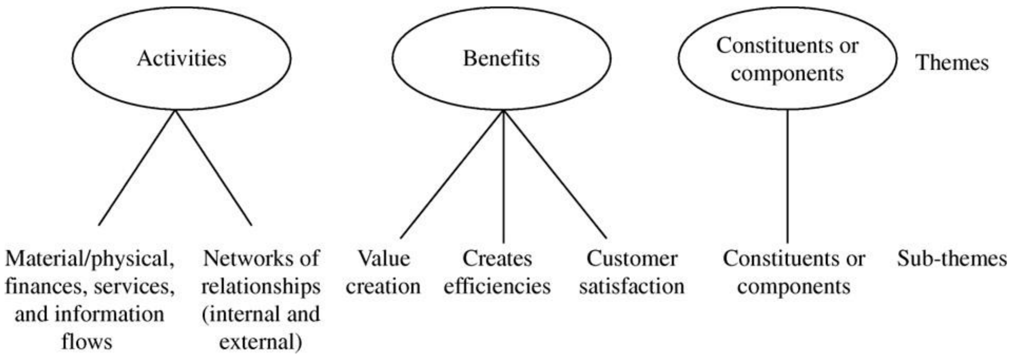


Figure 4. Themes and sub-themes of a supply chain (Stock & Boyer, 2009).

Tan (2001) noted that the complexity of the supply chain makes it difficult to define, but only through the various activities happening along the value chain. Their definition of a supply chain highlights the need for the consideration of the entirety of the lifecycle of the raw materials. This makes the logistics an important entity to consider. In addition, it is believed that material flow in a supply chain is 'pulled' by the customers through the value chain.

Finally, Slack et al (2010) noted that the supply chain is a cluster of several organisations that are interlocked together by the upstream and downstream operations with the ultimate aim of adding value to the end consumer.

Consistent with the above definitions is that supply chain performance depends highly on the level of integration of the various components through the efficiency of information sharing. Integrating the upstream and downstream segments enhances material and information flow across the network. Figure 5 illustrates the E2E supply chain process, showing the upstream and downstream activities of which the formal is the focus of this study. The upstream is composed of the various tiers of raw material suppliers, logistics operations and manufacturing operations with raw materials and information flow.

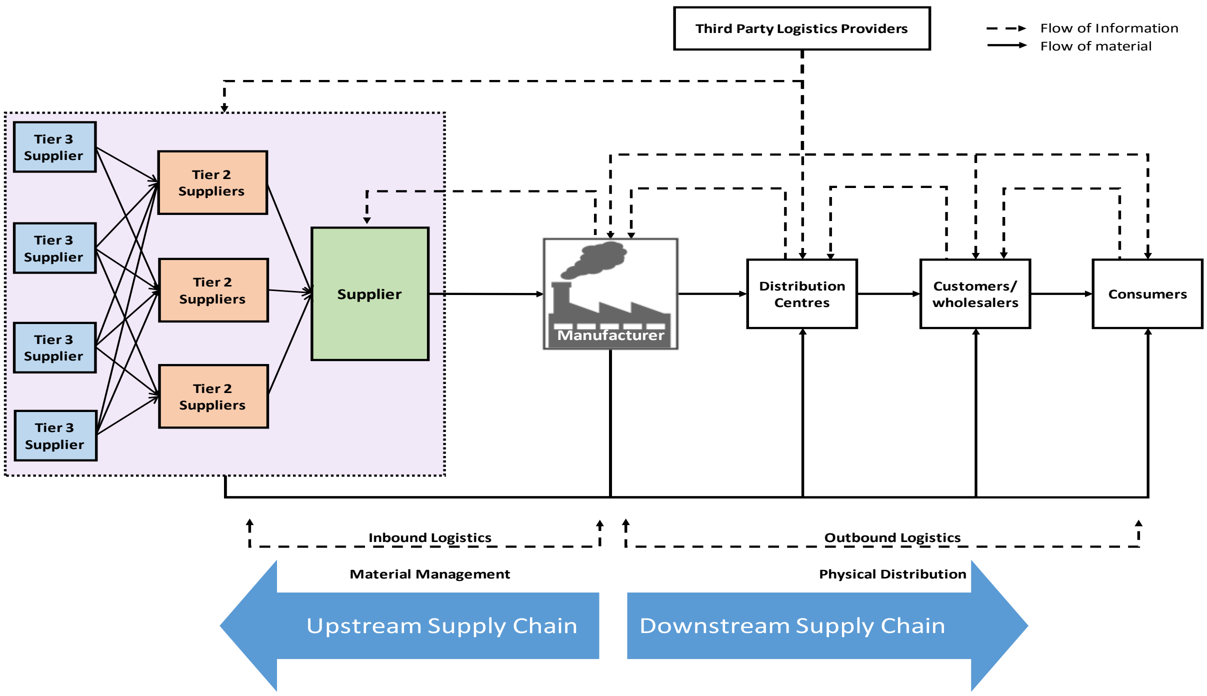


Figure 5. E2E supply chain process (Adapted from Min & Zhou, 2002)

2.3. Information Systems in Supply Chain Integration

The complexity of today's supply chain network necessitates the need to constantly and efficiently share information among the network partners. This complexity is inherent in the connectivity and structure of the subsystems (e.g. companies, business functions and processes), and the operational behaviour of the systems and its environment, thereby making managing it a serious challenge (Serdarasan, 2013). But as the supply networks increasingly cut across national economies and geopolitical boundaries to a more global entity, there is need to systematically integrate the entire supply chain partners in order to achieve business needs. Hence, there is need for a well-coordinated information sharing and communication system that aids informed decisions about the needs of supply chain network thereby shaping the network strategy and actions.

The implementation of IS in a supply chain aid the integration of the independent systems, and subsystems into a single entity in order to achieve the network goals. IS technologies are in use today to simplify and automate various tasks in many organisations within the supply chain. However, information technology (IT), as a subset of an IS system is termed as a supply chain ‘enabler’ that enhances communication and reduces supply chain cycle (Tarek & Mchirgui, 2014). They integrate the key processes both of a firm’s internal and external processes within a supply chain and along the value chain, thereby aiding the sharing of information. Whereas internal integration involves a firm’s functional areas e.g. marketing, finance, purchasing, and manufacturing; external integration involves interconnectivity of the firm with other supply chain stakeholders (Chen & Paulraj, 2004). In other words, supply chain integration through IS can contribute to improving the exchange of information and trade data within an organisation and among the supply chain partners with the aim of facilitating the efficiency of the value chain (Wagner & Enzler, 2005, p. 200). However, Handfield and Nichols (2002, p. 147) argues that “before these technologies can provide their full benefits, supply chain member organisations must establish relationships characterized by a willingness to share and receive information, and collaborate to improve performance”. This means that having the right technological connectivity is not enough. Collaboration of the supply chain partners can aid the improvement of the supply network and deliver value-added products and services that meet the needs of the end consumers. An effective IS in a supply chain network is capable of effectively integrating the upstream and downstream supply chain partners through undistorted information dissemination and reduces or eliminates the impact of the bullwhip effect (Yu, Yan, & Cheng, 2001).

Effective implementation of IS processes requires considerable commitment of huge time and financial resources and therefore companies are continually striving to make them even more effective in order to improve their financial standing and market positions" (Williamson, Harrison, & Jordan, 2004). Such commitments to IS by the supply chain players requires a long-term relationship among the independent firms to realise the aim of the consortium. This ensures that there is enough time to actualise competitive advantage through enduring collaborative innovative efforts, research and development, shared knowledge and capability development, and conflict resolution (Soosay, Hyland, & Ferrer, 2008).

Today's advanced IS systems utilise automated technologies and systems to simplify the inter-organisational and intra-organisational integration processes of the supply chain. The ERP system now integrates more than the manufacturing process but extends to the entire supply chain management, finance, human resources, project management, etc. It is an enterprise information system that is used to manage all aspects of the business operations (Ge & Voß, 2009). Other technologies such as the electronic barcode scanners and RFID readers are now increasingly integrated with the ERP system in the warehouse management systems (WMS). These technologies decipher information that are pre-encoded on labels and RIFD tags, compute the information and transmit them through wireless connectivity to the server which updates the material on the ERP server. Hence, they provide real-time, up-to-date control of material inventory within the supply chain. Similarly RTCIS, one of the case proprietary WMS is used in material handling and to record the flow of material within the supply chain (Andel, 2003). The RTCIS is interfaces with SAP to record material usage and physical movement within the supply chain operations using IDOCs. The IDOC is the communication interface through which RTCIS and SAP communicate. While RTCIS only manages the entire inventory in its own server, SAP manages 100% of all inventories, including all those in RTCIS inventory.

It can be conclusively noted that the implementation of IS has greatly improved material information visibility (e.g. quantity, type, serial number, etc.) within internal and external processes by providing in real time an accurate, coordinated and reliable information to the stakeholders (Matičević, Čičak, & Lovrić, 2011). The overall aim of IS integration within the supply chain, in the context of improving MU efficiency is to maximise and optimise material flow and usage in the supply chain value chain.

2.4. Supply Chain Process Improvement and Optimisation

Through the infusion of quality management into the very core of supply chain management and its strict implementation, the quality of product and services is assured within the supply chain operations. Hence, there is a constant need for the provision of effective improvement of product quality among the supply network partners.

Supply chain quality management (SCQM) is "a systems-based approach to performance improvement that leverages opportunities created by upstream and downstream linkages with suppliers and customers" (Foster, 2008). Its aim, as stated by Robinson and Malhotra (2004) is to formally coordinate and integrate the business processes involving all partner organisations in the supply channel by measuring, analysing, and continually improving products, services, and processes in order to create value and achieve satisfaction of intermediate and final customers. Simplistically, SCQM is the ability of the supply chain to meet the needs of its collaborating partners and the end customers' expectations and the need to strive for continuous improvement. The goal of SCQM is to achieve process optimisation with the aim of cost minimisation, throughput and efficiency maximisation in other to achieve improved standard-based operation. Moreover, this can be achieved only if quality is built into each process elements in the value stream while proper monitoring and control of the outcome is done. With the use of quality control tools, supply chain players are able to effectively monitor, control and manage key metrics of processes in order to achieve competitive advantage. This importance is highlighted by Lin et al. (2005) stating that “the effective management of technology and quality is the key to increased quality and enhanced competitive position in today’s global environment”. This can be achieved in setting up strategic quality goals and standards, and working to achieving them in a sustainable manner.

However, it is worth noting that variability exists in the quality outcomes of any supply chain process i.e. materials, methods, equipment(s), people, and the environment within which the activities are happening (Oakland, 2008). Supply chain practitioners must focus on investigating and minimising these variabilities along the value chain in order to improve price, delivery and quality. Hence, it is important to first identify and eliminate the special causes of variations to achieve process control.

The Six Sigma methodology aims at variability reduction and continuous improvement through Statistical Process Control techniques. Statistical process control provides techniques and strategies are used for monitoring and controlling a process with the aim of continuously improving it and reducing its inherent variability. It does this using several tools and techniques of which the control chart is of vital importance (Montgomery, 2009). The control chart makes visible the process variability and determines if the process is in statistical control or otherwise. It depicts the process mean in relation to the specification targets, which informs what appropriate action(s) to be taken to achieve and maintain a state of statistical control, and to further improve the process.

However, it is not enough to understand the state of a process, conscious effort is required to improve it and bring it to statistical control based on customer specifications. The Process Capability Indices (PCIs) are used to compare the process outputs by providing numerical measures of whether or not a process is capable of meeting a predetermined level of tolerance and specification (Wu, Pearn, & Kotz, 2009). It depicts the present status of the process and also provides a vivid look into how process variability can be minimised with an assumption that the process follows a normal distribution. An example of a normal distribution curve is shown in Figure 6.

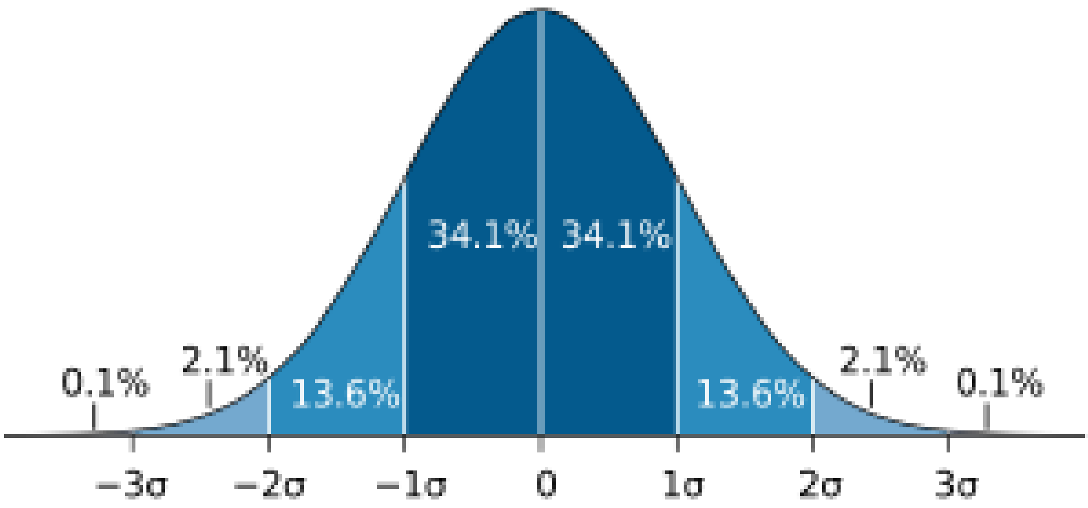


Figure 6. A normal distribution curve (Wikipedia, 2015)

However, care must be taken in the calculation of the process capability indices whose data do not follow a normal distribution. The process capability indices may be erroneous by either underestimating or overestimating the process states therefore giving misleading interpretation of the process. In the case of a non-normal dataset, a Box-Cox or Johnson's transformation of the original data and its specification limits will be appropriate or the identification of its exact distribution is required before PCA is carried out.

This two key indicators for process capability are: Process capability (C_p) and Process Capability index (C_{pk}). Where σ is the Standard deviation of the dataset and T the target, it is calculated as:

$$C_p = \frac{USL - LSL}{6\sigma} \quad \text{or} \quad C_p = \frac{2T}{6\sigma} \qquad [2]$$

The C_p value does not put into consideration the location of the process mean (μ) within the specification limits, the centring capability index. C_{pk} on the other hand measures the centeredness of the process data between the USL and the LSL using the process standard deviation, σ. Also known as the process potential index, the C_{pk} measures the fitness of the obtained process data between the upper specification limit (USL) and the lower specification limits (LSL) without particular interest in whether the data is centred within them or not.

Whereas,

$$C_{PU} = \frac{USL - \mu}{3\sigma}, \qquad C_{PL} = \frac{\mu - LSL}{3\sigma} \qquad [3]$$

The C_{pk} index is computed as the minimum of the C_{PU} and the C_{PL} values.

$$C_{pk} = \min\{C_{PU}, C_{PL}\} \qquad [4]$$

That is,

$$C_{pk} = \min\left\{\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} \quad [5]$$

It is worth noting that "the magnitude of C_{pk} relative to C_p is the direct measure of how off-centre the process is operating" (Şenvar & Tozan, 2010). Table 3 shows the summary of the improvement objectives of the C_{pk} and C_p indices.

Table 3. PCI Interpretation (Oakland, 2008, p. 264)

Results	**Interpretation**
Cpk < 1	A situation in which the producer is not capable and there will inevitably be non-conforming output from the process
Cpk = 1	A situation in which the producer is not really capable, since any change within the process will result in some undetected non-conforming output.
Cpk = 1.33	A still far from acceptable situation since non-conformance is not likely to be detected by the process control charts.
Cpk = 1.5	Not yet satisfactory since non-conforming output will occur and the chances of detecting it are still not good enough.
Cpk = 1.67	Promising, non-conforming output will occur but there is a very good chance that it will be detected.
Cpk = 2	High level of confidence in the producer, provided that control charts are in regular use

One of the shortcomings of the C_{pk} value as a measurement of process capability is that it only denotes the centring of the datasets with respect to the specification limits but not target. In that regards, C_{pm} is a better index that measures the process conformation to the upper and lower specification limits and the process data deviation from the target value, T instead of its mean value. “It is defined as the ability of the process to be clustered around the target or nominal value, which is the measurement that meets to exact desired value for the quality characteristic” (Şenvar & Tozan, 2010).

$$C_{Pm} = \frac{USL - \text{LSL}}{6\tau} \qquad [6]$$

Where, τ is the average sample data deviation from the target value,

$$\tau = \sqrt{\sigma^2 + (\mu - T)^2} \qquad [7]$$

Therefore, C_{Pm} is calculated as:

$$C_{Pm} = \frac{USL - \text{LSL}}{6\sqrt{\sigma^2 + (\mu - T)^2}} \qquad [8]$$

Like other process capability indices, a C_{pm} value that is less than the benchmark value of 1.33 depicts that the process needs improvement.

3. RESEARCH METHODOLOGY AND DESIGN

The discussion on the research methodology and the research design adopted for this study is introduced in this chapter.

3.1. Research Methodology

Popularised by Saunders, et al. (2012), the research onion model explains the process of actualising the research objectives from the research questions. The Onion consists of different layers - Research Philosophy, Methodical Choice, Strategy, Time Horizon, and Techniques and Procedures - that guides the researcher in the construction of the research methodology. The "research onion" for this study is shown in Figure 7. The following sub-sections explain the methodology of this study.

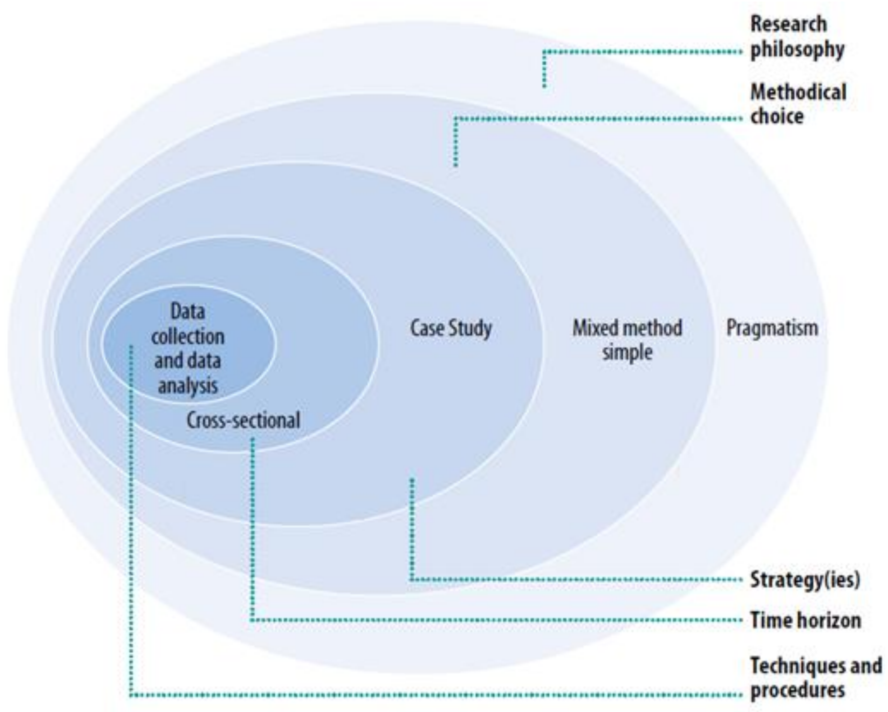


Figure 7. Research Onion adopted from Saunders et.al. (2012)

3.1.1. Research philosophy

The study takes a more pragmatic philosophical approach. A pragmatist research philosophical view is adopted because the study is more of a practical applied research in nature and that it integrates different but complementary perspectives (mixed methods) that can better be used to interpret collected data (Saunders, Lewis, & Thornhill, 2012).

3.1.2. Methodical Choice

A mixed method applies the use of a qualitative and a quantitative research methods in one study to achieve the aims of the research. According to Saunders et.al (2009, p. 152), "it uses quantitative and qualitative data collection techniques and analysis procedures either in parallel or sequentially, but does not combine them". It makes use of both approaches in tandem so that the outcome of the study surpasses the lone application of either the qualitative or quantitative research (Creswell, 2009, p. 23). A methodical choice that Creswell (2009, p. 31) refer to as the "concurrent mixed method", in which collected quantitative and qualitative data are merged or converged in order to comprehensively analyse the research problem. It makes sense of the collected data by concurrently collecting and analysing both the qualitative and quantitative data components independently. The rationale for the mixed research method is for the purpose of achieving data triangulation, analysed from the research questions, in order to obtain the research results. In addition, it also helps to achieve complementarity of both the qualitative and quantitative techniques so that the different aspects of the research can be merged reasonably (Saunders, et al., 2009, p. 154). Furthermore, to make sense of the results, crystallisation is used to combine and synthesise the results into a more coherent and understandable form (Denzin & Lincoln, 2011).

The data collection and analysis comes from the researcher's participation and inclusion on the research project through observation, questioning, meeting and interviews of the various stakeholders, etc. The output of the analysis is therefore the results of the study.

3.1.3. Research Strategies

The research strategy adopted is that of a multiple case study. Just as a single case study considers only one case, a multiple case study has two or more cases in view. The purpose underlying the use of this multiple case study is to provide a basis for comparison between the cases understudied and to clearly show if there are observable patterns (Saunders, Lewis, & Thornhill, 2012, p. 127). It also helps to strengthen the inherent weaknesses that a single case study provides. The two case organisations considered in this study are top multinational FMCG organisations with competitive brands, similar operations and machinery, and are located in the sub-Saharan Africa market.

3.1.4. Time horizon

The time horizon of this study is cross-sectional. It spans an active period of three months and two months with Case Alpha and Case Beta respectively. During these periods, both qualitative and quantitative data were collected and analysed concurrently.

3.1.5. Techniques and Procedures

Lastly, techniques and procedures refers to the way data collection and analysis is done. During this study, the researcher uses techniques as observations, field notes, statistical processes etc. to collect and analyse both the qualitative and quantitative data. The procedures for each of the collected qualitative and quantitative data are discussed separately in section 3.2.

3.2. Research Design

Research design provides a clear and detailed step-by-step plan that tells how the study is conducted with the aim of ensuring the research questions are addressed. The research design of a mixed method study employs corroborating support for the respective qualitative and quantitative components. For this study, the schematic overview of the research design represented in Figure 8 begins with defining the research problem, of which the research questions earlier presented were derived from. On this basis, the theoretical foundation of this study was framed. This ensures previous but relevant studies are consulted and hence provides a theoretical basis for the study. To accomplish the uniqueness of this mixed study, the quantitative and qualitative aspects to data collection from the case organisations were reviewed and analysed. The result of the study is a synthesised analysis that compares the differences, similarities and the observable patterns obtained from the two case organisations. The respective qualitative and quantitative research design components of the study are discussed separately below.

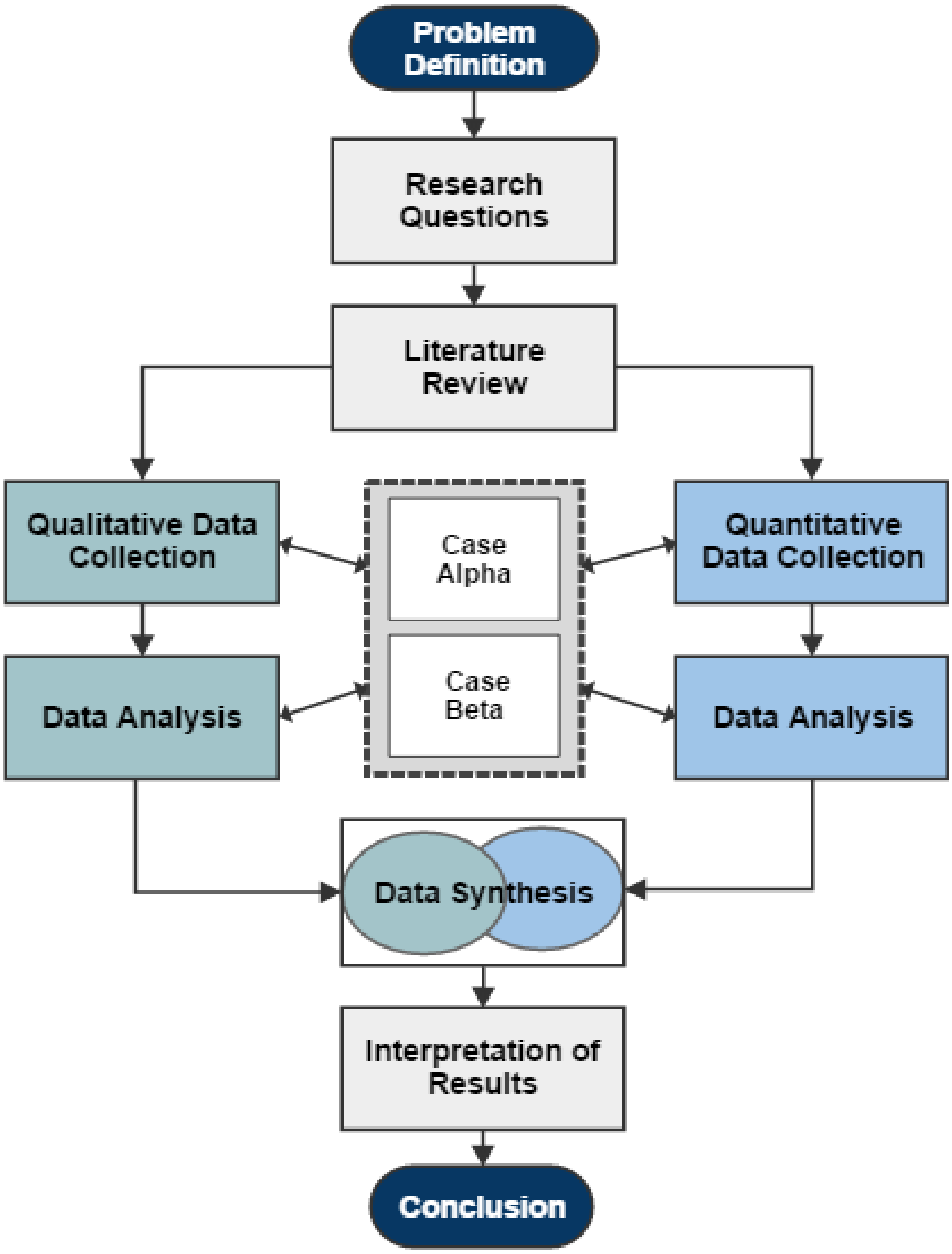


Figure 8. Research Design

3.2.1. Quantitative Data Collection and Analysis

The quantitative data obtained in this study were collected mainly from machine process measurements, raw material variable measurements, machine data, ERP system (SAP) and MES reports. The data obtained from SAP applications are such that shows the usage and consumption of the individual raw materials in the entire supply chain. Data obtained from MES reports are from GE's Proficy Plant Application software which are specific to the manufacturing operations and the production system. The outcome shows individual material utilisation efficiencies, scrap level, total usage, and amount lost or gained in local currency, etc. Quality variables were obtained from product samples to monitor compliance to quality targets. Data from material (SAP & Fluff) dosages were recorded from the production line's actual feedback display on the HMI and from SAP On/Off tests conducted at intervals. Other data obtained are those from archived reports of material consumptions and production operations and this serves as baselines for the study. By combining these sources of data, a holistic view of the material consumption on the production line can be achieved.

The study makes use of statistical procedures to analyse its quantitative data. Statistical process control techniques were extensively used to analyse for variation in the data while the process capability analysis were used to measure the capability of the process to continue to meet set specifications.

3.2.2. Qualitative Data Collection and Analysis

Tacit knowledge of the production process through previous experiences gained and the pre-study training about production systems and processes plays an important role in the collection of qualitative data of this study. The data sources were mainly from primary and secondary sources, via observations, meetings, field notes, electronic sources and through experience working on the project with the research team and other expert resources (Näslund, et al., 2010). Other sources of data are from print media such as manuals, publications, electronic sources such as data obtained from the case organisations' intranet sites, knowledge repositories, and by active participation.

The data collection techniques are through collaborative participation, observations, meetings (Creswell, 2009, p. 168), and using available propriety documentations. Field notes and diaries were used to collect data throughout the period of the research. The data collected were based on observations, meetings and thoughts during the research project participation (Koshy, 2005, p. 142). In addition, they also contained key points from training and study materials, process flows, reflections of the research process, and the events unfolding and innovation that occurred during the research process (Koshy, 2005, p. 97).

The qualitative data are analysed descriptively highlighting important themes and issues resulting from the collected data. Each cases are analysed separately and inferences are made through a comparative analysis in order to synthesise the observable patterns.

4. RESEARCH ANALYSIS AND RESULTS

To select the appropriate process areas to optimise, the raw materials that has high loss-cost impact from previous months' historical data were considered. This was obtained from SAP ERP raw material utilisation transactions. Prioritisation of these materials were done so as to focus on the top few that has the greater impact on the bottom-line results, which is a target to driving improvements.

For this study, the results, processes and applications of two raw materials are presented and analysed for Case Alpha (A-D1 and A-D2) while three raw materials were the focus of Case Beta (B-F1, B-D1 and B-D2). Raw materials A-D1/ B-D1 and A-D2/ B-D2 are similar in the physicality of the components that makes up the product compositions of the cases, others are therefore dissimilar. The similarity of the analysed raw materials within the case organisation and their categories according to their mode of application on the converting lines are shown in Table 4 and the summary descriptions are shown in Table 5.

Table 4. Mode of application of raw materials per case

Cat.	Raw Material	Mode of Application	Case Alpha	Case Beta
F1	Poly back sheet	Servo driven spindle unwind	-	B-F1
D1	SAP	Granule Metering System	A-D1	B-D1
D2	Pulp Fluff	Fluff Feeder	A-D2	B-D2

Web materials are unwound with a servo driven application before they can be fed to the main converter using a spindle unwind systems that is used to feed polythene and nonwoven web materials to the converter. In addition, the metering application system is used to feed a uniform dosage quantity of granulated Sodium Polyacrylate otherwise known as a Super Absorbent Polymer (SAP), the fluff feeder is used to feed fiberized paper-like pulp materials using vacuum transport system to the converter. The combination of categories D1 and D2 is termed the "Absorbent core" for each case organisation.

Table 5. Summary description of the raw materials researched

RM ID	Material Description
B-F1	A web sheet hydrophobic material used as the back sheet for leakage prevention and insult containment.
A-D1, B-D1	A hydrophilic granulated sodium polyacrylate material which is an active absorbent agent in the diaper composition. It turns into gel after water absorption and can absorb 30 times its own mass of water.
A-D2, B-D2	A fiberized wood pulp sheet made into fluff to aid the even distribution of A-D1 and B-D1. It can absorb 30 times its own weight of urine.

In this section, the research data is analysed quantitatively and qualitatively and the result is presented based on the research questions guiding the study as presented in chapter one.

A typical diaper is a physical combination of raw materials that do not undergo a chemical transformation. Hence, the chemical state of each combining material remains unchanged after process transformation. Therefore, a physical separation technique is used separate the various components in order to carryout characteristic measurements and analyses. Furthermore, statistical process control and process control analysis are used to analyse the stability and capability respectively of the Absorbent core material application process of the converter for Case Alpha's A-D1 and A-D2, and Case Beta's B-D1 and B-D2. Since it was difficult to as at the time of this study to disintegrate all the samples needed for the analysis of the Absorbent core into its constituents, the absorbent core was considered as a whole in the analysis. Their process capability indices were calculated in order to assess the stability and the capability of the converting machines with respect to achieving set quality expectations.

4.1.1. Research Question 1

RQ1: What is the capability of the machines with respect to minimising material losses for the selected materials?

RQ 1 generally follows a quantitative analysis that begins with the collection of quantitative data from the machines under review. It involves a critical analysis of the machines so as to unearth areas of material losses. Figure 9 illustrate the process from data collection to analysis for each of the cases in view.

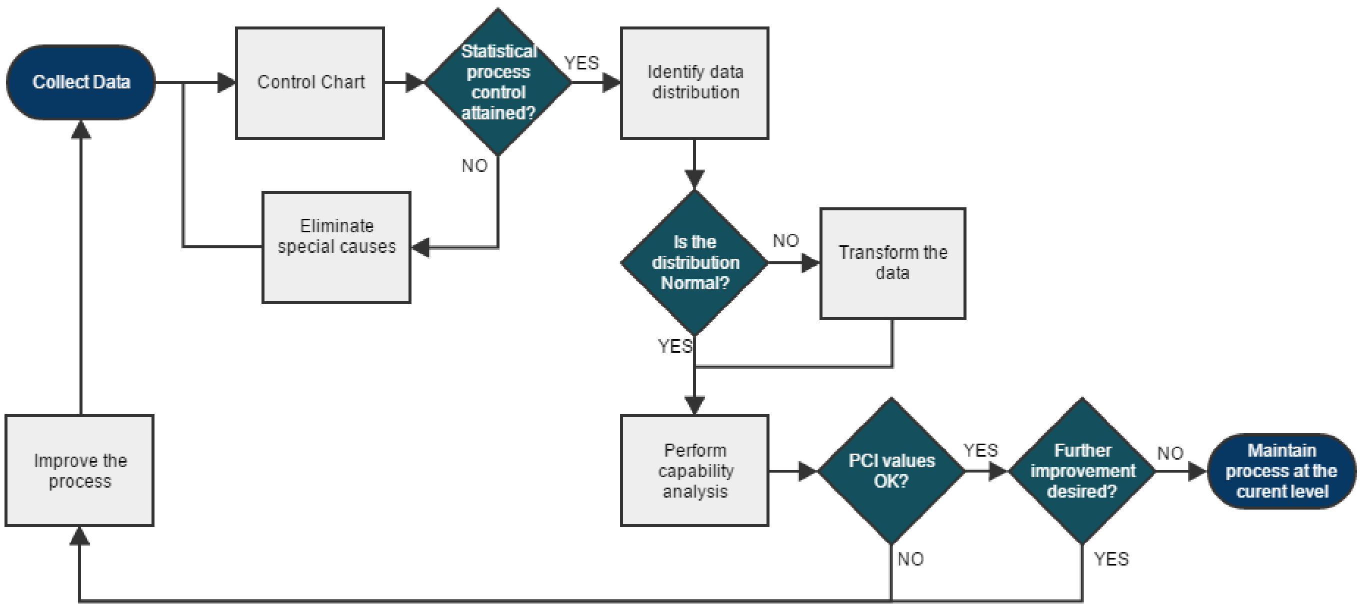


Figure 9. Process Capability Flow chart

First, the data collected is plotted on a control chart to confirm they are in statistical control. If otherwise, it is advised that inherent special causes are eliminated because out-of-control process will produce inaccurate capability analyses.

Second, the data distribution type of the data is determined in other to ascertain if the process naturally produces normal or non-normal data and what type of capability analysis will be employed. Usually, non-normal distributions are transformed but there are non-normal capability analyses as well.

Lastly, the capability analysis is performed by analysing the process capability indices values and comparing with the industry or generally acceptable values. process capability indices values below the acceptable values indicates that the process be improved while those above the acceptable values indicates the process needs to be maintained at the current level in other to continue to deliver the required results.

4.1.1.1. Case Alpha Capability Analysis

With the use of process capability indices, a process is studied to ensure that it is capable of consistently reproducing the end product parameters, within the pre-specified set quality tolerance. To begin with, the pad samples were collected to measure the weight of the Absorbent core composition of the pad. The Absorbent core is the homogenous composition of SAP and Pulp fluff which are the main materials in focus for this study. With the current equipment and techniques available during this study, the absorbent core cannot be perfectly separated into its component materials. Hence, this study calculates the process capability indices of the Absorbent core using pad samples from the production line.

The capability analysis for case Alpha is centred on the absorbent core masses (which comprises the A-D1 & A-D2) and based on different SKU obtained from two production machines. The SKUs samples of MN and MD were obtained from

L1 machine while that of MX samples were obtained from L2 machine. The sample masses were collected from archived quality department data samples of a month’s production in other to ensure consistency of results.

The product samples are carefully deconstructed according to the standard operating procedure of Case Alpha. 10 sample masses of the absorbent core are obtained for each of the 4 subgroup and measured with a precision accuracy of 0,01g. Since a subgroup size of 50 is required for each SKU, 40 samples are generated from simulation in Minitab® based on the standard deviation and Mean of the deconstructed samples. The descriptive statistics for the 2 SKU samples are shown in Table 6 below.

Table 6. Descriptive Statistics for MN & MD SKUs

SKU	N	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
MN	200	18,8103	0,0754	18,81	18,6	18,99	-0,18350	-0,15333
MD	200	23,3105	0,1139	23,31	23,02	23,69	0,14283	0,33343

In order to confirm that the machine processes for absorbent core production for L1 machine is in statistical control, an Xbar-S chart is computed from the sample data as shown in Figure 10. In this case, the Xbar-S chart is used to analyse if the data set considering the subgroup size is greater than 8 (i.e. 50 subgroup size) otherwise, an XBar-R chart will be used to assess the stability of the process.

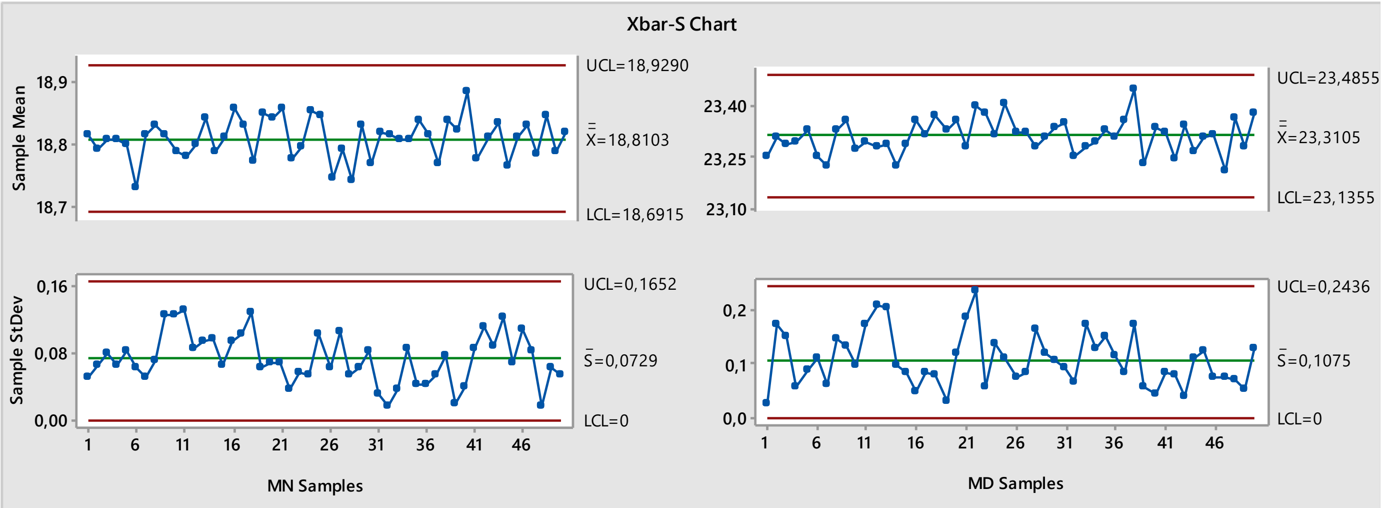


Figure 10. L1 control chart for MN & MD SKU absorbent core mass samples

The absorbent core production process for L1 SKUs are in statistical control because the processes are well contained within the UCL and LCL for not only their respective mean charts, but also for their standard deviation charts as shown in Figure 10. Furthermore, using the eight default standard tests for special causes in Minitab®, as shown in Figure 11, the result depicts that the data samples are randomly selected and distributed, and that no special causes were observed.

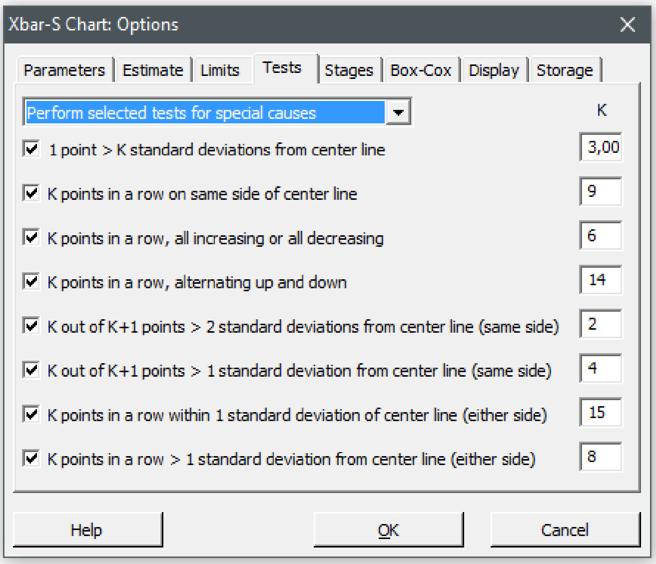


Figure 11. Test for special causes

Before commencing on computing the process capability for the data samples, it is essential to ensure the data is normally distributed. A test for normality is therefore carried out to confirm that the data can be modelled by a normal distribution or a non-normal distribution, and it is shown in Table 7 for each of the SKUs.

Table 7. Test for normality for MN and MD SKUs

	MN SKU			MD SKU		
Distribution	**AD**	**P**	**LRT P**	**AD**	**P**	**LRT P**
Normal	0,596	0,118		0,566	0,141	
Box-Cox Transformation	0,659	0,084		0,479	0,233	
Lognormal	0,605	0,114		0,59	0,122	
3-Parameter Lognormal	0,654	*	0,815	0,562	*	0,558
Exponential	91,031	<0,003		90,881	<0,003	
2-Parameter Exponential	25,016	<0,010	0	41,654	<0,010	0
Weibull	2,189	<0,010		1,474	<0,010	
3-Parameter Weibull	0,679	0,053	0	0,377	0,33	0
Smallest Extreme Value	2,245	<0,010		1,521	<0,010	
Largest Extreme Value	2,929	<0,010		5,006	<0,010	
Gamma	0,609	0,121		0,578	0,149	
3-Parameter Gamma	0,799	*	1	0,878	*	1
Logistic	0,787	0,023		0,39	>0,250	
Loglogistic	0,794	0,022		0,402	>0,250	
3-Parameter Loglogistic	0,787	*	0,883	0,39	*	0,659

The general rule to selecting the appropriate distribution fit is to choose the distribution whose p-value is greater than the selected p-value (P>0,05). The best fit distribution is however the one with lowest Anderson-Darling (AD) statistic or one with the highest P-value because the smaller the AD values, the better the distribution fits the data. The output from the tables above shows that the data can be modelled using a normal distribution or other non-normal distribution types such as Lognormal, 3-parameter Lognormal, 3-parameter Weibull, Gamma and 3-parameter Loglogistic distributions. However, since the p-values of the normal distribution which are 0.118 and 0.141 for MN and MD are greater than 0.05, there is not enough evidence to reject the H_0 that they do not follow a normal distribution. The indication that the data presented pass normality test is also shown in the probability plots in Figure 12. Hence, the data sets will be modelled using a normal distribution.

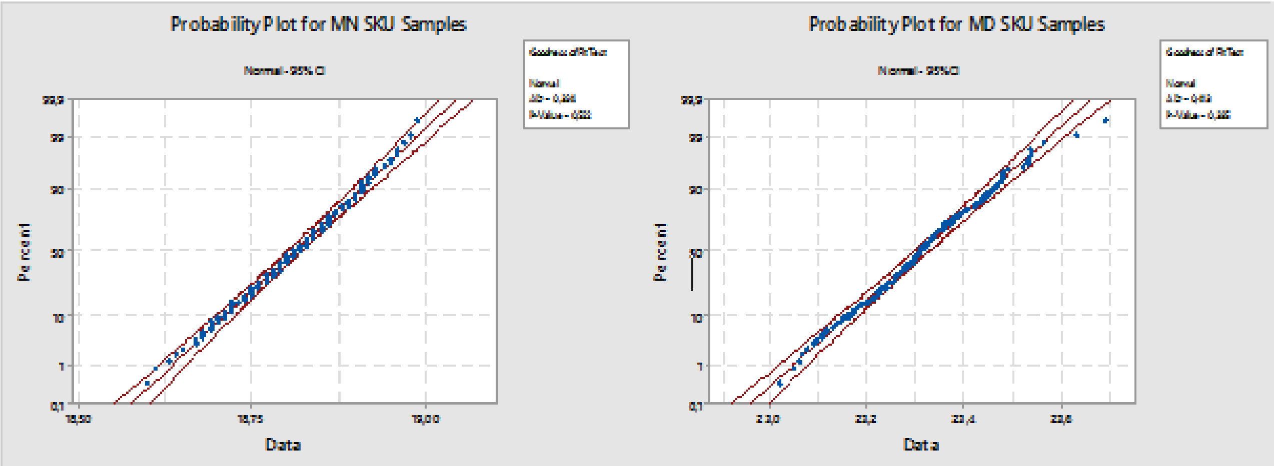


Figure 12. Case Alpha: Normal probability plots for MN and MD SKUs

Lastly, since the data are in statistical control and pass the test for normality, the process capability can then be computed for each of the MN and MD SKUs.

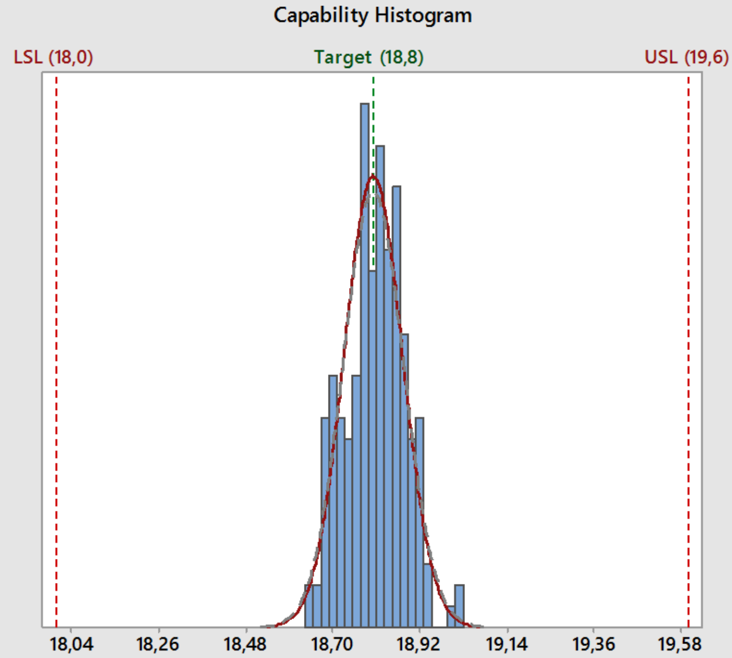
Figure 13 is an output from Minitab® that shows the histogram, process characterisation and the capability statistics of the MN data. The following can be deduced from the capability analysis of Case Alpha's MN SKU:

i. The process is within its USL and LSL with zero DPMOs.
ii. The C_p and C_{pk} values of 3,47 and 3,46 respectively are significantly equal. This suggests that the process is within and centred at the midpoints of the specification limits.

iii. Since the C_p and C_{pk} are greater than 2, the process is therefore capable at producing conforming products at 6 sigma levels with a high level of confidence that the machine process is well in control.

iv. There are zero DPMOs i.e. there are zero defective products or out-of-specification data points when compared with the LSL and USL values.

v. It is however important to focus on controlling the long term variation that may ensue while maintaining the process centeredness.



Process Characterization	
Total N	200
Subgroup size	4
Mean	18,802
Standard deviation (overall)	0,074229
Standard deviation (within)	0,076791

Capability Statistics	
Actual (overall)	
Pp	3,59
Ppk	3,58
Z.Bench	10,71
% Out of spec (observed)	0,00
% Out of spec (expected)	0,00
PPM (DPMO) (observed)	0
PPM (DPMO) (expected)	0
Potential (within)	
Cp	3,47
Cpk	3,46
Z.Bench	10,35
% Out of spec (expected)	0,00
PPM (DPMO) (expected)	0

Figure 13. Capability Analysis for MN

In addition to measuring the machine's capability of producing the Core of MN SKUs, it is necessary to compute its process capability in producing MD Core since machine L1 is used to produce both SKUs. This is essential in order to contrast the overall machine capability from the two standpoints.

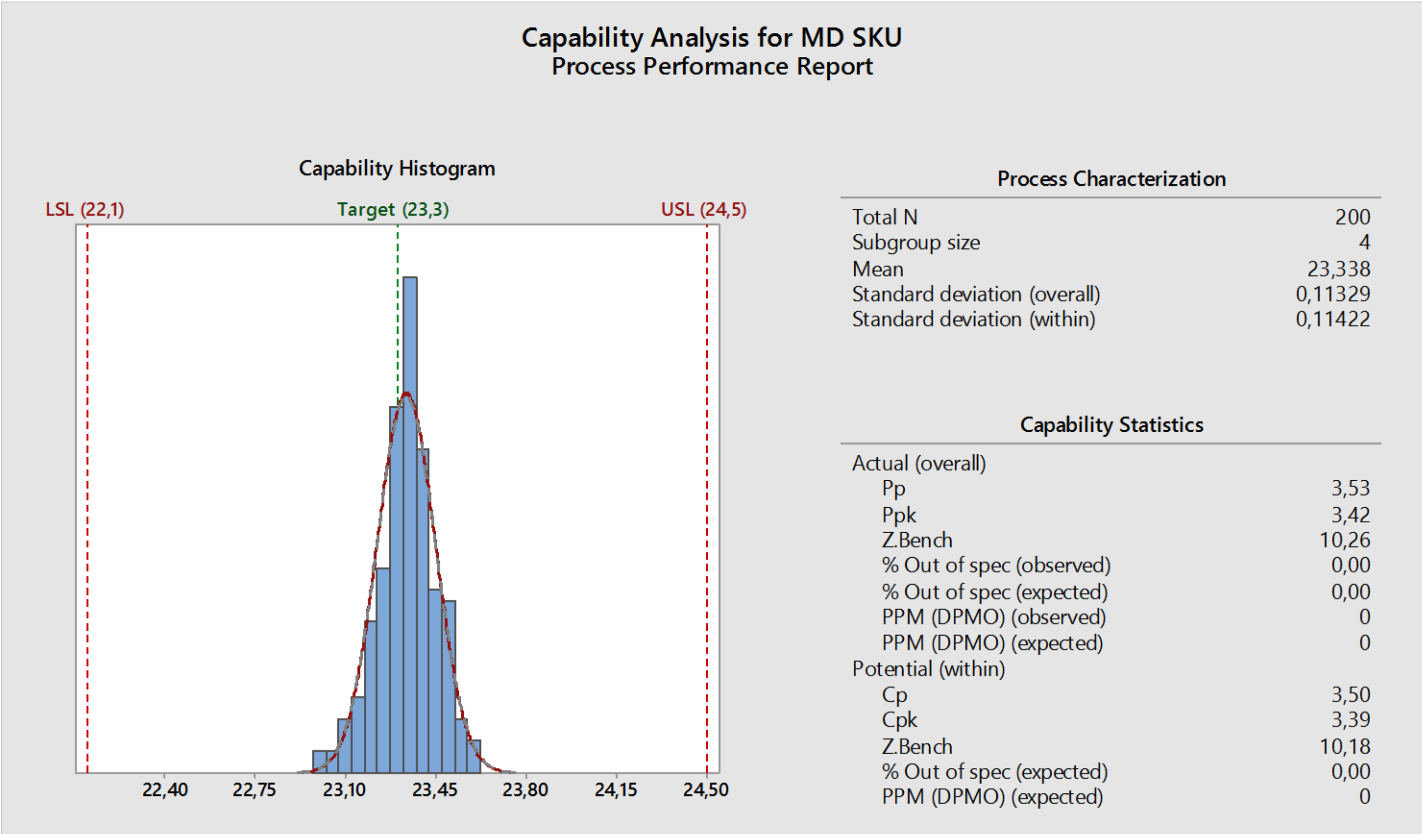


Figure 14. Capability Analysis for MD

Figure 14 also shows the capability analysis for MD SKU Core. The following deductions are derivable from the capability statistics and the histogram represented by the samples:

i. The C_p and C_{pk} values of 3,50 and 3,39 respectively indicate that the process mean differs significantly from the target. Hence, it is essential to improve the process such that the mean is close to the target as much as possible.

ii. The C_p and C_{pk} values indicate that the process is highly capable with a 6 sigma capability of producing the core components since the indices exceed an index value of 2.

iii. There are zero DPMOs i.e. there are zero defective products or out-of-specification data points when compared with the LSL and USL values.
iv. The next action is to focus on controlling the long term variations that may ensue while maintaining the process centeredness.

Hence, both MN and MD SKUs Cp and Cpk values are close. This is an indication that the samples obtained are from the same machine (L1). It is also an indication of consistency in the masses of absorbent core produced on this machine.

However, in the case of L2 in the production of MX SKU, preliminary analysis done on the initially collected samples showed that the process of core production on machine L2 needed improvement. The purpose of the improvement is to ensure that the process mean is close to the target as much as possible and that the variation in the process is minimised. Therefore, MX analysis is presented in before/after format in line with the process highlighted in the analysis methodology earlier presented in Figure 9. The improvement done are discussed in the qualitative part of this study.

Figure 15 shows that the control graph of the before/after of the process in which both processes are in statistical control since no sample data are outside the control limits and no special causes detected. The process variation for the mean, standard deviation and range charts for the before process (26,782g; 0,675g) and after processes (27,110g; 0,2719g) shows that there is considerable change the reduction of the process standard deviation and an increase in the process mean.

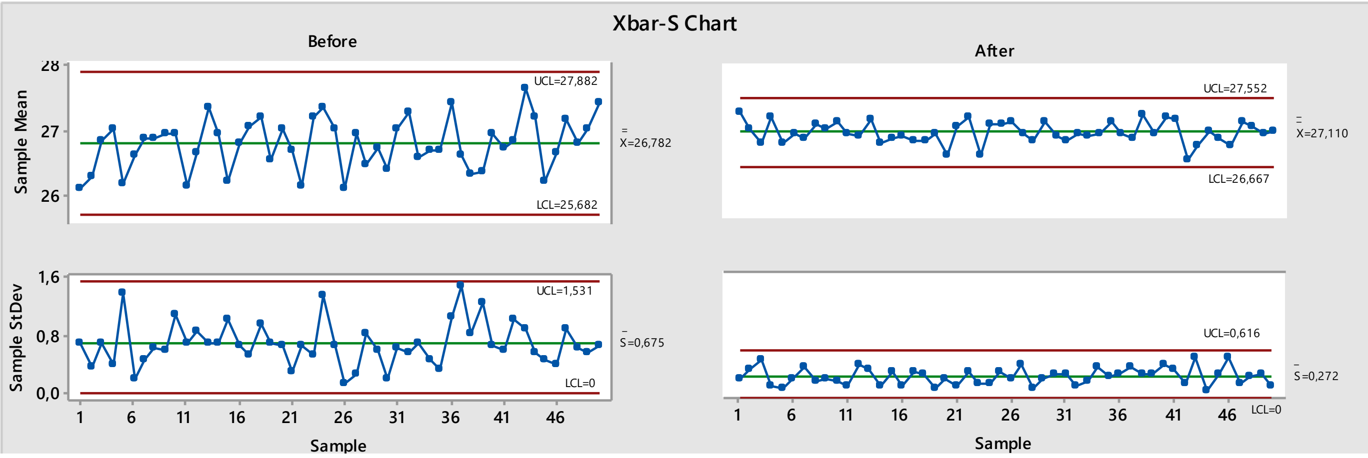


Figure 15. Before/After Xbar-S for MX absorbent core samples

The next stage is to test for the normality of the before/after samples by identifying the distribution model that best fit the data samples and verifying that both samples pass the normality test in other to be modelled by a normal distribution.

Table 8. shows the goodness of fit test for different distribution type to model the data. Although, several other distributions can fit the sample data, the normal distribution is selected for the sake of simplicity in computing the capability analyses.

Table 8. MX Before/After Goodness of Fit Test

	Before			After		
Distribution	AD	P	LRT P	AD	P	LRT P
Normal	0,328	0,515		0,237	0,784	
Box-Cox Transformation	0,284	0,627		0,179	0,917	
Lognormal	0,284	0,627		0,263	0,699	
3-Parameter Lognormal	0,297	*	0,879	0,239	*	0,528
Exponential	86,836	<0,003		89,834	<0,003	
2-Parameter Exponential	37,172	<0,010	0	39,716	<0,010	0
Weibull	2,528	<0,010		1,548	<0,010	
3-Parameter Weibull	0,414	0,273	0	0,200	>0,500	0
Smallest Extreme Value	2,909	<0,010		1,657	<0,010	
Largest Extreme Value	2,075	<0,010		3,252	<0,010	
Gamma	0,297	>0,250		0,256	>0,250	
3-Parameter Gamma	0,273	*	1	0,457	*	1
Logistic	0,530	0,136		0,299	>0,250	
Loglogistic	0,486	0,184		0,312	>0,250	
3-Parameter Loglogistic	0,470	*	0,876	0,299	*	0,633

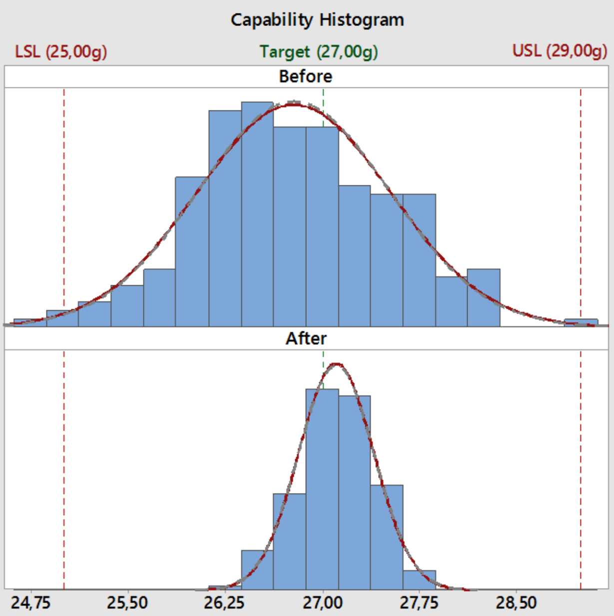
The process performance report is presented in Figure 16. It shows the capability histogram, process characterisation and capability statistics for the before/after samples. The following are can be deduced from the report:

i. L2 'Before' process has a C_p and C_{pk} values of 0,90 and 0,81 respectively which suggests that the process is off-centre, out of specification limits and incapable since its indices are less than 1,33. This however necessitated an improvement to centre the data and reduce the process variation by containing its data within the specification limits.

ii. Furthermore, with the L2 'After' process C_p and C_{pk} values of 2,28 and 2,15 respectively, this depicts a significant shift in the process mean, closer to the target value with zero out of specification value. The L2 'after' process is therefore capable of producing absorbent core that will meet the customer specifications owing to its capability indices above 1,33.

iii. The process mean increased significantly from 26,782 to 27,110 closer to the target of 27. There is also a significant reduction of the overall standard deviation from 0,7477 to 0,2902.

Before/After Capability Comparison for MX SKU
Process Performance Report



Process Characterization

	Before	After	Change
Total N	200	200	
Subgroup size	4	4	
Mean	26,782	27,110	0,32805
StDev(overall)	0,74772	0,29018	-0,45753

Capability Statistics

	Before	After	Change
Actual (overall)			
Pp	0,89	2,30	1,41
Ppk	0,79	2,17	1,38
Z.Bench	2,32	6,51	4,19
% Out of spec (obs)	2,00	0,00	-2,00
% Out of spec (exp)	1,01	0,00	-1,01
PPM (DPMO) (obs)	20000	0	-20000
PPM (DPMO) (exp)	10093	0	-10093
Potential (within)			
Cp	0,90	2,28	1,37
Cpk	0,81	2,15	1,35
Z.Bench	2,36	6,45	4,09
% Out of spec (exp)	0,92	0,00	-0,92
PPM (DPMO) (exp)	9156	0	-9156

Figure 16. MX process performance report

While L1 is stable and can consistently deliver the set target of absorbent core masses needed for the production of quality diapers, L2 needed some process improvements to consistently deliver the required absorbent core masses. Although there remains opportunity areas for the continuous improvement of the processes, the process capabilities of L1 and L2 are well above the generally acceptable 1,33 index.

4.1.1.2. Case Beta Capability Analysis

Similar to the data obtained from Case Alpha, the data obtained for the process capability analysis for Case Beta are that of the absorbent core masses (B-D1 and B-D2) of the machine.

To achieve this, a total samples of 400 diapers, with subgroup of 40 and subgroup size of 10 with each size representing different day were obtained from within a month run at times the process seem to be statistically under control. The masses of the obtained samples were measured on a top loading balance with a precision accuracy of 0,01g. The result is the total mass of the sample diapers, of which the Absorbent core is a constituent. However, in other to obtain the mass of the Absorbent core, a physical separation technique of meticulous deconstruction of the 40 samples for each subgroup into its separate constituents is required. 10 sample masses of the absorbent core are obtained for each of the 10 subgroups and measured with a precision accuracy of 0,01g. The Absorbent core mass obtained were used to simulate for each of the subgroups based on the sample standard deviation and Mean in Minitab®. The subgroup data summary is shown in Table 9. This result serves as the baseline for analysing the process capability of the machine with N=400.

Table 9. Sub-group component mass

Subgroup	1	2	3	4	5	6	7	8	9	10
Mean	**12,58**	**12,57**	**12,54**	**12,59**	**12,66**	**12,60**	**12,63**	**12,49**	**12,49**	**12,60**
Std Dev	0,1488	0,1342	0,1546	0,1457	0,1134	0,1606	0,1695	0,1810	0,1810	0,1422
SE Mean	0,052	0,0474	0,0546	0,0515	0,0401	0,0567	0,059	0,0639	0,063	0,0502
MAX	12,80	12,69	12,71	12,79	12,81	12,84	12,84	12,65	12,65	12,89
MIN	12,40	12,35	12,29	12,34	12,46	12,36	12,34	12,13	12,13	12,43

The first step according to the step-by-step process flow as earlier shown in Figure 9 is to ensure that the process is in statistical control before process capability is computed and improvements made. This can therefore be shown using a control chart that illustrates the sample data points. However, with a subgroup size of the samples of 40, an Xbar-S chart is therefore more appropriate than an Xbar-R chart. While the former is used for subgroup sizes ≥ 8, the latter is used for subgroup sizes < 8.

The variability in the subgroup process mean ($\bar{\bar{x}}$) and standard deviation (s) of 25,088g and 1,506g respectively are shown in Figure 17. The process variation is in control since none of the data subgroups exceeds the control limits values for both the Xbar and S charts. In addition, no special causes is observed in the data distribution which is an indication that the data is randomly collected.

It is also important to be sure about the kind of distribution is represented by the data before performing a capability analysis. This is important in other to know how the capability analysis will be done using either a normal or non-normal means. The output result from Minitab® about the identification of the best-fit distribution for the before/after data is shown in Table 10. The best fit distributions are those whose P-value is greater than or equal to the α-level of 0,05. It can be noted that the data fit several distributions (denoted in blue texts) as well as the Normal distribution. Hence, there is no enough evidence that the obtained absorbent core sample data do not follow a normal distribution. The null hypothesis H_0 is therefore not rejected. However, for the sake of simplicity and ease of calculation, the normal distribution is used to model the data and conduct process capability analyses.

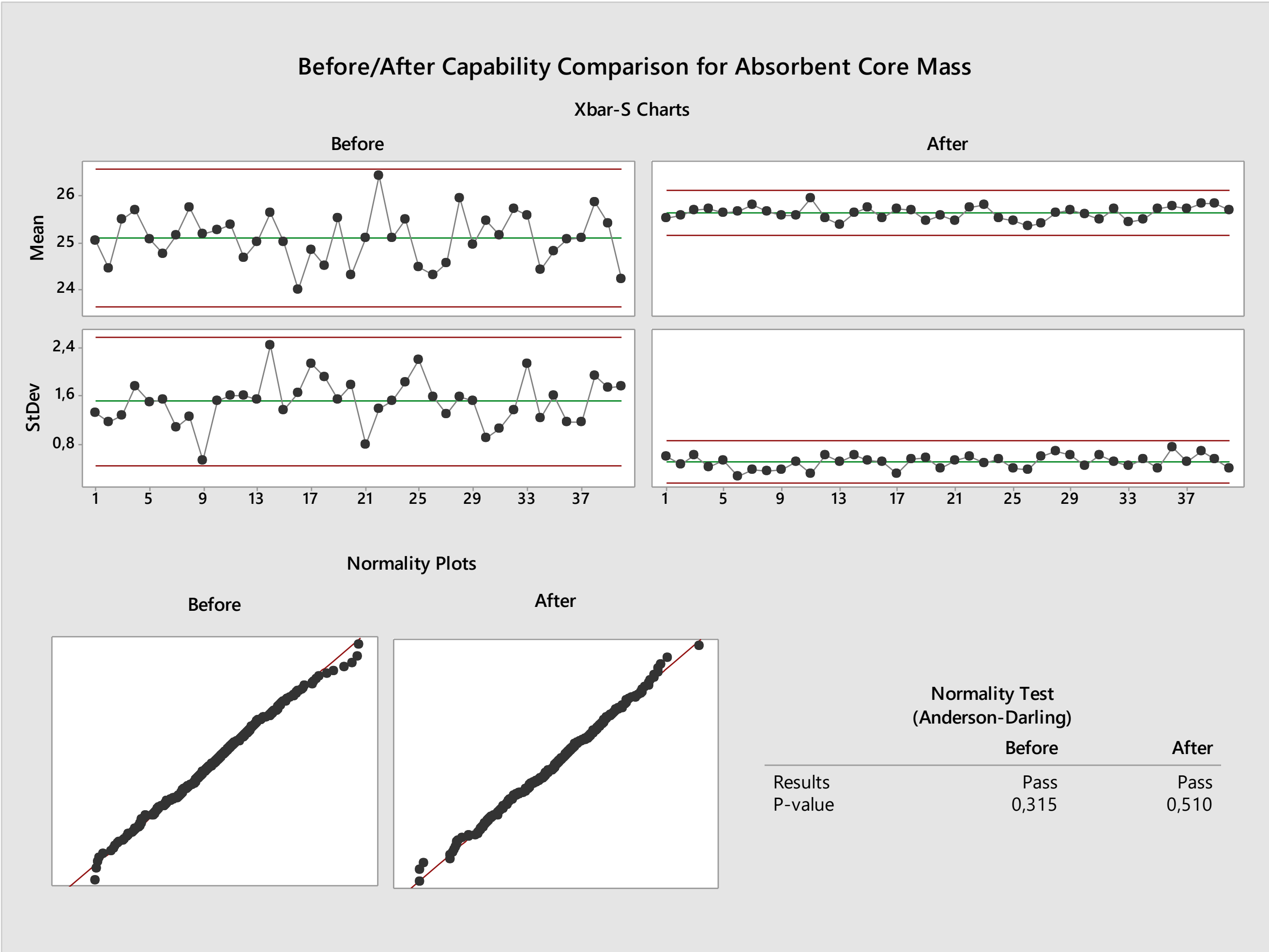


Figure 17. Case Beta: Absorbent core Control chart

Table 10. Case Beta: Before/After distribution identification

	Before			After		
Distribution	**AD**	**P**	**LRT P**	**AD**	**P**	**LRT P**
Normal	0,332	0,51		0,425	0,315	
Box-Cox Transformation	0,274	0,661		0,481	0,232	
Lognormal	0,406	0,349		0,625	0,103	
3-Parameter Lognormal	0,333	*	0,343	0,462	*	0,372
Exponential	176,583	<0,003		162,016	<0,003	
2-Parameter Exponential	77,707	<0,010	0	66,037	<0,010	0
Weibull	3,505	<0,010		4,642	<0,010	
3-Parameter Weibull	0,344	0,419	0	0,79	0,024	0
Smallest Extreme Value	3,986	<0,010		6,769	<0,010	
Largest Extreme Value	5,819	<0,010		5,623	<0,010	
Gamma	0,379	>0,250		0,515	0,208	
3-Parameter Gamma	0,581	*	1	0,62	*	1
Logistic	0,573	0,095		0,23	>0,250	
Loglogistic	0,62	0,071		0,374	>0,250	
3-Parameter Loglogistic	0,573	*	0,453	0,243	*	0,376

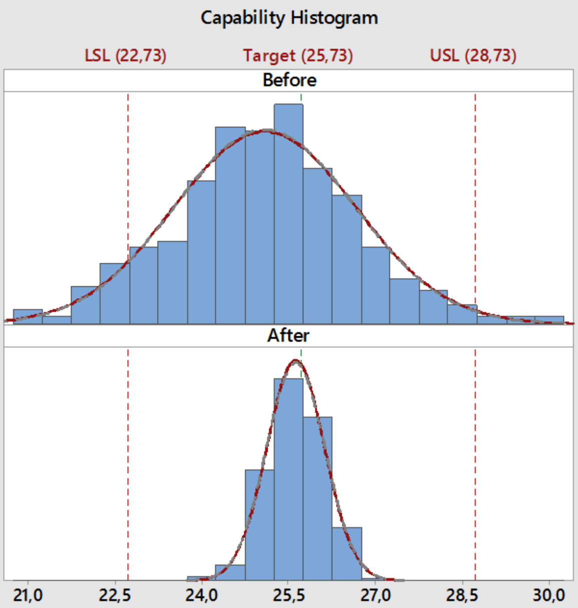
Figure 18 shows the process performance report for the before/after analysis of Case Beta absorbent core mass. The following deductions are deducible from the process capability histogram, capability statistics and process characterisation:

i. While the process mean for the 'before' is significantly different from the target of 25,73g the 'after' process improvement is closer to the target. The process mean changed significantly and it is now closer to the target ($p < 0,05$).

ii. The process standard deviation was reduced significantly ($p < 0,05$) by 1,07.

iii. The C_p and C_{pk} values changed by 1,33 and 1,40 respectively to a more acceptable values of 1,98 and 1,91 respectively. This shows that the process is now capable of producing the acceptable ranges of absorbent core masses.

Before/After Capability Comparison for Absorbent Core Mass
Process Performance Report



Process Characterization

	Before	After	Change
Total N	400	400	
Subgroup size	10	10	
Mean	25,088	25,621	0,53235
StDev(overall)	1,5697	0,49962	-1,0701
StDev(within)	1,5557	0,50567	-1,0501

Capability Statistics

	Before	After	Change
Actual (overall)			
Pp	0,64	2,00	1,36
Ppk	0,50	1,93	1,43
Z.Bench	1,43	5,77	4,35
% Out of spec (obs)	9,50	0,00	-9,50
% Out of spec (exp)	7,67	0,00	-7,67
PPM (DPMO) (obs)	95000	0	-95000
PPM (DPMO) (exp)	76663	0	-76663
Potential (within)			
Cp	0,64	1,98	1,33
Cpk	0,51	1,91	1,40
Z.Bench	1,44	5,70	4,26
% Out of spec (exp)	7,44	0,00	-7,44
PPM (DPMO) (exp)	74391	0	-74391

Figure 18. Case Beta - Before/After Process Capability

4.1.2. Research Question 2

To understand the key MU loss areas, the study considers holistic and discrete views of the all the processes in other to analyse the material loss points within the study scope. These loss points are the possible and potential areas of material losses within the system, whether in the process of quantifying the losses or through the discrete physicality of the nature of the raw materials. This however brings about the RQ2 which aims to investigate these loss points from three major perspectives namely: manufacturing bill of material review, equipment process optimisation, and human factors influences.

RQ2: What are the key MU loss areas impacting operational productivity and efficiency?

Appendix B is a summary of the analysis of the various loss points within the material utilisation sections. By depicting the ideal state, the gaps in each areas are made visible, hence aiding the development of action plans to eliminating them. The above categories were analysed using a cause and effect analysis to ascertain the direct causes responsible for material losses within the supply chain as seen in Figure 19.

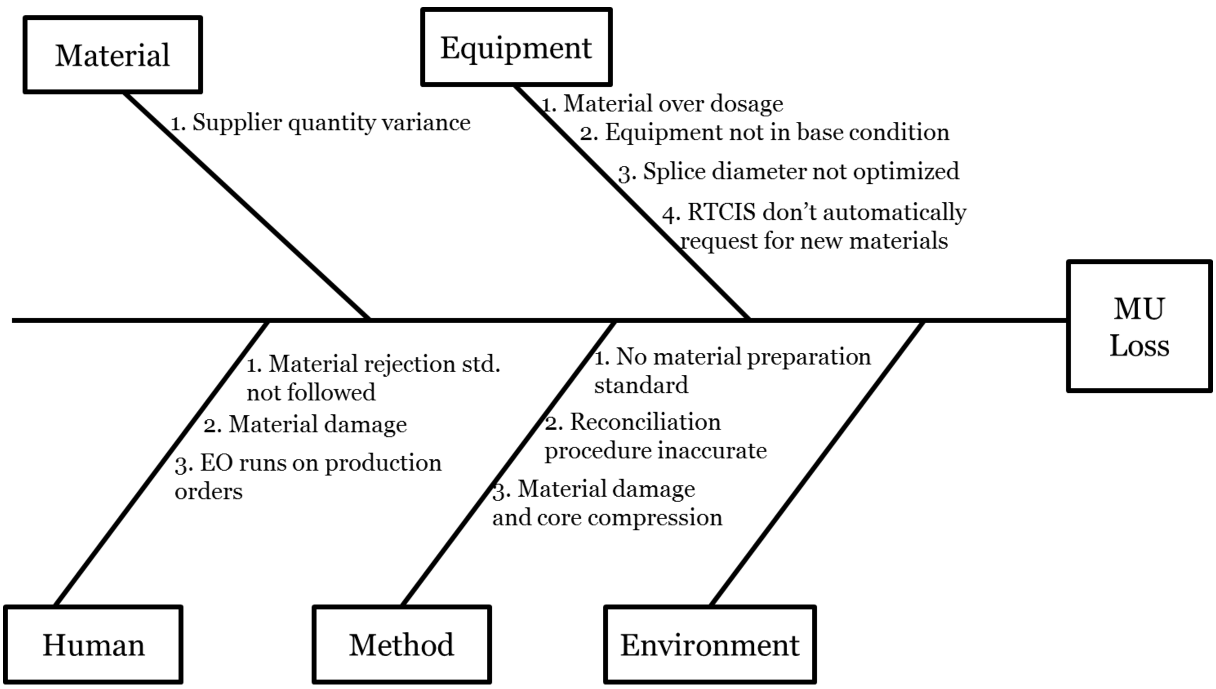


Figure 19. Cause and Effect Analysis of MU Losses

The root causes necessitate the review of MBOM, Creation of standards and the optimisation of the machine processes.

4.1.2.1. Review of MBOM

Further investigation of material losses in the supply chain operations at the cases under review necessitated the review of the manufacturing bill of material (MBOM) for the recipe of different SKUs. The MBOM review did not only take into consideration the selected raw materials previously highlighted in this study, but an extended focus into other raw materials required by the case organisations. The need for MBOM review was to investigate:

i. That scrap factors are not built in the recipe,
ii. Significant differences between material component values in MBOM and recipe, and the need to adjust accordingly
iii. If scrap factors needs to be reviewed as MU improves

Both Cases however do not have scrap factors factored in the recipe. However, as at the time of this study, the scrap levels at both organisations were higher and above the scrap factor thresholds or targets. Although there were times when the scrap factors at Case Alpha were reviewed because material utilisation improved significantly for some raw materials, Case Beta however had high waste above the threshold limits for most of its raw materials. This therefore did not necessitate the need for scrap factor review for the raw materials.

The result also reveals that while Case Alpha has a considerable minimal variation in its raw material recipe values, Case Beta required an updated MBOM based on its Fluff, SAP and Adhesive raw material applications. Further investigations at Case Beta reveals that there are huge losses of these raw materials along its transformation process on the converter line. For example, leakages in adhesive applicators, fluff and SAP mixture loss along the converter during transformation to the finished product that are not recycled. Another reason observed is the use of non-calibrated equipment e.g. SAP dosage application that gives inaccurate feedback quantity of material dosage. Hence, these losses necessitated an increase in the raw material dosage so as to make up for the material losses without compromising the product efficacy and the MBOM specifications. It is therefore good practice to ensure that the process base condition is achieved before improving it.

4.1.2.2. Equipment Process Optimisation

The general goal of process optimisation is to achieve cost minimisation and maximisation of efficiency and eventual throughput. In the course of this study, many improvements and equipment optimisations were carried out to ensure the maximum capacity of the equipment process is achieved. For example, at Case Alpha, immense work was done in ensuring fluff and SAP metering and dosage were as close to target as possible. This involves the optimisation processes of the equipment that deliver these raw materials during the production conversion and close monitoring of the systems until material utilisation targets are achieved. The technicality of the processes were studied and solutions were proffered after experimentation and simulations had been carried out. The process at Case Alpha involves a cross-functional team of professionals with insights into different areas of the system in other to improve it. Its supply network collaboration coordinates all the activities and helped drive the MU results.

On the other hand, Case Beta uses a functional management approach to drive its material utilisation targets. Although its activities are similar to that of Case Alpha, it is less systematic in its approach. Fluff and SAP optimisation were the highlights of the equipment improvement carried out. The SAP dosage system is continually monitored to ensure material losses are minimised. The feedback dosage readings are part of quality inspection process for each shift. A deviation from specification targets usually necessitate a planned action to optimise the process. SAP monitoring is therefore given a higher priority due to its high cost impact of its losses as compared to fluff dosage. Most of the fluff MU loss impact at Case Beta arises from its non-recyclable and inefficiency in its dust control system (DCS). Its DCS are obsolete with low capacity to efficiently drive the MU target. An option is to adopt a more reliable or similar system at Case Alpha.

Generally, running at optimised conditions of the process equipment help minimise MU losses impacting operational productivity which may result from inefficiency and ineffectiveness of the process.

4.1.2.3. Human Factors

No doubt, human interactions have great influence in material utilisation efficiency in any supply chain operation and this is also true for the cases understudied. The human factors aspect of this study therefore covers all organisational cultures such as behavioural attitudes of people and personnel in connection to the work systems within the organisation which impacts material utilisation. Two main findings were made from the case organisations which points out to human factors that affect inefficient utilisation of raw materials. While there are differences among these findings, there are also peculiarities in the observations.

4.1.1.2.1 Material Handling

Findings from material handling point of view account for most human factors contribution in material utilisation in both case organisations. Similar to both cases under review, raw material damages were occasionally seen especially due to the use of incorrect lifting and transportation equipment and improper storage standards of which most of the material damage were roll materials.

In both cases, clamp trucks were used for the movement and transportation of roll materials from the raw material storage locations to the staging area and the production floor. Material damages that occurred were usually out-of-roundness and edge damages (Figure 20). The former is usually as a result of the material compression due to too high clamp force applied to the material, causing deformation of roll cores. Similarly, the latter exist due to wrong handling of the roll material during transportation and loading, especially with the use of forklift prong by third party suppliers. Rolls with compressed core that cannot be salvaged were destroyed while those with defective layers were cut off before use on the converting lines. Both damages therefore constitute to raw material utilisation losses.

Figure 20. Out-of-roundness damage

4.1.1.2.2 Material preparation standards and splicing

Although scrap factors exist for all the raw materials used in the production system, the level of waste above the scrap factors is prevalent for both cases. Usually when a new roll material is to be loaded to replace an old one, the operator removes the top defective layers before splice preparation. Although this is a standard practice in both case organisations, there exist no standards on the amount of layers to cut off. Hence, while some operators barely cut off any material layer, others take out excess materials. Hence, creating a material preparation standard will be helpful in ensuring material losses are limited during splice preparation. This will ensure that every machine operator achieves complete the procedure in a similar and exact way as stated in the procedure. As at the time of this study, a standard procedure was being planned to be developed in Case Alpha while Case Beta has developed a procedure in place but has yet to effect and enforce its adherence.

Another common practice observed in both case organisations is the use of a subjective manual splice in place of a better controlled automatic splicing of roll materials therefore leaving behind unused roll materials. This usually occur if material breakages is experienced, especially when the roll diameter becomes smaller. Although there may be inherent defects in the materials, operators often do not analyse the causes of the breakage before deeming the material defective and manual-splicing it. A critical view of the process is important so as to verify the causes of breakage before rejecting the material. However, while this is more prevalent in Case Alpha, it is less prevalent in Case Beta.

4.1.3. Research Question 3

RQ3: What are the ways to improve overall material utilisation efficiency?

The material utilisation and optimisation process starts with gathering the data that depicts the actual representation of the operational processes. The focus is on B-F1, A-D1 and B-D1 materials of the case organisations. As in the case of process capability analysis, the line processes have to be in their respective base conditions in order to achieve any improvement whatsoever. Such conditions are the right temperature, right raw materials, process centreline, etc.

RQ3 therefore takes a two-path perspective of material optimisation and process optimisation in order to provide standard scientific ways of improving the Cases' MU efficiency. These perspectives are applicable to the two cases understudied because of the similarity in operations, supply chain and machine processes and product.

4.1.3.1. Material Optimisation

Roll splice diameter reduction was carried out on web and roll materials of which efficient utilisation of B-F1 material was pivotal to this study. This is achieved by optimising the web unwinding process to automatically splice expiring roll of B-F1 to a new one at a predetermined diameter which as close to the core as possible without compromising the stability of the entire process. A general representation of an unwinding system is composed of two web materials loaded on the material spindles, an automatic splicing system and a web accumulator which is designed to store and dispense the material during splicing from an expiring one to a new one at a constant feed rate (Figure 21).

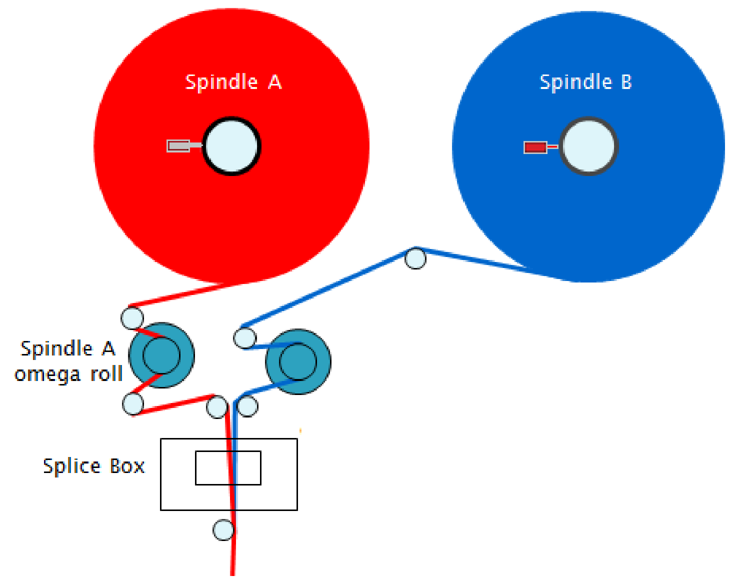


Figure 21. A general representation of a web unwinding system

4.1.3.2. Process Optimisation

To optimise the unwinding splice diameter of an expiring roll to a new one, it is important to understand the characteristic relationship of the diameter and time of the unwinding system as represented in Figure 22. The regions A, B and C

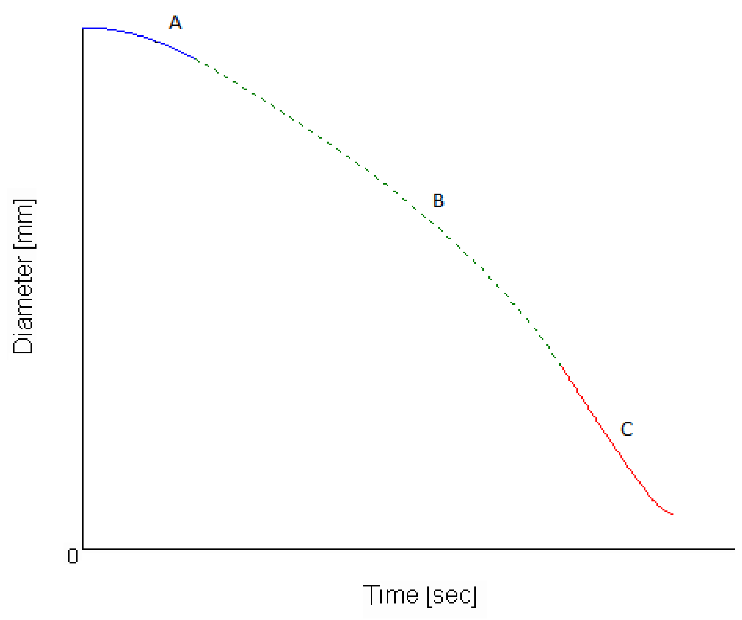


Figure 22. Unwinding roll diameter (Boulter, 2003)

According to Boulter (2003), an unwinding roll undergoes three main stages A,B and C which are the roll diameter during accelerating line speed, constant line speed and decelerating line speed respectively (equations 9, 10 and 11).

At full roll diameter and accelerating line speed,

$$R_{ACC} = \sqrt{{R_{FR}}^2 - \frac{TH\ .\ A_{CC}}{2\pi}\ .\,\Delta t^2} \qquad [9]$$

Where:

R_{ACC} = the roll radius after Δt (sec) of acceleration,

R_{FR} = Radius of a full roll (m), and

TH = web thickness (m).

Furthermore, at Stage B during a constant line speed and where R_{ACC} is the radius of the roll at the end of line acceleration and *V* = Roll surface velocity, R_{DEC} which is very close to the core is the diameter at which line deceleration starts is represented as

$$R_{DEC} = \sqrt{{R_{ACC}}^2 - \frac{TH\ .\ V}{\pi}\ .\,\Delta t} \qquad [10]$$

Lastly, at Stage C during decelerating line speed and before web accumulator buffering and auto splice action is achieved, the target ending roll radius or empty core radius (R_{EC}) is represented as,

$$R_{EC} = \sqrt{{R_{DEC}}^2 - \frac{TH\ .\ D_{EC}}{2\pi}\ -\ \Delta t^2} \qquad [11]$$

Where:

D_{EC} = the roll surface speed deceleration (ms^{-2}), and

Δt = final time.

D_{EC} can be determined using a hand tachometer to measure the surface speed.

After the time for the accumulator to achieve full material buffer is completed, spindle deceleration begins (near the core) to splice the expiring material with a new prepared roll. It is therefore preceded by the Equation [11] which is the optimised target radius at which the splice action is of the expiring roll occurs. Therefore, the optimal splice diameter of an expiring roll at the point of splice to a new roll, without running out the expiring material can be computed using Equation [11]. When the empty core diameter is known, the target ending roll radius, R_{EC} can be determined.

Figure 23. Siemens Simatic Panel controller

However, the B-F1 unwinding applicator uses a Siemens Simatic Panel controller (as shown in Figure 23) that displays the splice parameters such as the actual running diameter, splice diameter and the open diameter for the web accumulator. This makes it simple to input the various parameters but caution must be exercised to ensure a smooth running of the unwinding operation.

The qualitative aspect of this study contrasts the qualitative findings from the case organisations by observing visible trends and patterns. It supports and complements the findings from the quantitative data analysis and captures areas that were not quantitatively explicated through further expatiation of the cases loss point analysis summary in Appendix B and their standard work processes in Appendix C and in Appendix D.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study is focused on the efficient utilisation of raw materials during storage, transportation and transformation to finished products. The case organisations are multinational FMCG firms involved in the business of disposable diaper brands, with new production facilities in the sub-Saharan region. The project is a multiple case study that is aimed at saving cost that is normally lost in the upstream supply chain operations and accomplishing efficient utilisation on raw materials with an end-to-end perspective. The essence is to better utilise raw materials in the best possible way to ensure the minimisation of losses. To achieve this, more focus was placed on the raw materials with high losses and cost impacts on the overall utilisation efficiency. This data is obtained from historical records the case organisations. The study delves into the various factors of machine and human influences that affects the efficiency of raw material utilisation with the aim of improving its shortcomings.

This chapter finalises this research thesis. Based on the research questions, general conclusions are made by summarising the main findings of the study. The discussion of the limitations of the study is presented and suggestions are made for further study on the subject. Finally, recommendations are made to the case organisations based on the findings by suggesting improvement ideas that will ultimately improve the efficient utilisation of raw materials along the value chain of the supply chain operations.

5.1. Summary of findings

The findings from this study suggest that the utilisation of raw materials in the upstream supply chain are affected by multiple factors and requires a holistic and end-to-end approach of its various echelons. While there are different approaches to resolving material utilisation issues within an organisation, the study reveals the similarities and peculiarity of the entire processes in the case organisations. It also uncovers the significant factors that influences raw material utilisations through a comprehensive study of the case organisations, and proffers ways to achieving sustainable cost savings. Whereas the application of the study is peculiar to the case organisations, they are also applicable and could be replicable by organisations in belonging to other industrial sectors.

5.1.1. Summary of the Quantitative Findings

Raw material utilisation during process transformation is highly dependent on the capability and stability of the machine processes to achieve effective management of raw materials. The fact that the mass of the absorbent core which comprises the fluff and SAP material contribute about 67% of the total weight of a disposable diaper is a focus for process capability assessment. This is to ensure that the right amount of the raw material is consistently metered into the final product and mass variations are minimised. Quantitative quality tools such as statistical process control and process capability analysis are used to access the absorbent core masses produced. This is to ensure that there is a continual meeting of the need of the end consumers and minimisation of losses through continuous monitoring and control of critical process parameters.

The study however reveals a direct relationship between the impact of machine stability and material savings for both case organisations. The process capability analysis conducted for both cases reveal the need to reduce process variability and improve process centeredness by ensuring the mean is as close as possible to the target specifications. When achieved, this will improve the effectiveness of raw material utilisation thereby minimising material loss.

The study also reveals that splice diameter optimisation also has a positive but direct impact on the utilisation of roll materials. This ensures the optimum minimisation of leftover on core without negatively impacting process stability. It entails the economical minimum splice diameter for each of the roll material is achieved. Whereas case alpha achieved 100% splice diameter optimisation for all roll materials, case beta barely made it a goal.

5.1.2. Summary of the Qualitative Findings

While there are operating standards at Case Alpha, Case Beta has little or none. This is revealed in the scrap and MU trend presented in Appendix A. The impact of non-systematic operating procedures is enormous when dealing with and accounting for raw material losses. This in turn contribute immensely to the human influences in raw material losses. Conscious effort must therefore be taken in other to ensure that standard procedures are created, followed, monitored and continuously improved on. Moreover, similar approaches were done at both case organisations in managing and optimising its machines processes. The output were steadier and more reliable SAP and fluff processes. Hence, this helped to ensure that the core mass were within specification limits and as close to the target value as possible.

5.2. Conclusions

The output of this multiple case study is gained from the interaction of the researcher with the stakeholders in the case organisations, and from whom the data presented were obtained. Literatures from relevant sources gave substantial backing to the study by presenting and synthesising previous studies done in the research areas. Data was collected from primary sources such as field observations,

The result reveals machine processes and human factor influences that affect material utilisation within the E2E supply chain processes. Solutions were recommended to the case organisations on further ways of improving the processes involved, thereby improving bottom line profitability. The results indicate that a holistic perspective of the totality of the supply chain operation is beneficial in other to unearth raw material losses.

The results also support the conclusion that when a rigorous but systemic approach is adopted in monitoring and controlling material utilisation efficiency, enormous benefits are foreseeable. However, a compelling strategy must precede such attainment in other to eliminate supply chain disruptions such as raw material stock outs, inefficient production forecast, huge waste to landfill and dwindling profitability. Hence, a top-down approach that is fully supported and driven by management must be developed using a standard-based model that is capable of operationalising such strategy in other to achieve a sustainable operation.

5.3. Limitations and Suggestion for Future Study

There are a few limitations in the findings of this multiple case study. The findings from this study mainly arises from the perspective of the researcher, of which may not necessarily represent that of the case organisations. Such views can create a bias, especially in the qualitative findings. Although the study should have followed an action research methodology in which there is a more collaborative effort of key stakeholders from the case organisations with the researcher, the latter had little support from the case organisations. This may result in outcomes that may solely be the bias of the researcher. A collaborative approach that involves the key stakeholders of the organisation will definitely improve the outcomes of future studies. Such implementation usually requires a systematic planning and implementation of action plans, and involves a cohesive team of professionals as a team of which the researcher is an active member. Another approach may be to interview the key stakeholders as a backing for the qualitative aspect of this research. This may enrich the research outcome in such a way that there is a balance of views both from the researcher and the case organisations.

The quantitative data presented for PCA has some degree of data limitation. This is because of the difficulty to physically deconstruct the samples in order to obtain the absorbent core. Hence, since computer simulations in Minitab® are used to generate quantitative data of the subgroups, it poses a validity constraint on the data analysed. Future studies should utilise a more realistic analysis that do not make use of computer simulations to reflect the real data.

Since the two cases understudied are the disposable diaper business, the difficulty in the generalisability and the applicability of the study findings to other industries aside those of the cases understudied is another limitation that ensued from this study. Hence, the approaches and result may not similarly be applicable to other industries and FMCG operations, which may therefore require a modification in its methodology and approaches. Suggestion for future study seek to involve other case organisation within and outside of the FMCG industries to validate the applicability of the study findings and enhance its generalisability.

Since the study requires several iterations that follows the plan-do-check-adjust cycle, time was a major constraint on the researcher. Hence, the action plans and solutions of the study were not thorough enough. A consideration of a longitudinal time horizon over a cross-sectional one will improve the validity and the correctness of the future studies.

5.4. Recommendations

Today, many organisations are advocating and driving towards the need for sustainable business practices due to the need to minimise waste and environmental risk impact, thus advancing the principles of sustainable supply chain. For the case organisations, it is however recommended that SAP extraction, recycling and reuse from scrapped product be fully utilised. Although this is being utilised in other manufacturing plants of the case organisations, it is yet to be implemented in the cases' facilities. This will ensure the recyclability and reclamation of SAP from scrapped products hence increasing its positive cost impact on the bottom line profits. However, it is suggested that the fluff return process from the rotary vacuum drum filters to the main lines be properly utilised as this will improve recyclability of fluff on a small scale.

Standardisation of material handling processes need to be created and enforced within both case organisations. For example, clamp force factor (CFF) should be determined for each of the raw materials in the organisations other to avoid excessive grip force by trucks that usually result in material damages. Other areas of standardisation is in raw material preparation and transportation that uses the right equipment and processes that minimises losses.

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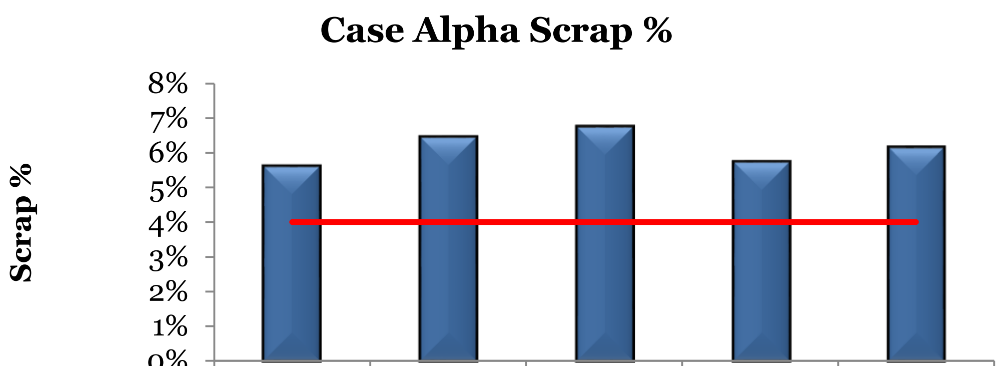
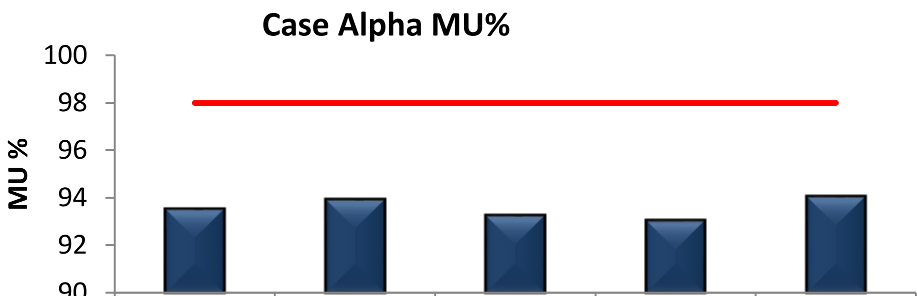
APPENDICES

Appendix A. **Case Alpha's Scrap and MU trend**



	Sept	Oct	Nov	Dec	Jan
Scrap (%)	5,62%	6,46%	6,76%	5,75%	6,17%
Target	4%	4%	4%	4%	4%

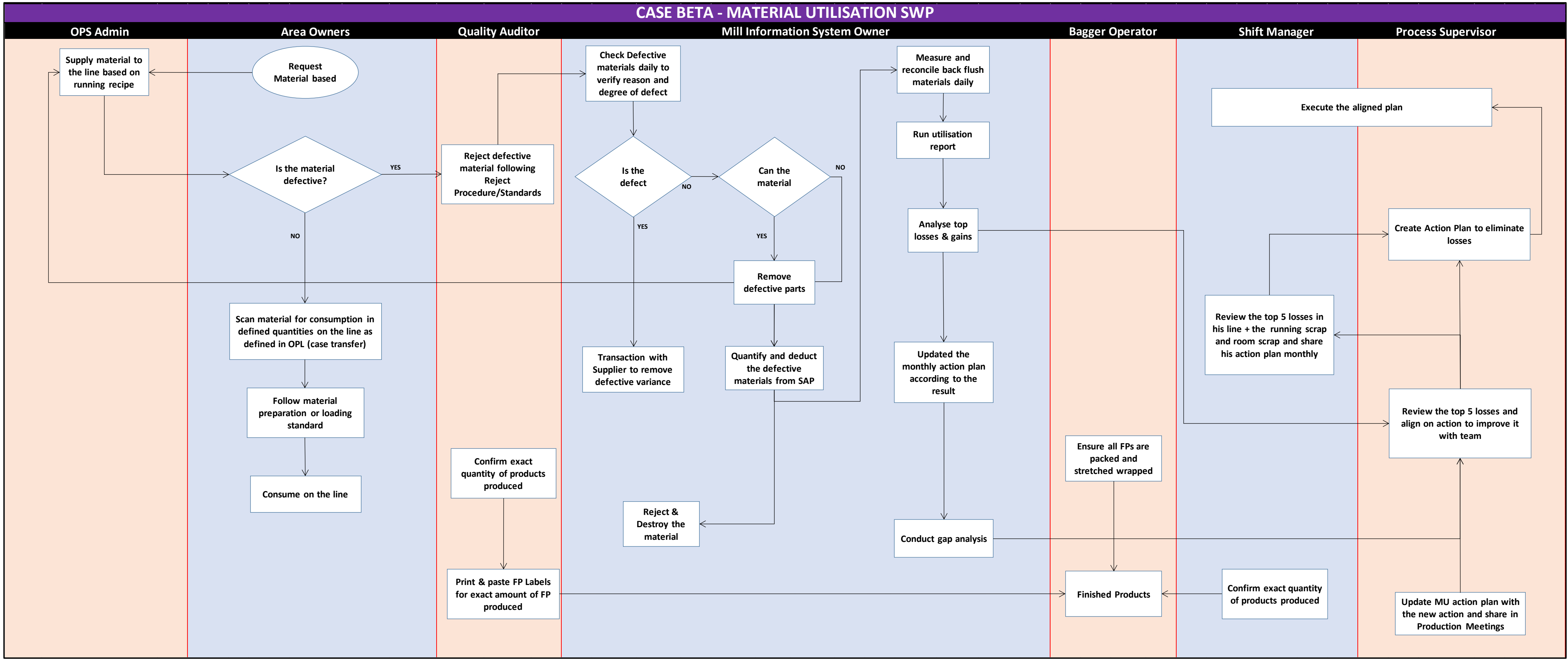


	Sept	Oct	Nov	Dec	Jan
MU (%)	93,53	93,93	93,24	93,03	94,05
Target (%)	98	98	98	98	98

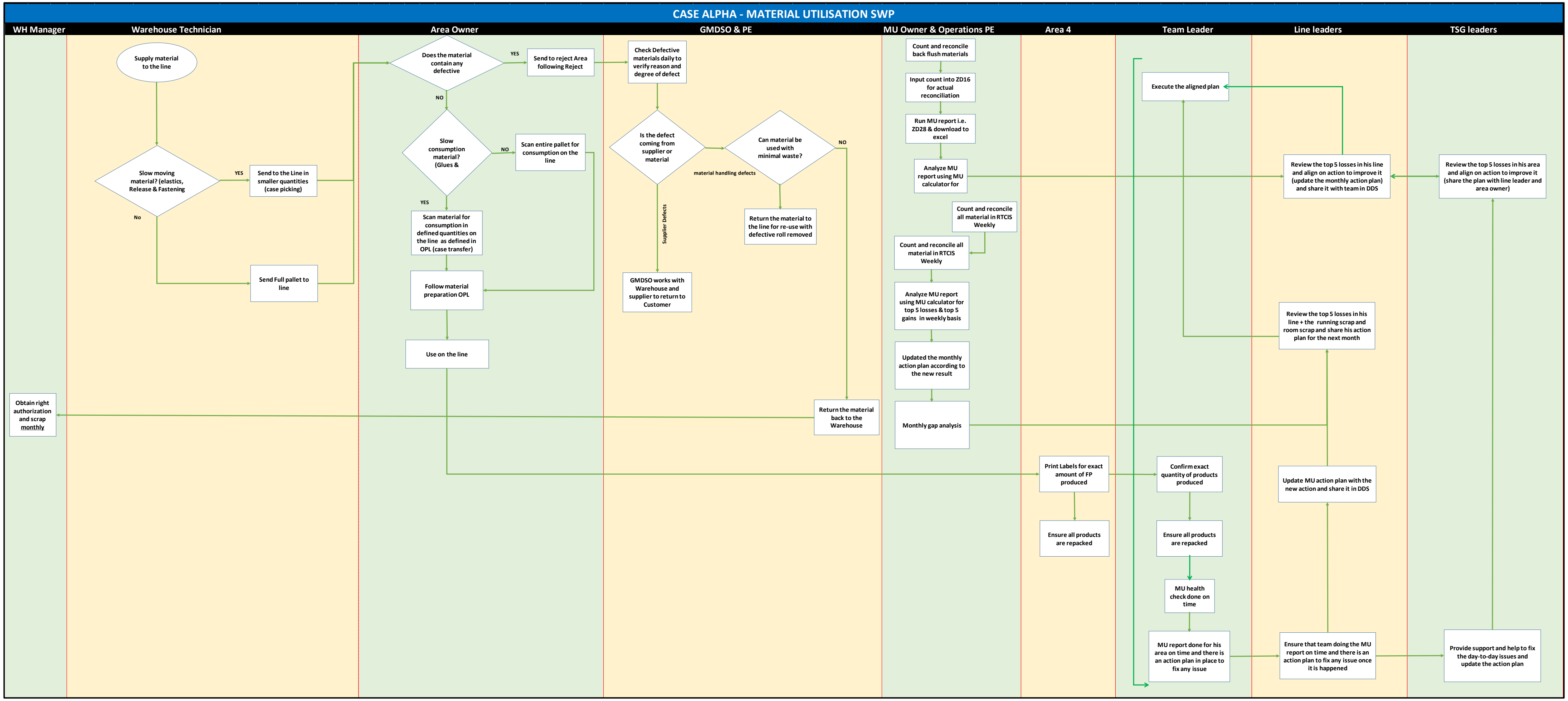
Appendix B. **Analysis of Loss Points**

Cat.	Loss Point	Ideal State	Action Required - Hypothesis to validate	Result of Cause-Effect Validation	Case Alpha	Case Beta
Master Data	Formular Card/Recipe	Formula cards are not over designed beyond what the consumer needs	Scrap factors are currently built into formula card for each raw materials	Scrap factors are built in the FC	**TRUE**	**TRUE**
	Bill of Materials (BOM)	BOM correspond with final product recipe	1. Validate that BOMs values don't match formula cards/recipe values	BOM values are different from FC values	**TRUE**	**TRUE**
		No scrap factors built into BOM's (ZERO) BOM= SF+FC	2. Scrap factors are at optimised levels for each material	SF needs to be reviewed as MU improves	**TRUE**	**TRUE**
Machine Optimisation	Raw Material consumption and Equipment Parameters	1. Only adds ideal amount of material to meet consumer needs with no excess.	1. Overdosage of raw materials exist at levels that are more than what is in the formula card	Material overdosage exists	**FALSE**	**TRUE**
		2. No material under usage. RMs usage is optimised as much as possible.	2. Equipments are optimised to run materials on target or within specification limits	Capability analysis of critical equipment	**TRUE**	**FALSE**
		3. No losses due to line processes and equipment parameters not in base condition	3. Splice diameters are within limits and as close to lower limit as possible.	Optimum splice diameters are set	**TRUE**	**TRUE**
			4. Line parameters run in base conditions	Equipments are in base conditions	**TRUE**	**FALSE**
Human Factors	Production	1. Room scraps are minimised. Product quality adhered to.	1. FP quality not compromised	High room scrap	**TRUE**	**TRUE**
		2. Material preparation and reject standard followed	2. Area owners follow material preparation procedure as outlined in the SOPs	Material preparation procedures are non-existent or not adhered to.	**TRUE**	**FALSE**
			3. Line reject standards thoroughly followed	Defective materials follow rejection standards	**FALSE**	**FALSE**
	Warehouse	Materials are handled correctly and according to SOPs, CBAs, WIs etc.	1. Damaged materials are not taken to the line	Damaged materials are often issued to be used on the production floor without taking out the damaged part	**TRUE**	**TRUE**
			2. Forklifts don't damage RMs. Clamps are installed to avoid core compression.	Fork lifts damage RMs due to improper handling and non-use of standard equipments	**TRUE**	**TRUE**

Appendix C. **Case Beta MU SWP**



Appendix D. **Case Alpha MU SWP**



Appendix E. **Overview of Case Alpha and Case Beta Supply Chain Operations**