UNIVERSITY OF DERBY

AN INTEGRATED DECISION SUPPORT FRAMEWORK FOR THE ADOPTION OF LEAN, AGILE AND GREEN PRACTICES IN PRODUCT LIFE CYCLE STAGES

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ABSTRACT

In order to stay competitive in today's overly competitive market place, businesses must be engineered to match product characteristics and customer requirements. This increased emphasis on achieving highly adaptive manufacturing with reduction in manufacturing costs, better utilization of manufacturing resources and sound environmental management practices force organisations to adopt efficient management practices in their manufacturing operations.

Some of the established practices in this context belong to the Lean, Agility and Green (LAG) paradigms. Adopting these practices in order to address customer requirements may require some level of expertise and understanding of the contribution (or lack of it) of the practices in meeting those requirements. Primarily, the wide choice of LAG practices available to address customer requirements can be confusing and/or challenging for those with limited knowledge of LAG practices and their efficacy.

There is currently no systematic methodology available for selecting appropriate LAG practices considering of the product life cycle (PLC). Therefore, this research provides a novel framework for selecting appropriate LAG practices based on PLC stages for reducing costs, lead time and generated waste. The methodology describes the application of analytic hierarchy process (AHP), statistical inference and regression analysis as decision support tools, ensuring a systematic approach to the analysis with appropriate performance measures. The data collected were analysed with the aid of SPSS and Excel using a variety of statistical methods. The framework was verified through a Delphi study and validated using a case study. The key findings of the research include the various contributions of lean, agile and green practices towards improving performance measures, the importance of green in improving performance measures and the importance of selecting appropriate practices based on product life cycle stages.

This research makes a clear contribution to existing body of knowledge by providing a methodological framework which could serve as a guide for companies in the FMCG industry to systematically integrate and adopt lean, agile and green to better manage their processes and meet customer requirements in their organisations. However, the framework developed in this research has not been tested in other areas.

Keywords: Analytic hierarchy process, Competitive, Product life cycle stage, Lean, Agility, Green.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3PL - Third Party Logistics

AHP – Analytic Hierarchy Process
ANP – Analytic Network Process

BOM – Bill of Material

CF – Conceptual Framework

DEA – Data Envelopment Analysis

DMU – Decision Making Unit

FANP – Fuzzy Analytic Network Process

FMCG – Fast Moving Consumer Goods

Institute of Operations Management – IOM

JIT – Just In Time

LAG - Lean, Agility and Green

LOA - Level of Awareness

MAA – Multi-Attribute Analysis

MAUT – Multi-Attribute Utility Theory

MCDM – Multi-Criteria Decision Making

NATA – New Approach to Appraisal

OD – Operations Director

PLC – Product Life Cycle

Sig. – Significance

SLR – Systematic Literature Review

SPSS – Statistical Package for Social Sciences

TOPSIS – Technique for Order Preference by Similarity to an Ideal Solution

UK – United Kingdom

VE – Value Engineering

VG – Virtual Group

LIST OF CONFERENCE PAPERS

Udokporo, C, Anosike, A and Lim M (2014), A Comparative Analysis of Agility and Sustainability, Proceedings of the 12th International Conference on Manufacturing Research Southampton, United Kingdom, 9th-11th September, 2014

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CHAPTER ONE

INTRODUCTION

This chapter outlines the background and research motivation, problem statement, research question, research aim and objectives, contributions to knowledge and the framework of the thesis. The objective of this chapter is to outline the reason why this research is being conducted through the presentation of the problem statement, and a brief explanation on how those problems are resolved. The research background explains why organizations need to continually evolve and assess their business practices in order to meet the challenges of the business environment. The background also presents a brief introduction of the lean, agility and green paradigms. The research aim is stated to show what this research believes addresses the problem presented in the problem statement and the objectives is an outline of the various means of achieving the research aim. This chapter also presents the contributions made to the body of knowledge as a result of conducting this research

1.1 Background

Today's business environment is characterised by the emergence of highly dynamic and cost driven global competition (Gecevska et al., 2012). Business innovation has to occur in all dimensions of the business – product, process and organisation – to improve competitiveness and business performance (Gecevska et al., 2012; Breznitz and Cowhey, 2012; Casadesus-Masanell and Ricart, 2010).

Increased competition and fluid customer expectations require organisations to endeavour to gain powerful competitive advantages in the market place (Pakdil and Leonard, 2014). Due to this increasing rate of competition, businesses in every sector are under increasing pressure to embrace change and continually assess their business strategies in order to exploit the rapidly changing market drivers. Some of these drivers include:

Changing customer requirements: Customers requirements have continued to be fluid over time and must be adequately responded to as they contribute to the dynamics of the market (Yau-Ren, 2003). These changes in requirements mean that product features have to change, improved or upgraded; new products have to be developed and introduced into the market. As a consequence, manufacturing strategies would have to evolve to meet these dynamics.

Demand uncertainty: Changes in customer requirements are closely related to the uncertainty of demand as customer orders received by companies may be high for a given period and low the next. Fast Moving Consumer Goods (FMCGs) are good examples of products with unpredictable demand (Farahani et al., 2013).

Product Life Cycles (PLC): PLC is made necessary as a result of the need for improved awareness on the volumes required to be produced and the competitive priorities of each product and the way all this changes over the product's life cycle (Luna and Aguilar, 2004; Aitken et al, 2002; Sharma, 2013). The high level of demand uncertainty in the FMCG industry (Aljunaidi and Ankrah, 2014) makes FMCGs particularly vulnerable to PLC changes. According to Sharma, (2013) companies, especially those in the FMCG sector who persisted with the consideration of the PLC concept had a better competitive advantage than those who did not.

Competition: The current market is also characterised by increasing competition from other companies producing similar products or offering similar services. This is certainly the case in the fast moving consumer goods (FMCG) sector, described by Oraman et al. (2011) as one of the most intense competition driven markets. The list of competitive options include among others price - which is affected by production costs, delivery speed, quality and product image (Tersine and Hummingbird, 1995). Also, these competitive options and priorities change as products proceed through their different product life cycle stages. Tersine and Hummingbird (1995) argue that since no organization can excel in all these factors simultaneously, the decision to focus on one or a mix of these factors provides a unifying directional force for competitive advantage.

Striving to be a low cost producer in volatile and price sensitive markets is a powerful competitive advantage (Collins, 2013; Mariano, 2015). On another hand, management of time, particularly lead time is believed to make a positive contribution to the competitive advantage of a firm (Al Serhan et al., 2015; Tersine and Hummingbird, 1995).

Environmental Sustainability: This is fast becoming an important corporate performance metric – one that stakeholders, outside influencers and even financial markets have started to monitor. As a result, there has been an increase in the influence of regulatory bodies and governments on corporate strategy. Businesses are put under pressure to take responsibility for the impact of their business decisions on the environment and apply measures to reduce such impacts. As manufacturers focus of environmental sustainability, the PLC concept becomes even more important (Madu et al., 2002).

Addressing the above mentioned concerns require effective levels of leanness, agility and the deployment of environmental management practices, as they are advocated as the foundation of competitiveness (Cabral et al. 2012; Espadinha-Cruz, 2011; Hasanian, 2016). The following sub-sections provide background information to each of lean, agility and green.

1.1.1 Brief background to lean

This research will use the terminologies lean manufacturing, lean, lean production, lean thinking and lean paradigm interchangeably. Lean concepts and production principles were introduced by (Womack et al., 1990). Drawing upon the experience of the Toyota production system (TPS), and international research in the motor industry, the authors promoted ‘lean production’ and its principles as a production system which uses less human effort in production, less production hours, less production space, less inventory and so on to achieve fewer defects, lower costs and overall efficiency in production (Lowson et al., 1999).

Lean operations with low inventory have become an essential practice to address operational concerns. Many organisations have adopted lean thinking in order to optimize performance and competitive advantage. But by itself, lean will not enable organisations to meet the precise needs of customers (Ravet, 2011), because a lean manufacturer whose primary goal is to be lean compromises responsiveness overall cost-efficiencies (Gunasekaran and Yusuf, 2002). Lowson et al. (1999) observes that complexity and dynamism are often conveniently side-stepped as lean proponents have its practices applied in industries exhibiting relatively stable demand patterns. Lowson et al. (1999) believe that companies will increasingly display less features of lean and move closer to achieving capabilities that enable them cope with multiple differentiation through promptly changing value chain configurations.

1.1.2 Brief background to agility

In recent times, the emergence of customer-driven markets has resulted in rapid changes to the strategies adopted by organisations. The agile manufacturing paradigm has sometimes been highlighted as an alternative to leanness (Richards, 1996). Agility is also referred to in this research as agile manufacturing, the agile paradigm and agility. The proponents of agility believe that lean production is no longer able to cope with new competitive environments (Lowson et al., 1999). The TPS was developed as a result of inability of the mass production system to cope with increasing variety. However, customer requirements have further evolved and this unpredictability in customer requirements has led to a complete re-adjustment in manufacturing approach (Lowson et al., 1999).

Agile manufacturing systems are adopted as a result of the constantly changing consumer market, particularly assembly systems at the final stage of product differentiation. The aim of the agile manufacturer according to Lowson et al. (1999) is to produce highly customized products at a cost comparable with mass production and within reduced lead times. This tailoring of products to customer demand involves a higher element of service, and thus adds greater value.

1.1.3 Brief background to green

Changes in the legislation and regulations governing the environment-including non-renewable energy resource constraints and pollution, coupled with increasing pressure from stakeholders have resulted in organizations developing greater environmental responsibility (Martínez-Jurado and Moyano-Fuentes, 2013). Organizations are now increasingly expected to take responsibility for the impact of their business decisions on the environment and apply measures to reduce such impacts. Some innovation must also occur to meet these environmental demands as non-compliance might have legal consequences (Global Innovation Barometer, 2013). Green, green manufacturing, green management, clean manufacturing, environmentally conscious manufacturing, sustainable manufacturing and environmental management are terminologies often used in literature to refer to environmentally sustainable manufacturing/management.

Cortellini (2001) in Rehman and Shrivastava, (2012) defined green as a method of manufacturing that reduces waste and pollution, slows the depletion of natural resources and lowers the amount of waste that goes to landfill. Green manufacturing addresses issues including recycling, conservation, waste management, regulatory compliance, environmental protection and a variety of other related issues (Rehman and Shrivastava, 2012). Many companies consider green manufacturing as an essential part of economic development and a requirement to remain competitive in business (Rehman and Shrivastava, 2012).

Existing research on lean, agility and green (LAG) argues that they should be considered in an integrated approach in order to harness and possibly unify their individual benefits (Hasanian and Hojjati, 2016; Espadinha-Cruz et al., 2011).

1.2 Problem Statement

Unifying these paradigms requires a means of identifying which paradigm or combination of paradigms is applicable or suitable given a set of business circumstances. A number of researchers have proposed approaches for selecting applicable paradigms, however, there is no clarity regarding the specific practices of these paradigms to be adopted (Luna and Aguilar Saven 2004; Naim and Gosling, 2011 and Vinodh, 2010). By paradigm level, this research means discussions on lean, agility and green that does not involve the individual known/identifiable practices of lean, agile and green. Known/Identifiable practices lean practices would include practices such as Kanban, just-in-time, cellular manufacturing, and so on. Some researchers have proposed approaches with some support for adopting individual practices, but have focused mainly on lean and agility without considering green practices (Agarwal et al., 2006; Aitken et al., 2002). Other researchers have gone as far as considering the three paradigms with some direction on adopting specific practices (Cabral et al., 2012; Cabral et al. 2011a.; Cabral et al., 2011b; Hasanian and Hojjati, 2016; Azevedo et al. 2012; Espadinha-Cruz et al., 2011) but have not considered the product life cycle.

The PLC concept is important because like biological life, product life progresses through different stages and would require different strategies to deal with the products at their different life cycle stages. The research problem identified is that it is challenging to identify the most appropriate LAG practices within specific product life cycle stages. In order to synthesize a common focus of product life cycle in the adoption of optimal LAG practices, it is necessary to develop a structured and integrated methodology. However, no such methodology currently exists.

This research addresses this problem by providing a systematic methodology that acknowledges the contribution of LAG practices to reducing costs, lead time and waste at each stage of the PLC and integrating both qualitative and quantitative elements. As the FMCG sector is one of the sectors with inherent intense competition (Aljunaidi and Ankrah, 2014), research addressing this in the FMCG sector is necessary but scarce.

The FMCG industry is one of the largest manufacturing industries in the United Kingdom (UK) (Found and Rich, 2007) contributing more than 8% of the UK's Gross Domestic Product (GDP) (Aljunaidi and Ankrah, 2014). Found and Rich, (2007) posits that the most significant difference between the FMCG industry and the automotive industry, is the long setup and changeover times, hence the proclivity in the FMCG industry to produce in large batches. The FMCG industry is also characterised by high volume production and high product variability since. This increases the need to cover a large product portfolio just to keep up with the competition (Francis, Dorrington and Hines, 2006 cited in Aljunaidi and Ankrah, 2014). As a consequence of these characteristics, some of the challenges faced by FMCG manufacturers include the following:

- Competition and low cost production - Efficiently serving increasing customer expectations is a critical challenge in the FMCG industry (Farahani et al., 2013). Farahani et al. (2013) also believe that high competitiveness means that production has to be achieved at minimal cost.
- Long lead times – FMCGs present networks with long and variable lead times. Long set-up and change-over times also contribute to the long lead times observed in FMCG's (Aljunaidi and Ankrah, 2014; Farahani et al., 2013).
- Environmental waste management – Due to the sheer size of the FMCG industry, coupled with the need to ensure competitively high service level and product availability, FMCG manufacturers often end up with a remarkably large amount of damages and returns (Farahani et al., 2013). Also, the use of retail packaging could raise environmental waste management concerns.

Considering these challenges, the FMCG industry presents a unique opportunity to explore this area of research – adoption of lean, agile and green (LAG).

1.3 Research Aim and Objectives

The aim of this research is to develop an integrated decision framework that supports decision making in selecting the appropriate combination of lean, agile and green practices in product life cycle stages for organizations to improve competitiveness and environmental performance. This was achieved through:

1. Carrying out desk research to identify the lean, agility and green practices applied in industry.
2. Carrying out field research to:
    - identify the lean, agile and green practices operated in industry;
    - determine the life cycle stage of selected FMCGs;
    - identify the manufacturing strategy (mix of lean, agility and green practices) adopted for the products given their life cycle stage;
    - investigate the contribution of Lean, Agility and Green practices to cost reduction, lead time reduction and waste generated at PLC stages.

3. To develop a decision support framework for selecting the right mix of lean, agile and green practices that reduce costs, lead time and waste at each stage of the PLC.

4. To verify and validate the LAG selection framework.

1.4 Contributions to Knowledge

By achieving the above research objectives, this research aims to make the following contributions:

- Development of a decision support framework for selecting appropriate lean, agile and green practices taking into account the product life cycle. This is the key contribution of the research because so far, this has not been done as demonstrated in the literature review presented in CHAPTER TWO.

- Identification of the lean, agile and green practices used in the FMCG industry

- Development of Analytic Hierarchy Process (AHP)-based framework for selecting lean, agile and green practices

- Development of a model for evaluating the impact of selected LAG practices on performance measures.

1.5 Thesis Structure

This thesis is designed and structured to comprise seven discrete but successive chapters. A brief summary of the content of these chapters is described as follows:

Chapter One – *Introduction*: introduces the problem being researched and provides the reason for pursuing this interest. The chapter also includes aim and objectives, background to Lean, Agility and Green and knowledge contributions.

Chapter two – *Literature review*: reviews the literature related to the three different management paradigms namely Lean, Agility and Green. A characterization of the practices associated with each paradigm as well as the limitations of each. In addition, the literature review presents the measures of competitiveness adopted in this research and the contributions of Lean, Agility and Green practices towards achieving competitiveness as defined in this research. Lean, Agility and Green combinations, frameworks and their limitations are also presented in the literature review in order to identify the gap in literature and justify the need for this research. More importantly, this research describes the product life cycle (PLC) concept and the role it plays in the context of this research the importance of considering it in the adoption of LAG is also presented. The outputs from chapter two helped in the conception and development of the research hypothesis and sub-hypotheses presented in CHAPTER FOUR.

Chapter three – *Research methodology*: provides a brief background on the thesis research paradigm and general methodological approach. The chapter also reviews, justifies and discusses various aspects of the employed methodology. Arguments are presented justifying this choice of a conciliatory approach and the specific research methods applied to collect data. The data collection process is also detailed in this chapter.

Chapter four – *Pilot and main survey analysis*: presents the results of the pilot and main survey analyses. Results of hypotheses tested in this research are also presented herein. The chapter also investigates the contribution of LAG practices towards improving performance measures.

Chapter five – *Conceptual framework*: is devoted exclusively to the development of the conceptual framework for selecting the most appropriate Lean, agile and green (LAG) practices for each product life cycle stage. It also presents the development of the regression model for the appraisal of the effect of the practices the performance measures.

Chapter six – *Verification and validation*: presents the verification and validation of the framework, which was done using Delphi study, face validity and case study analysis; the conceptual framework already developed and presented is put to work using a case study. The information used for the case study was provided by high ranking staff member in the participating company. It investigates the usefulness of the framework. Experienced professionals in both academia and industry made useful input used in the validation of the framework to determine its feasibility, practicality and usefulness.

Chapter seven – *Discussion*: presents a philosophical synthesis based on reviewed literature and the findings as a result of this research.

Chapter eight – *Summary and conclusions*: presents the concluding remarks and contains an overview of the thesis and its main results.

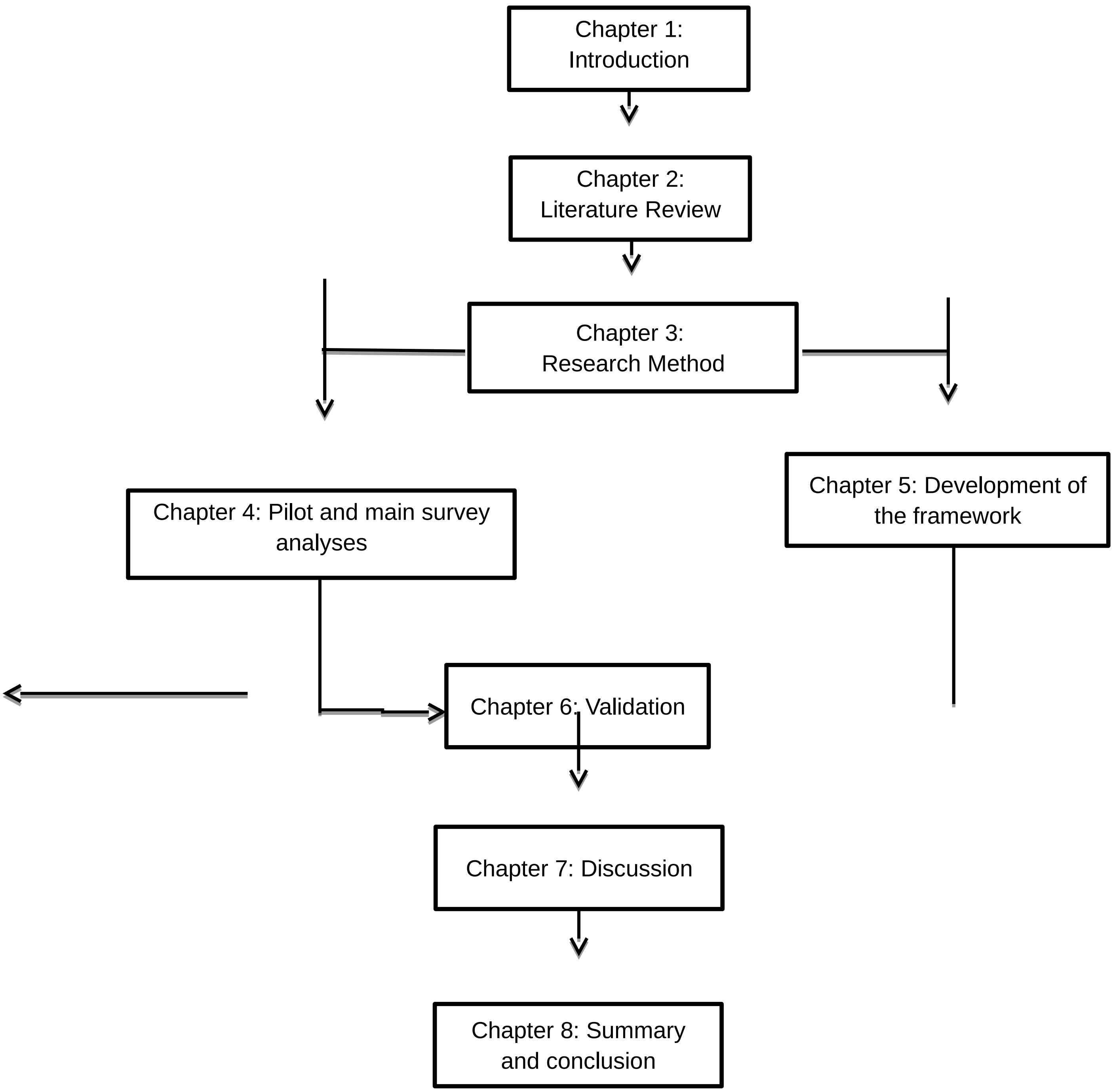

Figure 1-Thesis Framework

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

2.1 Introduction

In today's competitive environment, companies are required to improve their performance, to respond to market demands in various dimensions, such as enhanced product quality, quicker lead times, lower costs and improved environmental performance. The lean, agile and green (LAG) paradigms are advocated as the foundation of a competitive manufacturing business (Cabral et al. 2012; Espadinha-Cruz, 2011; Hasanian, 2016). This chapter examines the literature and provides an insight into the literary contributions made towards the lean, agility and green paradigms in order to provide a background as well as an understanding of the paradigms being studied as well as their combinations. The next section provides a background as well as an understanding of the practices of Lean, agility and Green and the product life cycle concept. This research argues that the PLC should be considered in the adoption of LAG. Section 2.3 provides a systematic literature review (SLR) of existing literature on LAG aimed at providing guidance on the topic and providing more clarity on the scantily explored dimensions and uncovering gaps in the literature. Section 2.4 presents existing frameworks/methods/processes and highlights the limitations of those, collates the key limitations of existing works and discloses the gap in knowledge which this research works to fill. Section 2.6 discusses the measures of competitiveness and the impact of Lean, Agility and Green on measures of competitiveness. Section 2.7 presents the research hypothesis which is as a result of the impacts of Lean, Agility and Green on measures of competitiveness. Section 2.8 presents a summary of the chapter.

This chapter also offers a systematic review of existing literature on Lean, Agility and Green, aimed at providing guidance on the topic, providing more clarity on the scantily explored dimensions and uncovering gaps in the literature.

2.2 Background

This section provides a background of the Lean (2.2.1), Agility (2.2.2), Green (2.2.3) and product life cycle (2.2.4).

2.2.1 Introduction to Lean

The Lean paradigm is an evolution of the Toyota production system (TPS) through the work of Ohno (1988) in Japan between 1948 and 1975. However, it was Womack and Jones' *the machine that changed the world* that consolidated the tools and techniques used in the TPS. The book chronicled the operations identified in the auto industry, capturing the differences in approach and subsequent performance found among the world's leading automakers.

Toyota is arguably the leading lean auto manufacturer in the world, only recently slipped behind Volkswagen in terms of overall sales (Tovey and Bloomberg News, 2017) and poised to become the largest automaker in the world once again. Its dominant success in everything from rising sales and market shares in every global market, and a market leader in hybrid technology, stands as the strongest proof of the power of lean enterprise. Lean production has since become increasingly popular among manufacturing firms and has been adopted in other industries.

Womack et al. (1990) defined lean manufacturing as the systematic elimination of wastes from an organisation's operations through a set of synergistic work practices to make products and services at the rate of demand. Lean manufacturing originates from the Toyota production system which is often referred to as just in time (JIT) production.

The aim of Lean is the total elimination of wastes (Lu, 1989). Waste is defined as any non-value adding activity (Harrison, 1992). Liker, (1997) defines waste as anything that impedes the flow of production. Toyota identified the following seven categories of waste which have been found to apply in both service and production (Lu, 1989; Harrison, 1992):

1. *Overproduction*: Identified as waste arising from overproduction, which includes producing too early and/or too much.
2. *Waiting*: Waiting time is a lean waste created in situations when a worker stands idly by an automated machine while it is in cycle to serve as a watchman or when the worker cannot physically do anything as a result of the machine being in cycle.
3. *Transport*: The waste arising from transporting refers to waste caused by item being moved a distance unnecessarily, rearranged or stored temporarily.
4. *Process*: The waste arising from inappropriate/over processing such as making things too complicated. This type of waste could occur by making use of inappropriate tools such as cracking a nut with a sledge hammer.
5. *Inventory*: Waste arising from inventory refers to keeping stock unnecessarily. This kind of waste is particularly unhealthy as it is used to conceal production problems

such as equipment breakdowns, lengthy setup times and poor coordination between processes.

6. *Motion*: Examples of waste arising from motion include going to the supervisor's office, looking for a tool, reaching, poor housekeeping and so on.
7. *Defective goods*: Waste arising from defective goods occurs when a product is not made to the customer's specification. It involves not doing it right the first time which then prompt reworking.

To eliminate Lean wastes, a number of practices have been developed. Some of the notable Lean practices are presented herein.

2.2.1.1 Lean production practices

Lean practices according to Mirdad and Eseonu, (2014) are those lean tools and techniques that improve process flow and achieve performance improvement through the elimination of wastes. Therefore it can be said that lean manufacturing is a very significant productivity improvement technique whose benefits can be described as the reduction of wastes in an organization (Fullerton, et al., 2003). There are many lean tools and techniques which help manufacturing organizations to apply best manufacturing practices (Mirdad and Eseonu, 2014; Shah and Ward, 2007; Tiwari, et al., 2007). It would benefit organizations if they choose the most appropriate lean practices that are ideal to their manufacturing needs. Successful application of lean practices requires functional understanding of the key operational tools of lean manufacturing. The lean tools used in this thesis are adopted from other research (Shah & Ward, 2003; Amin & Karim, 2011; Sahin, 2000; Lowson and Robert, 2001; Zsidisin et al., 2005; Daisy 2011; Han et al., 2013; Diaby et al., 2013; Cruz, 2012; Kakish and Yousef, 2012; Found and Rich, 2007; Aljunaidi and Ankrah, 2014; Fullerton and McWatters, 2001). They are presented in section 4.3.1. However, it is often difficult to select a proper tool from the list of large number of lean tools to address particular concerns. Below is a summary of some of the notable lean practices/strategies.

5S: Eliminates waste that results from a poorly organized work area (e.g. wasting time looking for a tool). 5Ss refer to five terms beginning with the letter "s". They are Sort, Set-in-order, Shine, Standardize and Sustain.

Just-in-Time (JIT): JIT manufacturing is a management concept which assures improvement through elimination of wastes like waiting time and overproduction. It is a method that ensures the production of the right items at the right time and at the right quantities (Womack and Jones, 2003). JIT is highly effective in reducing inventory levels. It helps to improve cash flow and reduce space requirements. The following are necessary to achieve JIT: Group technology, set up time reduction, kanban, uniform workload, quality control, quality circles, total preventive maintenance, multi-function employees (Amin, 2013).

Kanban: This is a Japanese word meaning ‘card’ or ‘visible’. Kanban is a signalling card which has information about amounts of product to be produced, origin of the product, and destination of the product (Amin, 2013). The Kanban methodology is designed to make material handling and inventory management easier.

Total Quality Management (TQM): TQM is defined as a process that improves the quality of a product by continuous improvement in the manufacturing process through effective feedback from employees (Bayazit and Karpak, 2007).

Cellular Manufacturing: Lean operations support a physical layout of the production facility that facilitates a streamlined one-piece process flow. Cellular Manufacturing is one such process in which equipment and workstations are arranged in a sequence such products with similar processing requirements are grouped together in a ‘cell’ (Prince and Kay, 2003). This supports a smooth flow of materials and components through the process with minimum transport or delay (Suzaki, 1985).

Single Minute Exchange of Die (SMED): SMED refers to the theory and techniques for performing setup of operations in less than ten minutes. Not every setup time can be realistically reduced to less than ten minutes, but the goal of SMED is to reduce the setup times to single digit (Amin, 2013). SMED is applied when there are varieties of products to be produced in a single production line. SMED reduces setup time and increases production flexibility.

Total Productive Maintenance (TPM): TPM emphasizes proactive and preventative maintenance to maximize the operational efficiency and reliability of production equipment (Smith and Hawkins, 2004 cited in Amin, 2013). It is a method used to improve overall efficiency of equipment through a complete and regular productive maintenance system of the equipment, with participation of all employees from higher management to employees. The goal of TPM is to reduce equipment breakdowns, defects and safety problems (Ahuja, 2011; Fullerton and McWatters, 2001).

2.2.2 Introduction to Agility

The origins of agility as noted by Richards, (1996) dates back to the 1950’s in the field of air combat where it was viewed as the ‘ability of an aircraft’ to change manoeuvre state, or, simply put, the time derivative of manoeuvrability. The US Army defines agility as the ability of friendly troops to act faster than the adversary (Aviation Brigades, 1997). In 1991, researchers at the Iacocca University formally launched agile manufacturing to help companies evolve methods for making products in accordance with customers' dynamic demands without compromising quality, productivity and profitability (Devadasan et al., 2012). Agile manufacturing concepts have been adopted by companies all over the world for goods production and the delivery of services.

Agility is defined by Kidd (1994) as a quick response to unexpected and unforeseen and changes adapting enterprise elements to meet those changes. It is considered to be one of the concepts that possess the ability to respond to change in rapidly differing environments (Sherehiy et al., 2007). The same author forged an understanding of Agility by distinguishing 'flexibility', 'adaptability' and 'agility' arguing that it constitutes the gradual development of the idea of the enterprise's ability to adjust to changes. Much of the work that has been done on agility is mostly in the area of agile manufacturing. Yusuf et al. (1999) defines manufacturing agility as the ability to survive and thrive in an environment with rapidly changing circumstances by reacting quickly and effectively to the changes, driven by customer-defined products and services. Qumer and Henderson-Sellers (2008) presented a more robust definition of agility as a persistent capability of a characteristically flexible entity to rapidly cope with expected or unexpected changes, follow the shortest period, and utilise economical, simple and most effective instruments in a dynamic environment. To become agile, a number of practices have been developed in literature and discussed herein.

2.2.2.1 Agility Practices

Several researchers presented their understanding of how agility works in practice including identification of appropriate attributes, characteristics, practices and capabilities. Yusuf et al. (1999) identified some 'competitive foundations' of agility which they believe are the absolutely essential attributes of agile manufacturing. The competitive foundations are speed, flexibility, innovation, proactivity, quality and profitability.

Burgess (1994) presents some IT-enabled strategies for achieving agility and identified five stages depending on the form of the manufacturing outcomes. These stages are given as business process redesign (BPR), internal integration, localised exploitation, business network redesign and business scope redefinition.

Having analysed top 10 agile businesses, Martin (2009) identified the following as the characteristics of agile organisations: their processes are closely aligned to the company's value proposition; they are responsive; they are less complex and their supply chains are customer driven

Other researchers have also identified several attributes, characteristics and practices including new product development (Gunasekaran, 1999); virtual enterprise (Denning, 2012); effectiveness and flexibility (Eric Owen and Mike Cansfield, 2013)

According to Sharifi and Zhang (1999), the capabilities that an agile organisation should have in order to make appropriate response to changes taking place in its business environment, are basically divided into four major categories as presented below:

Responsiveness: Which is the ability to identify changes and quickly respond to them, reactively or proactively, and recover from them. Responsiveness involves:

- Sensing, perceiving and anticipating changes;
- Immediate reaction to changes;
- Recovering from changes.

Competency: Which is the extensive set of abilities that provide productivity, efficiency, and effectiveness of activities towards the aims and goals of the company. Competency involves the following:

- Strategic vision;
- Appropriate technology or sufficient technological capability;
- Products/service quality;
- Cost- effectiveness;
- High rate of new products introduction;
- Change management;
- Knowledgeable, competent, and empowered people;
- Operations efficiency and effectiveness (leanness);
- Co-operation (internal and external);
- Integration.

Flexibility: Which is the ability to process different products and achieve different objectives with the same facilities. Flexibility involves the following:

- Product volume flexibility;
- Product model/configuration flexibility;
- Organisation and organisational issues flexibility;
- People flexibility.

Quickness: Which is the ability to carry out tasks and operations in the shortest possible time. Quickness involves:

- Quickness in new products time-to-market;
- Quickness and timeliness in products and services delivery;
- Quickness in operations (short operational lead-times).

Carvalho and Cruz-Machado (2011) and Cabral et al. (2012a) listed the following agility practices: inventory in response to demand, excess buffer capacity, quick response to consumer needs, total market place visibility, dynamic alliances, supplier speed, flexibility and quality and shorter lead times.

Ravet (2011) identified some more examples of agility practices as follows:

- Suggestion of additional inventory buffers;
- Spare capacity;
- Postponing product customisation;
- Market sensitivity: ability to read and respond to real demand;
- Information-based virtual environment;
- Process integration.

2.2.3 Introduction to Green (Environmental Sustainability)

Green is one of the three pillars of sustainability, the other two are economic and social. A number of terms are currently used in literature to describe environmentally friendly activities, example green, sustainable manufacturing, green manufacturing, environmental sustainability, environmental management and so on, these will be used synonymously in this thesis.

The definition of green manufacturing centres around the minimisation of environmental impact by the reduction of toxic waste, waste, pollution, the optimisation of the use of raw material and energy by the application of end of life (EOL), cradle to cradle and close loop approach (Rehman, 2012).

The concept of green manufacturing originated in Deutschland in the early 1980’s and early 90’s. At that time, it had been established that any enterprise wishing to compete globally must begin to make products which comply with the green regulation of the European market (Rehman, 2012; Porter and van der Linde, 1995 in Yang et al., 2011). From the 1980’s onwards, activities in sustainable manufacturing started to focus on waste reduction in production. Beyond this time, the concept of green manufacturing had evolved from process oriented to product oriented; focusing on reduction of resources, energy and toxic materials, as well as the development and use of renewable materials Seliger et al. (2008) in Rehman (2012).

Environmental sustainability is being incorporated with management as well as manufacturing strategies in many industry sectors recently in order for organisations to meet their environmental obligations and forge a competitive business edge. In this regard, a good manager will be able to pull ahead of inferior colleagues as long as measures adopted are proactive (Koechlin and Müller, 1992). Environmentally sound management therefore means understanding the complex interrelations and systems relevant to an enterprise. Even when products are in their planning stage, ways and means of disposing of them at the end of their useful lives (EOL) must be sought (Koechlin and Müller, 1992). Koechlin and Müller (1992) further posits that environmental consciousness, or rather the lack of it will eventually be the downfall of the manager who is no more than a highly specialized financial expert or production manager, while opening up unlimited opportunities for those blessed with it.

Koplin et al. (2007) argue that it is necessary to incorporate environmental sustainability issues into supply chain management. They analysed the impacts of environmental guidelines on purchasing decisions of a focal company in the car industry. Dayna and Damien (2005) believe that environmental standards constitute part of the requirements demanded from suppliers who aim to minimise the use of natural resources and of environmental risks by improving the efficiency of suppliers.

Sloan (2010) set out to answer the question, “does improving one dimension of sustainability for one link in a supply chain actually increase the overall sustainability of the entire chain?” (Sloan, 2010, p.2). And also to address assessment issues for industries, economies and countries. Sloan (2010)’s question could be adopted to answer the question, does improving environmental performance in one area (say energy use) improve the overall environmental performance of an enterprise?

In 2009 General Motors (GM) initiated a project to benchmark existing metrics in the market, dealing with sustainable manufacturing. The best metrics, comprising expenditure and benefit, were implemented and considered as GM Metrics for Sustainable Manufacturing (GM MSM). (Chen et al., 2013)

The logistics industry for instance works on such a tight schedule as charges have to be practical for the logistics manager who needs to meet targets and may not place adequate priority on green initiatives especially as the benefits may not likely be realised until the medium or longer term. However, for the hard-pressed logistics enterprise, using less energy lowers cost and grows profit (Why Green Energy Is Not a Luxury Item, 2014). For this reason and more, green technologies have continued to emerge to aid organisations in meeting their environmental obligations. TNT Express for one, recently announced plans to double its use of zero emission delivery vehicles deployed across London (Delivering Carbon Reduction, 2014). In 2008, the UK's Technology Strategy Board launched the Ultra Low Carbon Vehicle (UCLV) demonstrator programme as the first significant step in a country-wide journey to encourage the development of technologies and markets for ultra low carbon vehicles (Driving Forward Green Transport, 2014). A number of practices have been developed in literature to address environmental concerns, a summary of some of these practices are presented below.

2.2.3.1 Green practices

There are several definitions for green practices in literature. According to Sroufe (2003) green practices refer to a set of programs to improve the environmental performance of processes and products in the forms of eco-design, recycling, waste management and life-cycle analysis. Mark et al. (2011) agrees with the definition adding that green practices can be categorised as activities undertaken by an enterprise in order to achieve greater efficiency in their use of resources as well as reducing the production of pollutants Mark et al. (2011). These practices could vary between industries and produce different results among them. For instance, a car manufacturing company will have/adopt green practices different from a paper making company. A wide range of green practices have been identified in literature and some of them have been presented in section 4.3.1.1 of this thesis. Some general green practices may include the following Mark et al. (2011):

Reducing production inputs - Alternative materials could be sourced and used. For instance, the use of metal alloys and combinations that are lighter, yet tougher than iron.

Improving the efficiency of facility operations - Plants may be modified to reduce the use of resources.

Improving products to reduce impact in use and at the end of life - Greener products may enhance competitiveness. Products are also increasingly being made recyclable and upgradeable in order to extend their useful life.

Carvalho and Cruz-Machado (2011) and Cabral et al. (2012a) listed the following green practices: reduction of redundant and unnecessary materials, reduction of replenishment frequency, integration of the reverse material and information flow in the supply chain, environmental risk sharing, waste minimisation, reduction of transportation lead time and efficiency of resource consumption.

Decision making with regard to the green practices adopted is crucial because according to Amani et al. (2015) waste is generated by a cause related to other process steps than where the waste is detected.

2.2.4 Introduction to product life cycle (PLC)

The Life cycle (LC) concept was originally conceived in the context of biological studies and has now become extensively adopted as a model for interpretation and analysis of phenomena typified by processes of change. The application of life cycle theory to the development of industrial products has become an important factor in the management of technological innovation (Giudice et al., 2006). In this context, it is referred to as product life cycle (PLC). The PLC concept is used as a decision making tool in the management of product development. It may also be applied to corporate strategy development as well as the planning of activities at a tactical level (Polli & Cook, 1969 cited in Horvat, 2013). Hofer and Schendel (1978) in Fullerton et al. (2003) argue that the PLC is the fundamental variable in determining a workable business strategy.

PLC is used to describe the behaviour of the product from development to retirement in order to maximise the value of and the potential for profit in each phase of the cycle (Ryan and Riggs, 1996). While the product is in the market, these phases include: introduction, growth, maturity and decline as shown in figure 2.1 (Fullerton et al., 2003).

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Figure 2.1: Classical PLC curve taken from Wiley college document (2001)

Introduction: This stage takes place when a new product is first made available for general purchase in the market (Robinson Jr. and Pearce II, 1986). The customer starts to see the product as it is after it has been launched. This stage requires significant investment as the product has to be given the best chance of yielding financial returns. This stage is characterised by small market, low sales as could be observed by a gentle upward slope in the classical PLC curve, high cost of research and development come into play here. The initial parts of this stage is also characterised by losses encountered before a substantial gains are made as the product begins to sell. This stage may also be characterised by high price and very little competition. Aitken et al. (2003) states that key order winner at the introduction stage is lead time (from concept to availability of design) and capability of design.

Growth: A sharply rising PLC curve is indicative of the rapid gains that a product experiences as it enters this phase (Robinson Jr. and Pearce II, 1986). Aitken et al. (2003) states that this stage is characterised by increase in demand and that the key order winner is service level (in terms of availability of the product responding to unpredictable demand). Customer demand could be generated here through the use of marketing and promotional activities. This stage is also characterised by increase in competition (as demand starts to increase), lower prices (due to competitors entering the market), reduced support costs (due to production increasing to meet demand), increase in profits (as a result of reduced costs).

Maturity: At this stage, the PLC curve is observed to start flattening out, companies are concerned with maintaining their market share; the existence of the product is not given a second thought as a result. The maturity stage is said to last longer than others (Robinson and Pearce II, 1986) and is characterised by a decline in sales, intensified competition, decreasing market share, decreasing profits, further reduction in costs, innovation (aimed at increasing market share). Aitken et al. (2003) argues that the key order winner is cost after the product at this stage has been pushed to a Kanban supply chain.

Decline: At this stage, the market becomes saturated, demand for the product and hence sales begin to tail off, though the rate of decline can differ dramatically from one product to another. Drop in sales for some products may approach zero, whereas others remain at a stable low level for longer periods (Robinson Jr. and Pearce II, 1986). These differences indicate that the end of the PLC curve may take on a variety of shapes. This could be called the beginning of the end of the product. At this stage, costs reduce even further, demand reduces, the market is in decline as even competitors begin to withdraw, sales volume drop, profits are affected and the product is eventually retired.

Considering these stages, the objective of the product life cycle theory is to describe the behaviour of the product from introduction until it is retired, in order to optimise the value of and the potential for profit in each phase of the life cycle. This helps guide the managers' decisions regarding possible intervention.

2.2.4.1 Importance of PLC

The importance of the product life cycle is reflected in the fact that it points to market opportunities and threats that may have strategic implications. The product life cycle is a versatile framework for forming contingent hypotheses about appropriate strategy alternatives (Hofer 1975 cited in Day, 1981) and directing management attention toward anticipation of the consequences of the underlying dynamics of the market being served. Hayes and Wheelwright (1979) argued that the PLC concept does provide a useful and provocative framework for a meaningful consideration of the growth and development of a new product, a business, or an entire industry. The same author proposed the consideration of the process life cycle over PLC in his product-process matrix concept which is capable of showing how a company's position reflects its weaknesses and strengths; they also discussed the implications for corporate strategy. However, they acknowledged that there are several dynamic aspects of corporate competitiveness where the concepts of matching the product life cycle with the process life cycle can be applied. Nadeau and Casselman, (2008) believe that different competitive advantages are required at different stages in the PLC.

A firm's production volumes and competitive preferences change as the product progresses through its life cycle stages (Luna and Aguilar Saven, 2004). Therefore, PLC needs to be considered as a necessary factor in deciding on a befitting manufacturing strategy and this implies that failing to consider the PLC could lead to superfluous short-term investment on the one hand and high production cost on the other (Luna and Aguilar Saven, 2004).

Horvat (2013) explored the chances of using the PLC concept in private label management. Given that private labels are a particular brand type, it is necessary to adjust certain features of the product life cycle concept, as it was developed on the basis of manufacturer brands. For instance, during the growth stage of the PLC, retailers expand private labels to a number of product groupings and use the push strategy while manufacturers tend to widen their distribution network in the expansion of their brands and principally use the pull strategy in doing so. Also, there is a shift in focus from low-price strategy, mostly used in the introduction phase, to improving the quality and private label value in the subsequent stages of the PLC (Horvat, 2013).

Rink (1976) emphasized the importance of considering the application of the PLC concept by purchasing executives as increasing demands on cost reduction, supply continuity and materials quality coupled with rapidly changing technology and intensifying competition have significantly widened the scope of procurement, and elevated its importance at the corporate level (Rink and Fox, 2003).

In terms of environmental sustainability, environmental pollution can be generated throughout all the stages of a product's life cycle (Zhu et al., 2005). Mason et al. (2008) believes that an integrated vision is therefore required instead of a focus on achieving islands of environmental improvement.

2.3 Lean, Agility and Green - A systematic review of literature

This section offers a systematic review of existing literature on lean, agility and green, aimed at providing guidance on the topic, providing more clarity on the scantily explored dimensions and uncovering gaps in the literature. This section discusses the following dimensions:

- the need for an integrated approach
- the product life cycle dimension
- existing frameworks/methods/processes implementing lean, agile, green: frameworks that have offered some direction on the adoption of any of the paradigms (including practices) or any combination of them and their limitations, and hence the need for an integrated framework for selecting the most appropriate LAG practices.

The next sub-section presents the systematic literature review adopted in this research. The remaining sub-sections present the application of this process in this research.

2.3.1 Method for systematic literature review

This study rests upon a systematic literature review, which is a review with a clearly stated purpose, a question, a defined search approach, stating inclusion and exclusion criteria, producing a qualitative appraisal of articles (Jesson et al., 2012). The systematic approach consists of a method which is both explicit and reproducible (Fink, 2005; Booth et al., 2011). The method used to conduct this systematic review is adapted from Garza-Reyes (2015) and involves the following steps-

1) Question formulation: This involves the definition of the research purpose and scope.
2) Comprehensive search: Papers are searched and collected from the specified databases using the key words and the inclusion/exclusion criteria.

3) Study selection and evaluation: The full papers are read and it is decided whether or not papers should be included in the review. Reasons for exclusion are documented.
4) Synthesis and analysis: The data from the individual papers are synthesised into a story and tables that summarise and analyse the papers.
5) Write-up: A balanced, impartial and comprehensive document (a report or a paper) is written where the method and findings are presented so that the review can be replicated.

2.3.1.1 Aim, scope and research questions for systematic review

The aim of the literature review is to highlight need for an integrated approach for the adoption of LAG practices considering product life cycles, and to uncover the limitations of existing work. The scope of the review is therefore bounded the adoption of LAG paradigms and practices, and PLC. To accomplish this, the following literature review questions were constructed.

1) Is there a need for an integrated approach?
2) Is the PLC dimension important?
3) What are the critical evaluation criteria?
4) What are the limitations of existing frameworks/methods/processes?

Being aware that the literature may not fully contain the required details for a complete illumination on the subject, the intention of the questions is to guide the research.

2.3.1.2 Search strategy

Articles were located by considering key words in relevant electronic databases to find publications relevant to the scope of the review. Electronic databases included Emerald, Elsevier, Spinger, Taylor and Francis, IEEE, Google Scholar and Inderscience. In terms of adopting the Lean, Agile and Green paradigms as complementary strategies, literature shows that most researchers have been focused on the study of individual paradigms (Vokurka and Fliedner, 1998; Mohanty and Deshmukh, 1999; Zhang and Sharifi, 2000; Conboy and Fitzgerald, 2004; Anand & Kodali, 2010; Hong et al., 2009); or on the integration of only a couple of them, e.g., lean and agile (Naylor et al., 1999; Christopher and Towill, 2000), lean and green (Kainuma & Tawara, 2006). There is little evidence to show that the paradigms have been discussed complementarily in academic literature since the early 1990’s. Therefore the time-frame for this review was confined from 1997 to 2017.

Keywords were specified based on the scope of the research. The context-intervention-mechanism-outcome (C-I-M-O) (Rousseau, 2012) was adopted to determine the inclusion and exclusion criteria of the search key words. Key words such as, ‘lean’, ‘product life cycle’, ‘framework’, ‘agile’, ‘agility’, ‘green’, ‘environmental sustainability’, ‘environmental management’, ‘lean manufacturing’, ‘agile manufacturing’, ‘lean practices’, ‘agile practices’, ‘green practices’, ‘product life cycle stages’ and their combinations were applied to focus on the relevant information.

This allowed the definition of a specific search focus and the exclusion of articles when found that these did not refer to the inclusion of the terms and/or presented a relationship between them. In some cases, some of the search strings resulted in the same articles being found. However, this systematic search and selection approach was necessary to ensure the completeness of the literature exploration. A point of saturation was considered to have been reached when the same articles continued to appear. Additionally, ‘manual checks’ for all the articles that fell within the search strings criteria were performed based on the abstracts of the papers. This resulted in removing those papers that clearly did not address the topic of lean and green e.g. because they focused on ‘lean, agile or green’ in the context of sustainable buildings, construction management or anything outside the scope of this review, instead of relating lean to a green environmental aspect.

2.3.1.3 Study selection and evaluation

Having considered the entire search strings used, there were 1904 papers retrieved. By cross-checking, time-frame filtering and removing redundancy, the papers were dramatically reduced to 444. By reading the abstracts, the scope of each paper was checked and eventually the majority of the papers were excluded, leaving 72 papers deemed relevant and suitable for review. Judging from the abstracts (and in some cases a read through the papers when the abstracts did not present a clear enough view of the content of the papers) these papers demonstrated their relevance to the research questions. These papers were then analysed and reviewed in detail. Table 2.1 shows the extent of the relevance of the papers described in a format that shows both the purposes and whether frameworks are involved. Search results included academic journals and the proceedings of international conferences for the most part as these sources are the most reliable for literature reviews (Saunders et al. 2012).

Table 2.1: Lean, agility, green and product life cycle coverage in literature

Author	Year	**Paradigms discussed**			**Practices included**	**PLC**	**Framework proposed?**
		Lean	*Agile*	*Green*			
Abdollahi et al	2015	✓	✓	✗	✗	✗	Framework for supplier evaluation
Adhitya et al.	2011	✗	✗	✓	✗	✗	Framework for green SCM
Agarwal et al.	2006	✓	✓	✗	✓	✗	Modelling metrics of SC performance
Agyapong-Kodua et al.	2012	✓	✓	✗	✗	✗	Static cost and value stream model
Aitken et al.	2002	✓	✓	✗	✓	✓	Matching supply chain strategy to PLC
Alaskari et al.	2016	✓	✗	✗	✓	✗	Methodology for lean practice selection
Al Sheyadi	2014	✗	✗	✓	✓	✗	Framework involving GOM practices
Ameri and Patil	2012	✗	✓	✗	✓	✗	Digital manufacturing framework
Amin and Karim	2013	✓	✗	✗	✓	✗	Methodology for selecting lean strategies
Anand and Kodali	2010	✓	✗	✗	✗	✗	Framework for lean manufacturing
Anvari et al.	2013	✓	✗	✗	✓	✗	Framework for lean practice selection
Azevedo et al.	2012	✓	✓	✓	✓	✗	Influence of LARG on SC performance
Banihashemi	2011	✓	✓	✗	✗	✓	Process for improving SC performance
Bapat	2013	✗	✗	✓	✗	✗	N/A
Borchadt et al.	2011	✗	✗	✓	✓	✓	N/A
Brones and Monteiro de Carvalho	201	✗	✗	✓	✗	✓	N/A

	5						
Buchert et al.	2015	✗	✗	✓	✓	✓	Improvements along smart wheel life cycle
Cabral et al.	2011	✓	✓	✓	✓	✗	Information support model
Cabral et al.	2011	✓	✓	✓	✓	✗	Information model for SCM
Cabral et al.	2012	✓	✓	✓	✓	✗	Integrated decision making framework
Carvalho et al.	2011	✓	✓	✓	✓	✗	Model to grasp divergence and synergies
Chaurasia et al.	2015	✓	✗	✗	✓	✗	Method for selecting lean practices
Cherrafi et al.	2016	✓	✗	✓	✗	✗	N/A
Dombrowski et al.	2016	✓	✗	✗	✓	✗	Modelling of lean production systems
Dubey and Gunasekaran	2015	✗	✓	✗	✓	✗	Agile manufacturing framework
Dues et al.	2012	✓	✗	✓	✓	✗	N/A
Esfandyari et al.	2015	✓	✗	✓	✗	✓	N/A

Author	Year	Paradigms discussed			Practices included	PLC mention	Framework proposed?
		Lean	*Agile*	*Green*			
Espadinha-Cruz et al.	2011	✓	✓	✓	✓	✗	Business interoperability model
Eswaramorthi et al.	2010	✓	✗	✗	✓	✗	Model to determine cost per part
Fisher	1997	✓	✓	✗	✗	✓	Matching supply chains with products
Garza-Reyes	2015	✓	✗	✓	✗	✗	N/A
Garza-Reyes et al.	2014	✓	✗	✓	✓	✗	Green lean six sigma
Garza-Reyes	2015	✓	✗	✓	✗	✗	Enhancing green lean with six sigma
Garza-Reyes et al.	2016	✓	✗	✓	✓	✗	Methodology to improve routing operations
Hasanian and Hojjati	2016	✓	✓	✓	✓	✗	Framework for supplier selection
Helo	2004	✗	✓	✗	✓	✓	N/A
Hines et al.	2006	✓	✗	✗	✓	✓	Framework for new product development
Ho and Choi	2012	✗	✗	✓	✓	✗	Five-R analysis framework
Johansson and Sundin	2014	✓	✗	✓	✓	✓	N/A
Kainuma and Tawara	2014	✓	✗	✓	✓	✓	MAUT method for SC assessment
Khiewnavawongsa and Schmidt	2009	✗	✗	✓	✓	✓	N/A
Kwak and Kim	2015	✗	✗	✓	✓	✓	Decision support for life cycle design
Lake et al.	201	✗	✗	✓	✗	✓	Decision support for green supply chains

	5						
Li and Found	2016	✓	✗	✓	✗	✗	Framework of lean and green SC
Li et al.	2010	✗	✗	✓	✓	✓	Methodology for selecting green practices
Lin et al.	2015	✓	✗	✓	✓	✗	N/A
Linke et al.	2012	✗	✗	✓	✗	✓	N/A
Luna and Aguilar-Slaven	2004	✓	✓	✗	✗	✓	Methodology to define production strategy
Madu et al.	2002	✗	✗	✓	✓	✓	Framework for green design
Matawale et al.	2016	✓	✓	✗	✓	✗	Leagility evaluation framework
Mollenkopf et al.	2010	✓	✗	✓	✗	✗	N/A
Moreira and Tjahjono	2016	✓	✓	✗	✗	✗	Process framework for decision-making

Author	**Year**	**Paradigms discussed**			**Practices included**	**PLC mention**	**Framework proposed?**
		Lean	*Agile*	*Green*			
Naim and Gosling	2011	✓	✓	✗	✗	✓	N/A
Naylor et al.	1999	✓	✓	✗	✓	✗	N/A
Pampanelli et al.	2013	✓	✗	✓	✓	✗	Model to investigate benefits of lean, green
Pham and Thomas	2012	✓	✓	✗	✓	✓	Economic sustainability framework
Prince and Kay	2003	✓	✓	✗	✗	✗	Virtual group concept
Pullan et al.	2013	✓	✗	✗	✓	✗	Concurrent Engineering framework
Rauch et al.	2015	✓	✗	✗	✓	✗	Guideline for lean product development
Rehman and Shrivastava	2012	✗	✗	✓	✓	✗	N/A
Sabet et al.	2017	✗	✓	✗	✓	✓	Supply chain integration framework
Seyedi et al.	2013	✓	✗	✗	✓	✗	N/A
Shi et al.	2016	✗	✗	✓	✓	✓	N/A
Singh and Vinodh	2017	✗	✓	✓	✓	✓	Model for agility and green
Smith and Perks	2010	✗	✗	✓	✓	✓	N/A
Soosay et al.	2016	✓	✗	✗	✓	✗	N/A
Sorli et al.	2012	✓	✗	✓	✓	✓	Lean and green framework with PLC
Tseng et al	201	✗	✗	✓	✓	✗	Green evaluation method

	3						
Vinodh	201 0	✗	✓	✓	✗	✗	N/A
Yang et al.	201 0	✓	✗	✓	✓	✗	Model showing lean/agile relationships
Yang	201 4	✓	✗	✗	✓	✓	Framework with PLC for system design
Zhang	2011	✗	✓	✗	✓	✓	N/A

2.3.1.4 *Descriptive analysis of the findings*

The 72 articles are compliant with the selection criteria as the articles referred to lean, agile and green, as well as several combinations of these to a large extent. Figure 2.2 shows that for this review, 17% of the publications for this were conference papers, while 82% were journal articles from the Journal of Cleaner Production; Journal of Management Development; International Journal of lean six sigma; Journal of Manufacturing Technology Management; International Journal of Production Economics; International Journal of Production Research and so on. 1% of the publications represent PhD thesis.

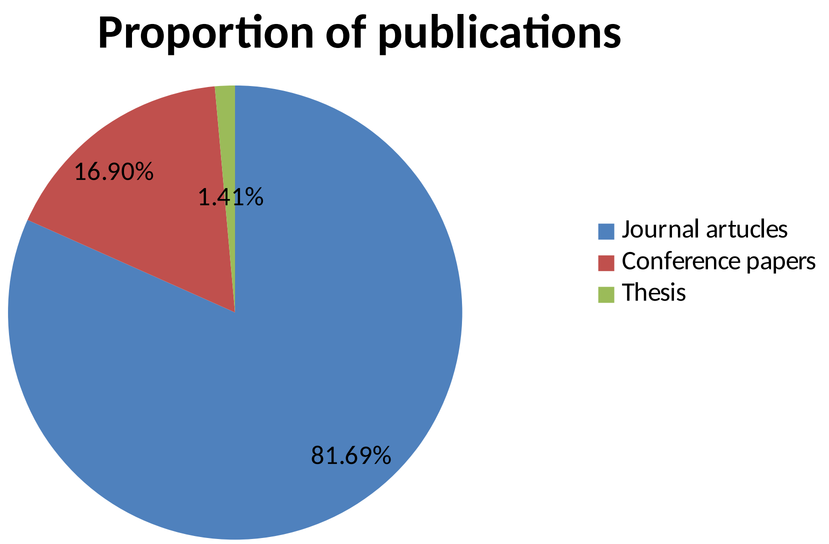

Figure 2.2: Proportion of publications

In terms of the combinations available, lean and agile accounted for 18% of the articles (12 articles) of which 5 of the articles included some direction involving the product life cycle or at least a mention of it, covering the period between 2002 and 2012. The earliest combination of lean and agile in this review occurred in 1997 and the latest in 2016. The majority of the papers were released after 2010 indicating that the lean and agile combination gained some prominence since then. Lean and green produced similar results, accounting for 18% of the publications covering the period 2010 to 2016. Four of the lean and green publications included some form of discussion on the product life cycle between 2012 and 2015.

The agile and green combination recorded 1 journal publication which involved the product life cycle from Singh and Vinodh, (2017) who acknowledged that researchers have focused on the two areas individually and not explored how they complement each other. The lean, agile and green combination accounted for 10% of the publications between 2011 and 2016 with none of the papers discussing the product life cycle or offering any direction given the product life cycle concept.

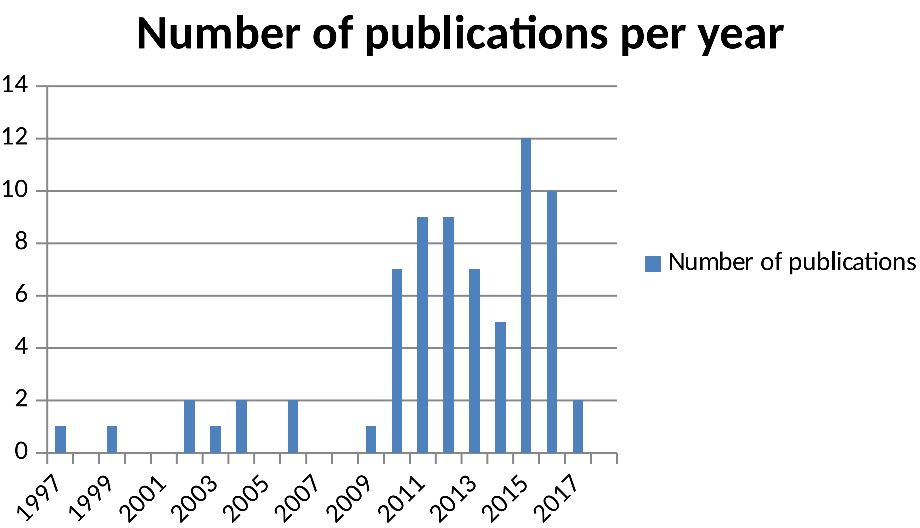

Figure 2.3: Publications on Lean, Agility and Green by year

Some other important aspects of the search showed some individual paradigms with consideration of the product life cycle. Paper discussing green and product life cycle accounted for slightly over 16% of the publications with 11 papers covering the period between 2002 and 2016 with majority of the paper released between 2010 and 2016; the agile paradigm with some discussion on product life cycle accounted for 4.4% of the publications with 3 papers and 1 paper offered some discussion on lean and product life cycle.

Regardless of the combinations of lean, agile and green offered by the publications in this review, 75% of the publications discussed them in some relation to competitiveness, in conjunction with some key performance indicators such as lead time and cost. This implies that researchers recognise the capability of each of the paradigms and/or a combination of them to have some impact on competitiveness. Table 2.2 shows the individual articles which are part of this review, their titles and the databases from which they have been drawn. Figure 2.3 shows the number of publications on Lean, Agility and Green by year of publication and figure 2.4 shows the number of publications per database.

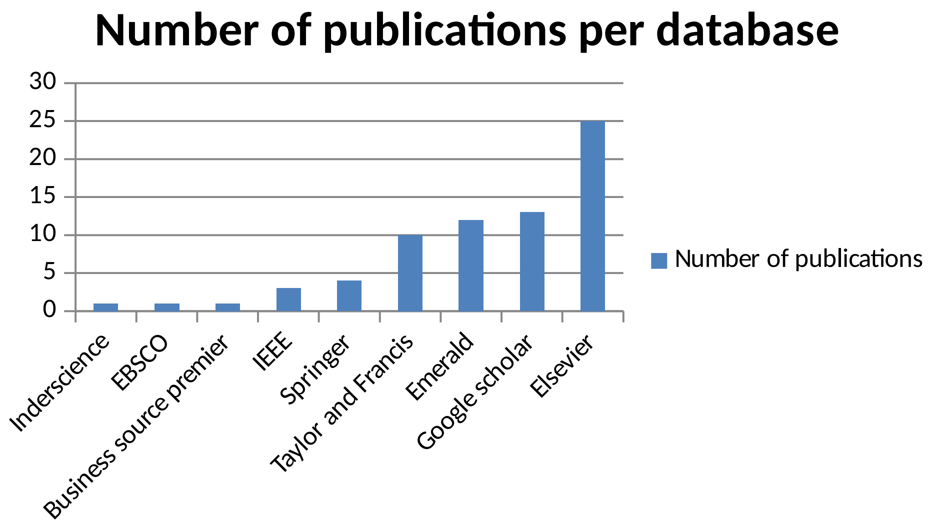

Figure 2.4: Publications per database

Table 2.2: Literature published on lean, agility and green with PLC

No	Author	Title	Database
1	Abdollahi et al. (2015)	An integrated approach for supplier portfolio selection: lean or agile?	Elsevier
2	Adhitya et al. (2011)	Decision Support for Green Supply Chain Operations by Integrating Dynamic Simulation and LCA Indicators: Diaper Case Study.	Google scholar
3	Agarwal et al. (2006)	Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach.	Elsevier
4	Agyapong-Kodua et al. (2012)	Development of a multi-product cost and value stream modelling methodology.	Taylor and Francis
5	Aitken et al. (2002)	The impact of product life cycle on supply chain strategy.	Elsevier
6	Alaskari et al. (2016)	Development of a methodology to assist manufacturing SMEs in the selection of appropriate lean tools.	Emerald
7	Al Sheyadi (2014)	Antecedents and consequences of the complementarities between green operations management practices: an empirical investigation in Oman.	Google scholar
9	Ameri and Patil (2012)	Digital manufacturing market: a semantic web-based framework for agile supply chain deployment	Springer
8	Amin and Karim (2013)	A time-based quantitative approach for selecting lean strategies for manufacturing organisations.	Taylor and Francis
10	Anand and Kodali (2010)	Analysis of lean manufacturing frameworks	Google scholar
11	Anvari et al. (2013)	Application of a modified VIKOR method for decision making-making problems in lean-tool selection	Springer
12	Azevedo et al. (2012)	Proposal of a conceptual model to analyse the influence of LARG practices on manufacturing supply chain performance	Google scholar
13	Banihashemi (2011)	Improving supply chain performance: The strategic integration of lean and agile supply chain.	Google scholar
14	Bapat (2013)	Supply Chain Management: Green Approach For Enhanced Sustainability.	Google scholar

No	Author	Title	Database
15	Borchadt et al. (2011)	Redesign of a component based on ecodesign practices: environmental impact and cost reduction achievements.	Elsevier
16	Brones and Monteiro de Carvalho (2015)	From 50 to 1: integrating literature toward a systemic ecodesign model.	Elsevier
17	Buchert et al. (2015)	Design and Manufacturing of a Sustainable Pedelec.	Elsevier
18	Cabral et al. (2011b)	An information model in lean, agile, resilient and green supply chains	IEEE
19	Cabral et al. (2011a)	Modelling Lean, Agile, Resilient, and Green Supply Chain Management	IEEE
20	Cabral et al. (2012)	A decision-making model for Lean, Agile, Resilient and Green supply chain management.	Taylor and Francis
21	Carvalho et al. (2011)	Lean, agile, resilient and green: divergences and synergies.	Emerald
22	Chaurasia et al. (2015)	An Integrated Fuzzy-based Multi Criteria Decision Making System to Selection of Lean Tool Performance: An Indian Automotive Parts Manufacturing Company Case Study.	Google scholar
23	Cherrafi et al. (2016)	The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model.	Elsevier
24	Dombrowski et al. (2016)	Impact Analyses of Lean Production Systems.	Elsevier
25	Dubey and Gunasekaran (2015)	Agile manufacturing: framework and its empirical validation.	Springer
26	Dues et al. (2012)	Green as the new lean	Elsevier
27	Esfandyari et al., (2015)	A Lean Based Overview on Sustainability of Printed Circuit Board Production Assembly.	Elsevier
28	Espadinha-Cruz et al. (2011)	A model for evaluating Lean, Agile, Resilient and Green practices interoperability in supply chains	IEEE
29	Eswaramoorthi et al. (2010)	Developing An Effective Strategy to Configure Assembly Systems Using Lean Concepts.	Google scholar
30	Fisher (1997)	What Is the Right Supply Chain for Your Product?	B. Source Premier
31	Garza-Reyes (2015a)	Lean and green – a systematic review of the state of the art literature.	Elsevier

No	Author	Title	Database
32	Garza-Reyes et al. (2014)	Lean and Green – Synergies, Differences, Limitations, and the Need for Six Sigma	Springer
33	Garza-Reyes (2015b)	Green lean and the need for Six Sigma	Emerald
34	Garza-Reyes et al. (2016)	Lean and green in the transport and logistics sector – a case study of simultaneous deployment.	Taylor and Francis
35	Hasanian and Hojjati (2016)	A Framework for Supplier Selection Criteria in "LARG" Supply Chain based on a Literature Review.	B.Source Premier
36	Helo (2004)	Managing agility and productivity in the electronics industry.	Emerald
37	Hines et al. (2006)	Towards lean product lifecycle management: A framework for new product development.	Emerald
38	Ho and Choi (2012)	A Five-R analysis for sustainable fashion supply chain management in Hong Kong: a case analysis.	Emerald
39	Johansson and Sundin (2014)	Lean and green product development: two sides of the same coin?	Elsevier
40	Kainuma and Tawara, (2006)	A multiple attribute utility theory approach to lean and green supply chain management.	Elsevier
41	Khiewnavawongsa and Schmidt (2009)	An Essay Of Green Supply Chain Management In The Electronics Industry.	EBSCO
42	Kwak and Kim (2015)	Design for life-cycle profit with simultaneous consideration of initial manufacturing and end-of-life remanufacturing.	Taylor and Francis
43	Lake et al. (2015)	An application of hybrid life cycle assessment as a decision support framework for green supply chains.	Taylor and Francis
44	Li and Found (2016)	Lean and Green Supply Chain for the Product-Services System (PSS): The Literature Review and A Conceptual Framework.	Elsevier
45	Li et al. (2010)	A methodology for selecting a green technology portfolio based on synergy.	Taylor and Francis
46	Lin et al. (2015)	The Impact of Integrated Practices of Lean, Green, and Social Management Systems on Firm Sustainability Performance—Evidence from Chinese Fashion Auto-Parts Suppliers.	Google Scholar
47	Linke et al. (2012)	Establishing greener products and manufacturing processes.	Springer

No	Author	Title	Database
48	Luna and Aguilar-Slaven (2004)	Manufacturing Strategy Linked to Product Life Cycle	Google Scholar
49	Madu et al. (2002)	A hierarchic metric approach for integration of green issues in manufacturing: a paper recycling application.	Elsevier
50	Matawale et al., (2016)	A fuzzy embedded leagility assessment module in supply chain.	Emerald
51	Mollenkopf et al. (2010)	Green, lean and global supply chains.	Emerald
52	Moreira and Tjahjono(2016)	Applying performance measures to support decision-making in supply chain operations: a case of beverage industry.	Taylor and Francis
53	Naim and Gosling (2011)	On leanness, agility and leagile supply chains.	Elsevier
54	Naylor et al. (1999)	Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain.	Elsevier
55	Pampanelli et al. (2013)	A Lean and Green Model for a production cell.	Elsevier
56	Pham and Thomas (2012)	Fit manufacturing: a framework for sustainability.	Emerald
57	Prince and Kay (2003)	Combining lean and agile characteristics: Creation of virtual groups by enhanced production flow analysis.	Elsevier
58	Pullan et al. (2013)	Decision support tool for lean product and process development.	Taylor and Francis
59	Rauch et al. (2015)	Axiomatic Design Based Guidelines for the Design of a Lean Product Development Process.	Elsevier
60	Rehman and Shrivastava (2012)	Green manufacturing (GM): past, present and future (a state of art review).	Inderscience
61	Sabet et al. (2017)	Supply chain integration strategies in fast evolving industries.	Emerald
62	Seyed et al. (2013)	A Decision-Making Process for Selecting of Lean Tools Implementation Methods by Means of Analytical Hierarchy Process in Health Center	Google Scholar
63	Shi et al. (2016)	Remanufacturing decision and sustainability under product life cycle uncertainty.	Taylor and Francis
64	Singh and Vinodh (2017)	Modeling and performance evaluation of agility coupled with sustainability for business planning.	Emerald

No	Author	Title	Database
65	Smith and Perks (2010)	A perceptual study of the impact of green practice implementation on the business functions	Google Scholar
66	Soosay et al. (2016)	Strategies for sustaining manufacturing competitiveness.	Emerald
67	Sorli et al. (2012)	Expanding lean thinking to the product and process design and development within the framework of sustainability.	Google Scholar
68	Tseng et al., (2013)	Improving performance of green innovation practices under uncertainty.	Elsevier
69	Vinodh (2010)	Improvement of agility and sustainability: A case study in an Indian rotary switches manufacturing organisation.	Elsevier
70	Yang et al. (2010)	Mediated effect of environmental management on manufacturing competitiveness: An empirical study.	Elsevier
71	Yang (2014)	Lean production system design and implementation in the product life cycle	Google scholar
72	Zhang (2011)	Towards theory building in agile manufacturing strategies—Case studies of an agility taxonomy.	Elsevier

2.3.1.5 Findings regarding SLR questions

This sub-section presents findings and answers to the literature review questions with focus on questions 1 to 4. Question 5 is addressed in the next section 2.4

Question 1: Is there a need for an integrated approach?

Businesses are constantly focused on issues of responding to customer demands for the sake of maintaining a competitive advantage over their rivals (Agarwal et al., 2006). In today's competitive market environment, manufacturing enterprises face considerable pressure as a result of customer expectations regarding product quality, demand responsiveness, lower costs, competitive lead times, reducing waste generation and product variety (Aitken et al., 2002; Helo, 2004; Nahm et al., 2006; Agarwal et al., 2006; Karim et al., 2008; Khiewnavawongsa and Schmidt, 2009; Smith and Perks, 2010; Borchardt et al., 2011; Islam and Karim, 2011; Ho and Choi, 2012; Pullan et al., 2013; Al Sheyadi, 2014). The lean, agile and green paradigms have been adopted in order to meet such expectations (Cabral et al., 2012a; Espadinha-Cruz et al., 2011; Hasanian and Hojjati, 2016).

Several other researchers believe that lean, agility and green should be advocated as the foundation of a competitive enterprise. Abdollahi et al. (2015); Matawale et al. (2016) and Moreira and Tjahjono (2016) believe that unpredictability in the modern and competitive market environment has made it necessary for enterprises to consider agility and lean practices in order to maintain a competitive advantage. Mollenkopf et al. (2010) suggests that lean operations improve competitive advantage through the implementation of complementary elements of environmental performance. On the other hand, Singh and Vinodh (2017) states that even though they are different manufacturing paradigms, agility and green should be merged by companies in order to enhance competitive advantage as they are equally important, and complementary in the long run. Furthermore, Pham and Thomas (2012) suggests that for companies to be competitive they should achieve an effective level of leanness, agility and sustainability which corresponds to the level of change and uncertainty in an operational system as well as the individual business environment.

The various integrations of lean, agile and green in the literature presented herein indicate that the availability of firm specific capabilities could enable firms to achieve competitive advantage. The literature also shows that environmental sustainability can be a strategic competitive issue (Madu et al., 2002; Garza-Reyes, 2015a; Khiewnavawongsa and Schmidt, 2009), because although the environmental impact is one of the major interests of green, other benefits could include an increase in competitiveness through cost reduction and the launch of new products (Borchardt et al., 2011). The literature also highlights that meeting customer expectation is not only the linchpin to competitiveness, but also crucial to survival.

Question 2: Is the PLC dimension important?

Lake et al. (2015) and Rehman and Shrivastava (2012) claim that there is lack of integration between business operations and product life cycle. However, the PLC is an important consideration because knowing exactly the life cycle stage of each product will enable companies to make decisions and employ different methods and strategies towards optimising its performance (Aitken et al., 2002; Pham and Thomas, 2012). With this knowledge, the authors believe that a company is equipped with the capability to match the competition during all stages of the PLC. Furthermore, the product life cycle is made necessary as a result of the need for improved awareness on the volumes required to be produced; and the competitive priorities of each product and the way they change over the product's life cycle (Luna and Aguilar Saven, 2004; Aitken et al., 2002).

Few authors have offered some directions on what PLC stages to adopt the lean, agile and green paradigms. Banihashemi (2011) states that the first two stages of the product life cycle, introduction and growth, are the testing grounds to ensure that organizations are achieving customization and market adaptability, and offered a solution for improving supply chain performance which involves having 'innovative products' designed and produced by agile supply chains in the introduction and growth stages, and lean supply chains in the maturity and decline stages of the PLC. He also suggests that 'standard products' be designed and produced by lean supply chains through all the stages of the product life cycle.

Lunar and Aguilar (2004) recommends a flexible a process for the initial stage of the product life cycle. In other words, an agile process is recommended for the introduction stage. Yang, (2014) on the other hand proposes having the lean production system designed at the early stages of the product life cycle. The author also advices that a full application of the lean production system at later life cycle stages should be avoided and that adopting certain lean practices such as pull system, kanban, preventive maintenance and so on should also be avoided as they will not work under a standalone condition.

Naim and Gosling (2011) posits that 'innovative products' need an agile supply chain in the initial stages of the PLC and a lean or leagile supply chain in the later stages (maturity and decline), while 'hybrid products are better served by a leagile supply chain throughout all four stages of the PLC.

One interesting finding made through literature regarding the PLC and environmental management is that the PLC concept becomes more important as manufacturers focus of environmental management practices (Madu et al., 2002). The PLC supports environmental management as products are available for remanufacturing throughout the PLC (Shi et al., 2016). Waste reduction is focused strongly on minimising the environmental loads associated with products and preservation of natural resources (Johansson and Sundin, 2014).

This literature review indicates that companies need to possess the appropriate mix of strategies to compete at all stages of the product life cycle (Aitken et al., 2002); that addressing environmental concerns throughout all stages of PLC may offer new opportunities for enhancing market competitiveness (Al Sheyadi, 2014) and that competitive priorities and environmental concerns are dynamic throughout the stages of the product life cycle. These findings necessitate the consideration of the product life cycle in decision making and developing/implementing business operations.

Question 3: What are the critical evaluation criteria?

Since this research advocates the integration of lean, agility and green (LAG) due to the limitation of each individual paradigm, it is important at this point to establish some criteria for examining the limitations of each paradigm. These are the criteria that could influence the decision on what paradigm or practice to adopt, depending on priorities. These criteria will be used for the evaluation of framework/methods for the adoption of LAG in subsequent sub-sections. The criteria for critical evaluation are:

Changing customer requirements

Customer demands are dynamic (Farahani et al., 2013; Found and Rich, 2007) and should be adequately responded to as they could be said to contribute to the dynamics of the market. Changing customer requirements might mean in some cases that, new products have to be developed and introduced into the market; that product features have to change, improved or upgraded (Zhou et al., 2017); that products can be purchased at lower prices; that products are made more readily available among other requirements. In the FMCG industry, rapidly changing customer requirements is one of the main challenges (Farahani et al., 2013). Overall, the ability to understand customers and anticipate these changes could be the key to a successful business. Therefore, in evaluating a paradigm, framework or method, attention will be paid to whether they possess the capability to efficiently address rapidly changing customer requirements with agility and cost-effectiveness, without compromising quality.

Demand uncertainty

The amount of product orders received from customers is variable (Naylor et al., 199). This could be driven by need, the availability of close substitutes (Lee and Cranage, 2010), the availability of the product (Farahani et al., 2013), price et cetera. Adapting production to effectively address fluctuating demand from customers is a source of concern for product manufacturers. Naylor et al. (1999) proposed the adoption of a decoupling point approach to deal with unpredictable demand. Decoupling point is essentially holding buffer stock; it is usually associated with product postponement strategies (Prince and Kay, 2003). This research will consider whether a method, paradigm or framework can be trusted to effectively handle fluctuating demand in a fashion that works to assure the survival of an organisation.

Product life cycle (PLC)

The PLC is an important consideration in making the decision on whether to go lean, agile or green, because being equipped with the knowledge of exactly the life cycle stage of each product will help organizations to decide on the methods and sub-strategies to employ in order to optimize performance (Aitken et al., 2002; Pham and Thomas, 2012). With this knowledge, Pham and Thomas (2012) believe that an organization is equipped with the capability to match the competition during all stages of the PLC. Therefore, in conducting this evaluation, this research will consider whether a paradigm, method or framework can be successfully applied at different PLC stages – introduction, growth, maturity and decline.

Environmental sustainability (Green)

In the last decades, environmental sustainability issues (including green product design, environmental awareness, collaboration and smart use of resources) have become major issues faced by organizations (Urvashi et al., 2013). The main reasons for the increased awareness in green issues are end-of-life of products, growing social pressure, legislative changes around packaging and increasing use of ecological requirements being cascaded from customers to suppliers (Urvashi et al., 2013). Given the current social and legislative pressures, the consideration of green issues cannot be ignored in manufacturing decision making. Therefore, this research will consider whether a framework, paradigm or method involves measures to addresses environmental concerns.

Organizations who endeavour to maintain customers will be able to obtain long-lasting competitive advantage in the fierce market competition (Li, 2009). Organizations must therefore commit themselves to providing better value to customers than their competitors; with this, they can obtain a competitive advantage in the fiercely competitive market (Li, 2009). This research therefore posits that effectively addressing customer requirements and demand uncertainty will lead to improved competitiveness. Competitiveness in this research is measured by lead time, cost and environmental waste. Therefore improved competitiveness means shorter lead times (Zaeh, 2013), reduced costs (Aljunaidi and Ankrah, 2014) and reduced environmental wastes (Paul, Shrivastava, 1995).

Having established the critical evaluation criteria, the question, "what are the limitations of existing frameworks/methods/processes?" is articulated explicitly in the following sub-section 2.4 by applying the critical evaluation parameters across the works.

2.4 What are the limitations of existing frameworks?

This section presents the findings in addressing the question, "what are the limitations of existing methods/frameworks/processes?" Included in this review are articles that have presented approaches for Lean, Agility and Green either individually or in some form of combinations.

Subsections 2.4.1, 2.4.2 and 2.4.3 present the works that have focused on Lean, Agility and Green individually. Section 2.4.4, 2.4.5 and 2.4.6 present the combinations Lean and Agility, Lean and Green, and Agility and Green. Sub-section 2.4.7 presents the combination Lean, Agility and Green.

2.4.1 Lean

I. *Methodology to select appropriate lean tools* - Chaurasia et al. (2015) proposed a systematic methodology for selecting the most appropriate lean tools for automotive industries. The method is based on multi criteria decision making methods and artificial intelligence.

   Limitations - This work includes a methodology for selecting the most appropriate lean tools but could also have included agile and green tools to provide for a methodology that addresses a wider range of issues including unpredictability and environmental sustainability concerns. Also, this methodology is focused on the automotive industry which does not represent the same characteristics as the fast moving consumer goods industry and it challenges, therefore it may not be successfully applied in FMCG.

II. *Approach for selecting lean strategies for manufacturing organisations* - Amin and Karim (2013) developed a systematic methodology to make optimal decisions for improving the identified wastes by selecting/implementing appropriate lean strategies within a manufacturer’s time constraints. The authors developed a mathematical model for evaluating the perceived value of lean strategies to reduce manufacturing waste. A step-by-step methodology is provided for selecting appropriate lean strategies to improve manufacturing performance.

Limitations - This work similar in a way to Chaurasia et al. (2015) presented in I above in providing for a methodology for selecting appropriate lean strategies but for addressing the issue of reducing lean wastes within the manufacturer’s time constraints. But as products progress through their life cycle stages, the methodology may not be sufficient in dealing with of the characteristics associated with PLC such as high costs in the introduction stage, decreasing market share in the maturity stage and so on.

III. *VIKOR method for lean tool selection* - Group decision making involving multiple criteria is the most popular method for ranking a set of alternatives (Anvari et al., 2013), however it may be difficult to select from a set of alternatives in the absence of a set of criteria or from a set of criteria that are related to various alternatives. Recognizing that lean tools selection is one of the main challenges faced by manufacturing managers, Anvari et al. (2013) developed a model to help practitioners improve their ability to resolve problems when the possible solutions have their own individual criteria. The study used lead time, cost, defects and value as criteria to investigate grades of importance of criterion based on paired comparison analysis. This is a modified VIKOR method to address the lean tool selection problems in manufacturing systems.

Limitations - This work shares the same limitations as Chaurasia et al. (2015)’s systematic methodology for selecting lean practices presented in I above.

IV. *Methodology to assist SME’s with lean tool selection* - Alaskari et al. (2016) points out that not all implementations of lean have delivered favourable outcomes due to a lack of understanding of lean performance and its measurement. This lack of understanding of the wide choice of lean tools according to Alaskari et al. (2016) often lead to confusion for those with limited knowledge of efficacy of lean tools. The authors therefore believe that there is the need for the development a methodology to assist companies in the adoption of the most appropriate lean tools for their specific aim and objective, thus reducing the difficulty in identifying the strategy that best addresses the company’s waste.

The methodology developed by Alaskari et al. (2016) supports decision-making, and selection of the most appropriate lean tool for a company experiencing difficulties in adopting lean tools. The methodology is designed by integrating the influence value

(I.V.) of factors affecting KPIs, and the strength of the relationship (relative strength) between these factors and lean tools using a selection matrix. In other words, given a collection of lean tools, the methodology uses a numerical approach to select the appropriate lean tool that leads to maximum benefits. The lean tools selected by Alaskari et al. (2016) based on a variety of benefits that can be gained from each tool were 5S, Kanban, Poka-Yoke and SMED (Single-minute Exchange Dies) considered against performance measures quality, flexibility, time delivery and cost. *Limitations* - This work shares the same limitations with Amin and Karim (2013).

V. Anand and Kodali (2010) proposed a framework to identify the list of lean manufacturing elements comprehensively and thereby help the practitioners to clearly understand what lean manufacturing is and what constitutes it.

Limitations - This framework does not offer a direction for selecting green and agile practices, i.e addressing customer requirements, demand uncertainty and issues prompted by the different PLC stages.

VI. *Lean production implementation in product life cycle* - Yang (2014) discussed the design and implementation of lean production system. The author identified value stream design as an essential technique for designing a fully integrated lean production system. The main input of the value stream design at the growth stage of the product life cycle is to identify the necessary customer/market requirements. The author believes that the chance of a successful and financially viable introduction of a lean production system quickly declines after the growth stage of the product life cycle. Therefore, a full application of the lean production system at later life cycle stages should be avoided and adopting certain lean practices such as *pull system, Kanban, preventive maintenance* and so on should also be avoided as they will not work under a standalone condition.

Limitations - Yang (2014)'s approach is focused on making a success out of lean implementation in production systems by addressing the timing of the implementation. Though it presents some direction for implementation in PLC stages, it fails to mention what customer requirements would be best addressed by this framework. And given possibility of unpredictability of demand in the market environment, this work does not address the need for agility nor does it address environmental concerns. Also, Yang (2014)'s work has not incorporated any feature to address environmental concerns.

VII. *Framework for new product development* - Hines et al. (2006) developed a model intended to serve as a guide for applied research within the field of new product development. This work according to the authors is a precursor to developing a framework for undertaking lean product lifecycle management (PLM). The outcome of this effort is a six-step theoretical framework that can be used as a point of reference for academics discussing the development of systemic approaches to lean PLM. The framework begins with the development and understanding of customer needs followed by value stream mapping (VSM) in the second step for the current state of a process.

Limitations - Hines et al. (2006) believe that this work "can be used for both high innovation and low innovation environments"; however, Fisher (1997) discouraged lean application to innovative products. This work does not consider situations of unpredictability in the market environment regarding customer requirements and demand, of which some elements of agility may be required. Lean PLM as proposed by Hines et al. (2006) has not incorporated environmentally sound management.

VIII. *Lean production system* - Dombrowski et al. (2016) described the modelling of individual methods of lean production systems (LPS) by using System Dynamics as the selection of the methods contained in LPS can be individually adapted to the respective requirements and conditions of the corresponding enterprise.

Limitations - This work is adaptable to individual enterprises regarding lean production systems but is lacking in efforts to deal with environmental concerns and responding to customer demands with agility. This work is also deficient in the incorporation of the PLC.

2.4.2 Agility

I. *Agile manufacturing framework*: With the aid of literature review, Dubey and Gunasekaran (2015) developed a framework for agile manufacturing. The framework consists of six constructs that includes technologies, empowerment of workforce, customer focus, supplier relationship management, flexible manufacturing systems and organizational culture. Organizational culture and empowerment were included, in an effort to incorporate often ignored soft dimensions. Some of the conclusions reached by Dubey and Gunasekaran (2015) in order to sustain in an intensively competitive environment are that organizations need to have enough product flexibility; that volume flexibility is needed to adapt their production strategy according to the market needs and that mix flexibility is also required to enable help them handle large product variants by using equipment with short setup times.

Limitations - Though this framework considers soft dimensions such as organisational culture and empowerment, it is limited in the agile practices considered and it may not be sufficient in dealing with environmental sustainability concerns, given that it has not considered addressing such concerns. It is not clear if this framework is capable of addressing some of the concerns for which the lean paradigm was developed, such as eliminating non-value adding activities and processes as well as reducing costs. It also has not included any direction for the different market situations prompted by the stages of the PLC.

II. *Digital manufacturing market*: Ameri and Patil (2012) introduced the digital manufacturing market (DMM) believing that the benefits of the manufacturing market can be better realized in a web-based framework. The objective of the framework is to support autonomous deployment of manufacturing supply chains based on the specific technological requirements defined by particular work orders. The framework supports rapid market responsiveness and competitiveness.

    Limitations: Considering the evaluation parameters, the work of Ameri and Patil (2012) is deficient in addressing environmental issues and cannot be relied on for addressing the concerns which led to the development of the lean concept. Also, the PLC has not been considered in this work for the development of the components of DMM.

2.4.3 Green

I. *5-R Analysis framework* - Ho and Choi (2012) reviews why fashion companies go green and proposed the Five-R framework to examine green supply chain management (GSCM) challenges. 5-R stands for recycle, reuse, reduce, re-design and re-imagine. The authors applied the 5-R to a fashion company in Hong Kong, and were able to gain a clearer understanding of the journey of the company towards environmental sustainability.

    Limitations - The 5-R analysis framework is designed to take care of green issues in a company, but it could provide more utility if it incorporated a structure for dealing with flexibility, speed and reduction of lean wastes when required in meeting customer requirements. The 5-R framework has not discussed the PLC concept which could be a critical issue in the fashion industry.

II. *Integrating green issues into manufacturing* - Madu et al. (2002) presented a hierarchic framework to consider environmental issues in environmentally conscious manufacturing. The framework helps manufacturers integrate green issues in the decision making process and at the same time design products that are technically feasible and cost effective.

Limitations - This framework shares similar limitations with that of Ho and Choi (2012)

III. *Framework for GOM practices* - Al Sheyadi (2014) developed a single integrated conceptual framework in an attempt to resolve inconsistencies in the results of previous studies. This framework aims to link and simultaneously examine the relationships between the antecedents and consequences of the adoption of green operations management (GOM) practices within manufacturing firms. The inconsistencies addressed are partially due to the variations in conceptualising drivers, practices and performance as well as the non-integrative nature of models when studying the relationships between these elements. The proposed framework therefore incorporates the three elements drivers, practices and performance as the main pillars for the development of the framework.

Limitations - This framework deals with the consequences of adopting green practices but does not offer any direction for dealing with situations such as unpredictable demand, rapidly changing customer requirements nor does it offer any direction for selecting green practices considering the stages of the product life cycle. Al Sheyadi, (2014)'s GOM framework could be used to address environmental concerns, but may not be successfully adopted for the purpose of addressing lean concerns such as eliminating non-value adding activities and achieving overall efficiency in manufacturing.

IV. Adhitya et al., (2011) proposed a framework for green supply chain management by integrating a supply chain dynamic simulation and LCA indicators to evaluate both the economic and environmental impacts of various decisions such as inventories, distribution network configuration, and ordering policy. The advantages of this framework are demonstrated through an industrially motivated case study involving diaper production.

Limitations - This framework share limitations with that of Al Sheyadi (2014).

V. *Life cycle assessment methodology* - Lake et al., (2015) provides both theoretical insights and a practical application to inform the process of adopting a decision support framework based on a life cycle assessment (LCA) methodology in a practical scenario. The authors helped enhance understanding and overcome the dichotomy between LCA model development and the practical implementation to inform carbon emissions mitigation strategies within supply chains.

Limitation - This does not indicate whether the process of adopting a decision support framework based on LCA could accommodate method(s) that address issues involving agility and lean. It also fails to discuss the PLC and issues prompted by it.

VI. *Design for life cycle profit* - Kwak and Kim (2015) proposed a nonlinear mixed integer programming model to help in product design that maximizes current profit from manufacturing and the future profit from remanufacturing. The model helps designers to identify which parts are expected to be reused or upgraded at end-of-life.

Limitations - The model proposed by Kwak and Kim, (2015) has similar limitations with the framework proposed by Ho and Choi (2012) in that it aims to achieve economic sustainability through the implementation of green design. However, the model does not include plans for addressing unpredictability in product demand; it may not be sufficient for eliminating lean wastes and it is deficient in dealing with market situations prompted by the different stages of the PLC.

2.4.4 Lean and agility

I. Agarwal et al. (2006) proposed a framework using multi criteria decision analysis for modelling performance of lean, agile and leagile supply chain on the basis interdependent variables. The framework provides some support for decision makers in analysing the variables affecting market sensitiveness, process integration, information driver and flexibility in enterprises operating lean, agile and leagile supply chains. A business in the fast moving consumer goods (FMCG) industry was used as a case study.

Limitations - Though Agarwal et al. (2006) has considered combining the lean and agile paradigms to evaluate some variables that affect market sensitiveness, it has neither included any variable to evaluate environmental sustainability nor considered a direction for the PLC.

II. *Matching supply chains with products* - Fisher (1997) discussed some directions for devising a business strategy by devising a framework that helps managers understand the nature of the demand for their products and devise the supply chain best suited to satisfy that demand. He considered aspects such as the market standards for lead times, product variety, demand predictability and product life cycles. Products were categorised into functional and innovative products. For functional products, Fisher, (1997) discussed a lean approach because of the predictability of demand for these kinds of products, but discouraged it for innovative products.

Limitations - Though this work has considered the product life cycle, it has not considered its different stages in proposing a lean or agile direction for functional and innovative products. It also lacks a plan for environmental sustainability.

III. Aitken et al. (2006) demonstrates how a lighting company's re-engineering effort aimed to match customer requirements and the product delivery process (PDP) by accommodating the product life cycle. The authors discussed the lean and agile paradigms and the importance of marrying them.

Limitations - This work is a demonstration of how a UK lighting company reengineered its supply chain to accommodate the impact of product life cycles; hence it may not be easily applicable in other companies in other sectors and for other products. It discusses situations for the application of lean and agile practices but fails to address environmental concerns which lighting products are capable of causing.

IV. *Manufacturing strategy linked to PLC* - Luna and Aguilar Saven (2004) dealt with the decision dilemma encountered by firms producing items with different life cycles. They identified two different decision patterns given four alternatives: lean or agile manufacturing; focused or non-focused facilities. Luna and Aguilar Saven (2004) proposed applying the lean paradigm on products presenting relatively long PLCs and low demand uncertainty and the agile paradigm on products with short PLCs and high demand uncertainty.

Limitations - Luna and Aguilar (2004) offered some direction on the application of lean and agility in production life cycle stages but failed to indicate what lean/agile practices to apply. It also lacks a solution for addressing green issues.

V. *Virtual group (VG) concept* - Prince and Kay (2003) argue that companies will be pressured to compete on cost in the short term within a lean production framework, while working to develop the manufacturing capability in the long term to supply to customers who can be categorized into niche markets and offered products and services that rival companies cannot easily match. Prince and Kay (2003) presented a background to why some manufacturing organisations require a combination of lean and agile characteristics in their organisations. The authors introduced the virtual group concept which seeks to identify groups of machines and families of parts to which lean and agile manufacturing strategies can be applied. It addresses the increasing pressures placed on manufacturers and are characterised by the identification of groups of machines that have the potential to form manufacturing cells. Prince and Kay (2003) argue that VGs enable the application of lean and agile concepts to different stages of production within a factory.

Limitations - The key feature of the VG concept is its ability to assign products to machines such that lean and agile practices can be applied to different groups of production equipment for optimal performance. However, considering the evaluation criteria stated earlier, the VG concept as described by Prince and Kay (2003) could not address environmental concerns. The authors also failed to state if, the VG concept could address the different market situations that arise as a result of the PLC stages.

VI. *Decoupling point* - Naylor et al. (1999) sought to apply the lean and agile concepts at different stages of the same manufacturing environment so that the benefits of both paradigms can be fully harnessed. They suggested that agile manufacturing concepts can be applied to the section of the supply chain under the most pressure to operate in an environment of fluctuating demand in terms of volume and variety, while lean concepts can be applied to the rest of the supply chain to encourage level demand necessary to achieve the cost benefits associated with supporting this production strategy. To achieve this, a de-coupling point was introduced to enable lean and agile concepts to mutually support each other at the operational level to improve overall performance and boost profits. A de-coupling point is essentially a point where stock is strategically held as a buffer between fluctuating demand, product variety and smooth production output (Naylor et al., 1999). It is therefore associated with product postponement strategies and is suitable in situations where the customer is prepared to wait for a customised product.

Limitations - Considering the evaluation criteria, Naylor et al. (1999)'s approach does not incorporate environmental management practices and hence could not address environmental concerns beyond areas where lean and green are synergistic. Also, the PLC concept has not been considered to address changing market situations as products proceed through their PLC stages.

VII. *An Integrated approach for supplier selection* - Abdollahi et al. (2015) proposed a framework for supplier evaluation and selection based on the lean and agile criteria. The supplier selection problem is resolved using a combination of multi-criteria decision making (MCDM) (DEMATEL–ANP–DEA). This made it possible to incorporate multiple suppliers in order to determine the relative efficiencies.

Limitations - Abdollahi et al. (2015)'s framework addresses supplier selection issues, thus it may not be easily applicable for selecting optimal LAG practices. Considering the critical evaluation parameters earlier established in this chapter, Abdollahi et al. (2015)'s framework lacks the features to effectively address environmental concerns, though it combines the lean and agile criteria in decision-making, which could address unpredictability and changing customer requirements. Furthermore, the framework has not considered features for addressing issues driven by the different stages of the PLC.

2.4.5 Lean and green

I. Garza-Reyes et al. (2016) discussed an adaptation of Villareal (2012)'s methodology on achieving greater levels of transport efficiency, presenting a systematic methodology which combined some of the fundamentals, philosophies and tools of the lean and green paradigms to improve both the operational efficiency and environmental performance of a case organisation in Mexico.

Limitation - This methodology is applicable in the transport industry and may not be easily adaptable in other sectors, such as the manufacturing sector, for addressing unpredictable product demand. Furthermore, considering the critical evaluation criteria established earlier in this chapter, Garza-Reyes et al., (2016)'s adaptation of Villareal (2012)'s methodology has not offered a direction for the PLC.

II. *MAUT approach to lean and green supply chain* - Kainuma and Tawara (2006) proposed a multiple attribute utility theory (MAUT) method for assessing a supply chain. To apply this method to the lean and green supply chain, the authors analysed the effect of information sharing in the supply chain and quantified the benefits of information sharing that can decrease the average stock level in the supply chain and the out-of-stock ratio at a retailer at a certain level.

Limitation - This work provides a solution for analysing the effect of information sharing in the supply chain, but does not provide a solution for applying agile strategies in the business to address rapidly changing customer requirements and demand uncertainty. Another criterion not present in this work is the incorporation of the PLC.

III. Sorli et al. (2012) proposed a framework which balances environmental factors with lean principles to be considered and incorporated from the beginning of product design and development covering the entire product lifecycle.

Limitation - This framework discusses the integration of lean and green. It could provide more utility if it also balanced agile principles within the framework to cover the entire PLC. In other words, the framework has not considered the PLC and agility features.

IV. Pampanelli et al. (2013) proposed the 'lean and green model' (suitable for application at the production cell level) where sustainability has been integrated with 'pure lean thinking' as part of a continuous improvement process. The model was proposed to investigate the potential benefits for the environment and businesses in terms of waste elimination, operational output and employee commitment.

The lean and green model according to Pampanelli et al. (2013) involves the following five steps: identify the value stream, i.e. need for improvement; identify environmental aspects and impacts i.e. defining the process improvement scope; measure environmental value stream i.e. identifying the actual data on the environmental process; improve environmental value stream i.e. identifying waste reduction opportunities during a kaizen workshop and continuous improvement i.e. developing action and communication plans

Limitations – Pampanelli et al. (2013)'s model contains features for dealing with environmental concerns and lean wastes by virtue of integrating lean and green. However, considering the evaluation criteria, the model is deficient by not considering the PLC to provide a direction for addressing market situations prompted by the stages of the PLC. It is also deficient by not providing a feature to successfully address changing customer concerns and demand uncertainty with agility.

V. Dues et al. (2012) discussed how lean practices can herald the greening of operations. The authors suggest that the relationship between lean and green overlap in more areas than one. The overlap is established in the following attributes: waste and waste reduction techniques, people and organisation, lead time reduction and supply chain relationship. They believe that lean goals could serve as a catalyst for implementing green practices and help in achieving green goals as well.

Limitations – This work addresses lean and green but not agility and the PLC stages. In other words, it may not be sufficient for addressing changing customer requirements and demand uncertainty at PLC stages.

2.4.6 Agility and green

I. Vinodh (2010) believes that in the contemporary production environment, agility needs to be combined with sustainability in order to achieve improved product variety with minimal environmental impact; reduced lead time and economic sustainability.

Vinodh, (2010)'s approach involves a case study in the Indian rotary switches manufacturing enterprise employing the expertise of a computer aided design (CAD) software Pro/E and sustainability express. With the aid of CAD, 5 different knob models were created using the same material to be compared with the baseline model initially developed. The sustainability analysis was then carried out using Sustainability express which helped in screening the CAD models and baseline model to obtain environmental impact parameters. Environmental impact was measured in carbon footprint, air acidification; total energy consumed and water eutrophication. Using statistical t-test, Vinodh, (2010) observed agility and sustainability to have improved overall.

Limitations - It is observable that there is little literature on this subject. Vinodh (2010) described a way to sustainably source materials and producing products while considering agility. The author observed an improvement in agility and sustainability using the statistical t-test, but the work failed to specify exactly what has been improved in terms of agility. Most of Vinodh (2010)'s work centred on making the rotary switch more sustainable through the use of technology. Considering the overall evaluation criteria, Vinodh (2010)'s work, like most others in this category have not included the lean paradigm which is seen by some as two compatible initiatives. Again, the product life cycle of the product delivered, in this case rotary switches have not been considered.

II. *Agility and sustainability for business planning*: Singh and Vinodh (2017) demonstrates the application of an integrated framework for modelling, assessment and decision making for a system that integrates agility and green characteristics. The study deals with identifying mutual areas that address both agile as well as environmental aspects, and enables practicing managers and decision makers to identify suitable characteristics that would simultaneously improve an organization's agile performance by considering aspects of sustainability.

Limitations: Singh and Vinodh (2017)'s integrated framework serves the purpose of assisting managers in identifying suitable characteristics for improving agility and green aspects. However, it could serve a larger purpose and provide more utility if a manager knows that their organisations could also reduce lean wastes by applying this framework. Also the PLC has not been considered.

2.4.7 Lean, agility and green

I. *Conceptual model to identify synergies and divergences in implementing LARG practices*: Carvalho et al. (2011) developed a model to help companies develop a deep understanding of the relationships between the LARG paradigms. The model explored the contribution of the paradigms to the overall competitiveness of business. Cause-effect diagrams were used to represent the relationships between the practices of each paradigm and supply chain attributes.

II. Espadinha-Cruz et al. (2011) proposed a model to evaluate the overall business interoperability in LARG approaches in the context of the supply chain particularly in the automotive industry and establish what measures can reduce interoperability problems in the supply chain. The model utilizes the Analytic Hierarchical Process (AHP) to assess interoperability in the supply chain and identify what LARG practices are more interoperable in specific industrial businesses.

III. *Model to analyse the influence of LARG of performance*: On the assumption is that there is a set of lean, agile, resilient, and green practices that contributes to an improvement in the performance of the supply chain, Azevedo et al. (2012) proposed a conceptual model to explore the relationships between LARG practices and business performance. The model proposed a set of management practices that are related to an improvement in inventory levels, quality of products, environmental costs, costs and time.

IV. *LARG information model*: Cabral et al. (2011b)This presented an information model to support lean, agile, resilient and green paradigms. The information model provides the necessary information for decision-makers to make the right decisions at the right time and thus optimizing business performance. The model was proposed as a conceptual model to identify the relationships between LARG practices and metrics. This model was developed on the understanding that information sharing through the use of Information Technology (IT) is crucial for effective supply chain management. Furthermore, Cabral et al. (2011a) presented some Use Case Diagrams and a Class Diagram. The purpose of Use Case Diagram is to identify the systems requirements, i.e., the interactions that the system will have with the players. It considers different players; each can be supply chain entities or a super entity which will have a global perspective of the business.

V. *A decision-making model for LARG*: On the recognition that the selection of the best LARG practices and performance measures is a complex problem, Cabral et al. (2012) proposed an integrated LARG model based on the analytic network process (ANP) to support managers in selecting the most appropriate practices and performance measures to be implemented by companies. The model was validated with businesses in the automotive industry.

VI. *LARG framework for supplier selection*: In another study involving LARG, Hasanian and Hojjati (2016) proposed a framework based on literature review and fuzzy set theory for supplier selection criteria in LARG supply chain. The fuzzy method is used to evaluate suppliers, based on the determined criteria and characteristic weights.

The one limitation of these models is the absence of the PLC dimension in decision making, evaluating interoperability and information models as requirements change and as products proceed through their PLC stages (Aitken et al., 2002). The LARG frameworks could also be developed to apply to sectors other than the automotive sector.

2.4.8 Key limitations and associated gaps

From the 71 publications of this SLR, 31 frameworks were identified and reviewed. The following inferences can be made from a cursory analysis of table 1:

- Most of the available frameworks (15 frameworks/methods) involve single paradigms of lean, agile or green; followed by frameworks with a combination of 2 paradigms (9 frameworks/methods) and 7 frameworks combining the three paradigms.
- Of the frameworks combining the three paradigms, 100% of them are publications discussing the lean, agile, resilient and green (LARG) covering the period between 2011 and 2016 by Carvalho et al. (2011), Espadinha-Cruz et al. (2011), Cabral et al. (2011a), Cabral et al. (2011b), Cabral et al. (2012), Azevedo et al. (2012) and Hasanian and Hojjati (2016).
- Of the frameworks considered, only 9 of them have included some consideration/incorporation of the product life cycle. They included single paradigms and a combination of two paradigms (lean-green and lean-agile); and none combining the three paradigms with the PLC.

In both operations and supply chain management, the sustenance of competitiveness lies in the ability of enterprises to achieve an effective level of leanness, agility and sustainability which corresponds to the level of change and uncertainty in an operational system as well as the individual business environment (Pham and Thomas, 2012). There is strong evidence to suggest that the application of lean and agility and green would yield benefits in meeting customer requirements. Despite the importance of the paradigms to competitiveness, few studies have provided an integrated approach considering their simultaneous deployment. Furthermore, product characteristics need to be matched with the appropriate management paradigm and practices because as products mature through their product life cycles, customer requirements may drastically change (Fisher, 1997). A company needs to possess the appropriate mix of strategies to compete at all stages of the product life cycle (Aitken et al., 2002). With this realization, the integration of paradigms and product life cycles is often lacking.

Managers may also encounter challenges in selecting appropriate practices. It is not uncommon for managers to encounter situations where they would have to select from a set of alternatives. Without a set of criteria or a set of criteria that are grouped/related to various alternatives, decision making could prove difficult. Incorrect application of LAG practices could adversely affect the competitiveness of an organisation. In these kinds of situations involving multiple criteria and alternatives (that could conflict each other), a multi-criteria decision problem is faced and the availability of structured solutions in selecting appropriate practices is also often lacking.

2.6 Measures of Competitiveness

Cost reduction: Making efforts to reduce production costs is a powerful competitive advantage (Muehlhausen, 2012; Porter, 1985; Williamson, 2015). For this research, it indicates the extent to which practices adopted contribute to the reduction of production costs. This is an essential factor to be reduced in production in order to stay competitive.

Ploy et al. (2011) states that cost as a manufacturing performance indicator is the ability to effectively manage production cost and its associated aspects such as overhead cost, inventory cost and value added cost.

Along with changes of product models in a production line, equipment (including machines) are relocated considering the overall costs of material handling and reconfiguration (Sanchez and Nagi, 2001). Hence cost can be considered in terms of material handling costs and reconfiguration costs. The authors also include the cost of purchase of resources, total processing cost and the cost of all possible system reconfigurations as part of possible measures for cost. In other words, costs could be measured by what each practice takes out of the operating budget of a firm.

Sharifi and Zhang (1999) mentioned changes in order quantity as a possible cost measurement strategy. If changes in order quantity can be monitored, that could provide an indication of how sales has either improved or decreased.

Cost of production is usually measured in terms of financial expenditure required to transform raw materials into finished products (Young et al., 1997).

Lead time: The length of lead time directly affects the competitive abilities of a business, hence, the reduction of lead can be a competitive advantage (Pan and Yang, 2002; Villarreal and Salido, 2009). For this research it indicates the ability of the manufacturing enterprise to execute a particular job - from the date it is ordered to the date it is delivered - quickly and as soon as the order is placed. Lead-time needs to be minimized in production as excess time is waste, and leanness calls for the elimination of all waste.

Lead time, being the time from customer order to receipt by the customer (Lederer, 2008) is measured in exactly what it is defined by-time. This is usually in days or weeks depending on the product and/or the company. Lead time is an important attribute of production and it can be reduced by applying various practices.

Waste: Waste is a bye-product of everyday activities that creates a serious hazard to civilization (Begum et al., 2012). It is the amount of commercial, industrial and other material wastes produced in all forms of the production process including management activities which need to be reduced and how practices adopted correlates with the reduction in waste. In this research, practices which contribute more or less to the reduction of waste will be identified. Rehman (2012) states that impact analysis identifies the activities with greater and lesser environmental impact including percentage of waste recovered/recycled/sold/disposed of. The handling, treatment and disposal of wastes has costs attached to them and hence must be reduced in order to be competitive. Generated waste is used as a measure for green because it ties into aspects of environmental performance including clean and renewable energy generation, environmental impacts and emission of greenhouse gases (Begum et al., 2012). Greenhouse gas emissions could either be avoided or produced by waste management activity (*Digest of Waste and Resource Statistics – 2015 Edition*, 2015).

The United Kingdom department for environment, food and rural affairs stated that the purpose of its 2015 waste statistics release was to announce estimates which have been calculated to comply with the European commission (EC) waste framework directive, EC waste statistics regulation, EC landfill directive and EC packaging and packaging waste directive. In this document, information on waste have been measured and reported in 000 tonnes.

EPA (2015) reports that the majority of waste disposed in North London is sent to landfill, with the rest of it either recycled or burned. The government introduced a tax on every tonne of waste sent to landfill because landfill waste creates methane and a liquid called leachate which damages the environment through improper management. As at 2011, the cost of sending a tonne waste to landfill was £48 (EPA, 2015). From 1 April 2016, the standard tax rate has risen to £84.40 per tonne of waste to landfill (EFW, 2015). In these documents, information on waste have also been measured and reported in tonnes. Other documents discussing and reporting waste prevention strategies include Barnish, (2013) and Waste Prevention Strategy for West London 2011-2015.

The following sections review the impacts of lean, agility and green on these measures of competitiveness i.e cost, lead time and waste. This review helped in the development of the questionnaire.

2.6.1 Impact of Lean

According to Shah and Ward (2003) lean practices are associated with high performance. The authors further stated that the implementation of lean practices is associated with improvements in operational performance measures. The most commonly cited advantages related to the adoption of lean practices are improvements in labour productivity and quality, as well as reduction in cycle time, manufacturing costs and customer lead time (Shah and Ward, 2003). Shah and Ward (2003)'s research have investigated the impact of the practices associated with several lean bundles/categories (TQM, HRM and TPM) but no mention has been made of the impact of lean practices on any one of cost, sales or profits.

2.6.1.1 Impact of Lean on Costs

Mackelprang and Nair (2010) believe that cost performance is positively related with set up time reduction, pull system, uniform workload, lot size reduction and preventive maintenance. In other words these practices identified by Mackelprang and Nair (2010) help in the reduction of manufacturing costs. Nakamura et al. (1998) also agrees that preventive maintenance helps improve performance costs because it helps minimize the average percentage downtime of machinery due to failure as it helps to minimize losses from wages that must be paid despite the stoppage of work due to machine failure.

Kumar et al. (2013) states that material handling contributes to the total manufacturing costs by between 15% and 75%. The authors argue that this may be due the poor layout of facilities. This implies that a poor cellular layout of the manufacturing facility may lead to an increase in total manufacturing costs. This then entails that a suitably reengineered production process involving the appropriate physical layout of facilities and equipment could in fact mitigate the negative impact on manufacturing costs ascribed to material handling and related practices. Other lean practices as identified herein that could be closely matched with material handling are focused factory and planning and scheduling, these help reduce costs. On planning and scheduling, Eyong (2009) states that when providing customer satisfaction can be directly translated into reduced cost.

Liebesman (2009) believes that the elimination of variability which tallies with uniform workload helps reduce costs. Group technology has also been identified by Vázquez-Bustelo and Avella (2006) as a practice that provides key advantages for production centers while lowering costs. Through employee involvement (multifunction employees, self-directed work teams and quality circles), resources required to monitor employee compliance (e.g., supervision and work rules) can be minimized, hence reducing costs (Hibadullah et al., 2013).

Amin and Karim (2013) believes that implementation of the lean strategies just in time (JIT) and total productive maintenance(TPM) does not automatically increase profit of a firm as the benefits derived from their adoption may be offset by their many direct and indirect costs. Because, the adoption of both JIT and TPM requires extensive training of employees on pull concepts; identification of key performance measures; new layout based on U-shaped cells; standardisation of operations; a maintenance procedure for each machine; housekeeping, visual control and multi-skill training (Amin and Karim, 2013). The authors also believe that choosing to implement both JIT and TPM together without due consideration of the undesirable impact they may have on each other may lead to increased implementation cost. The benefits of Kanban according to Edward (2007) are realised in the longer term as a result of their high implementation costs.

2.6.1.2 Impact of Lean on Lead time

Sharma et al. (2015) performed multiple regression analysis to examine the impact of several lean manufacturing practices on lead time (The manufacturing practices being the independent variables). In their research, pull system was found to be a positive predictor (Nakamura et al., 1998; Sharma et al., 2015; Singh et al., 2013) while set up time reduction was observed to be a significant positive predictor for lead time reduction meaning that a reduction in set up time leads to a significant reduction in lead time, hence improving the lead time performance. Sharma et al. (2015) expressed surprise at the negative coefficient observed for total productive maintenance (preventive maintenance) as it was contrary to popular belief with respect to lead time reduction. This result is surprising given the fact that regular maintenance practices prevent machines from pre-emptive break downs thus reducing throughput time. The benefits of preventive maintenance in improving manufacturing lead time could have been achieved had the responding firms implemented preventive in its entirety. In fact, many firms that participated in the study fell short on this account Sharma et al. (2015). Other practices which were observed to have improved include quality circles and total quality control.

Reducing lead time for a fixed service level requires a reduction in average cycle time (Singh et al., 2013). Other practices believed by Singh et al. (2013) to reduce lead times include set up time reduction, bottle neck removal (also identified by de Treville et al., (2004)) - as the symptoms of bottlenecks/constraints include congestion slowdowns, queue formation and shipping delays. The authors observed that when bottlenecks were removed or reduced the average velocity of the production traffic increased. Time based competition, lot sizing (production in small/large batches), continuous flow production are other practices identified by de Treville et al. (2004) to contribute positively in the reduction of lead times.

Aitken et al. (2002) states that several designers co-operate and concurrently work on the same project hence increasing the intellectual capacity of the division and compressing lead times. Hence by extension, the lean practice quality circles could be of help in reducing lead times.

Focused factory and continuous flow production are also practices believed to reduce lead times as simplicity, repetition, experience and homogeneity of tasks are qualities which make that possible (Singh et al., 2013).

Continuous improvement helps expose wasted time within the organisation, and once it is exposed, it becomes a lot easier for the employees to identify and subsequently eliminate it. Hence continuous improvement helps reduce lead time through its capability to expose and eliminate wasted time (Zhang, 2008).

2.6.1.3 Impact of Lean on Waste

This could be viewed from the point of that lean and green have certain commonalities as discussed in previous sections. Sroufe, (2003) cited in (Yang et al., 2011) contend that firms who employ lean practices to reduce internal waste also adopt practices for improved environmental management and that environmental management encompasses activities from product development to final delivery and disposal of products.

Also, the waste reduction techniques of both paradigms are often similar, with a focus on business and production process practices (Bergmiller and McCright, 2009b in Dues et al., 2012). Waste reduction through a change in business practices is achieved by an adaptation of a corporate company culture (Mollenkopf et al., 2010 in Dues et al., 2012). This means changing the company's vision and integrating Lean and Green practices into support functions, such as administration and building maintenance. Both Lean and Green paradigm look into how to integrate product and process redesign in order to prolong product use, or enabling easy recycling of products as well as making processes more efficient, i.e. less wasteful (Sarkis, 2003 and Bergmiller and McCright, 2009b in Dues et al., 2012).

Modi B and Thakkar (2014) contend that effective preventive maintenance is a lean tool which eliminates equipment breakdowns, defects, scrap and rework, mini stoppages and reduced speed. It can therefore be said that since it eliminates defects and scrap among other things, it will also reduce waste generated.

Generally, lean orientation may help firms to adopt environmental management practices which aim at reducing pollutants and environmental wastes (Yang et al., 2010 in (Yang et al., 2011).

2.6.2 Impact of Agility

Lin et al. (2006) agrees with Yusuf et al. (1999) that agile enterprises in general have the capability of ensuring lower manufacturing costs, increasing market share, satisfying customer requirements, facilitating the rapid introduction of new products, eliminating non-value added activities (as in lean production)and increasing firm competitiveness. Thus, the agile enterprise is seen as the winning strategy in the 21st century's as it helps equip companies to become national and international leaders in an ever increasing competitive market of fast changing customer requirements.

2.6.2.1 Impact of Agility on Costs

The cost of agility may be associated with actions like buying flexible machines, efficient information systems for real time capture/sharing of information, capacity enhancement to tackle sudden demand (demand flexibility), extra employees to cope with extra production volumes and reduced time of production, the selection, development and nurture of dependable multiple suppliers to provide supply flexibility, the development of capacity for quicker production in terms of larger fleet and the upgrade of technology (Ravet, 2011).

Yusuf et al. (2004) states that the agile supply chain impacts on cost leadership, but the impact did not translate to business performance according to their study.

Sherehiy et al. (2007) believes that in order to bring products to the market as rapidly and cost effectively as possible, it is necessary to utilize all existing resources notwithstanding their location and cooperate internally and with other companies. Pasutham (2012) echoed the same tune by stating that operating costs can be reduced through the adoption of new information technology that enhances internal communication. According to van Hoek et al. (2001), operational cost savings can also be achieved through strategic postponement.

The use of evolutionary agents in virtual design environment supports a global evolutionary optimization process in which successive populations systematically select planning practices that reduce cost (Gunasekaran and Yusuf, 2002). Hence the authors argue that virtual organisation contributes among other performance measures to cost reduction. Martin (2009) links improved productivity and reduced buffer stock with lower costs.

Tseng and Lin (2011) believe that the agile practices quick response (decision making), speed in new product development and demand flexibility decrease manufacturing costs.

Pilz-Glombik and von Lanzenauer (2002) argue that rapid information flows and the assurance of error-free and timely data helps achieve cost reductions and sustained competitive advantages.

Bose and Pal, (2012) believe that firms with late entry into the market tend to have higher development and manufacturing cost.

2.6.2.2 Impact of Agility on Lead time

Nakamura et al. (1998) and Singh et al. (2013) believe that excessively large lot sizes contribute to long lead times. It then follows that implementing the practice small batch sizes would help reduce lead time

Aitken et al. (2002) states that several designers co-operate and concurrently work on the same project hence increasing the intellectual capacity of the division and compressing lead times. The ability to link and exploit the tacit knowledge of designers and suppliers helps improve competitive advantage. By extension, research and development for new product development, supplier partnership and internal communication could be a catalyst towards cutting lead times.

2.6.2.3 Impact of Agility on Waste

Young et al. (1997) believe that there are considerable opportunities to reduce waste, through innovations in product design and production processes, which will also lead to substantial cost savings and improved competitiveness. Hence it can be said that research and development for new products could lead to waste reduction which in turn will lead to improved competitiveness.

2.6.3 Impact of Green

Most companies express the business value of sustainability programs in terms of cost reduction through reduced energy and material use and reputation protection through voluntary commitments on labour, water, energy, greenhouse gas emissions, waste, renewable materials, toxic substances, ecosystems and habitats, and dozens of other issues (PricewaterhouseCoopers, 2010). Within the consumer products and automotive industries, products are becoming more carbon-efficient as retailers demand increased understanding of the complete life cycle impact of products (PricewaterhouseCoopers, 2010).

The study of the relationship between green supply chain management practices and organisational performance is one of the most popular subjects of research (Min and Kim, 2012 in Wang and Sarkis, 2013). Green supply chain management according to Wang and Sarkis, (2013) represents a firm’s effort on reducing irresponsible environmental behaviour.

Dyllick and Hockerts (2002) cited in Schrettle et al. (2014) argue that firms need to concentrate on longer-term goals while reducing focus on short-term benefits in order for green efforts to be successful.

Every business generates waste. For some, it may be only waste paper or dirty water; for some others, it may be hazardous wastes that require special handling and disposal. Regardless the type or volume of waste generated, it is all the same in one respect - it costs money. And in some cases, twice as much - once when it is bought it and the second time when you it is disposed of. The bottom line is that preventing waste saves money (US EPA, 2015).

By consuming and disposing less material, the need to handle, treat and dispose waste is reduced. Waste reduction could take but is not limited to the following forms:

1. Buying durable long lasting materials
2. Using products free of hazardous materials
3. Using less packaging
4. Implementing in-process recycling
5. Water/energy conservation

Waste prevention is a business strategy from which any company, regardless of size or type, can benefit from. In addition to cost savings, it can also help improve worker safety, reduce liability, and enhance image in the community. Furthermore, if the waste eliminated or reduced is regulated under state or federal law - and reductions are significant enough - costly permits and government approvals may be avoided. Zhu et al. (2007) in Rehman (2012) reports that green manufacturing has the potential of saving 0.5-1.5% of the total costs of production companies by investments paying back according to present economic standard. Clean and green environment would support economic development by methods of cost savings through waste segregation. Green manufacturing leads to production efficiency (i.e. less energy and water usage), lower raw material costs due to (i.e. recycling waste rather than purchasing virgin materials), reduced environmental and occupational safety expenses (i.e. lower regulatory compliance costs and potential liabilities), and improved corporate image (Ghazilla et al., 2015).

Environmental improvement through waste reduction should also reduce cost unless the anomalies of the cost system mask the effect (Lagenwalter, 2006). For instance: Baxter International saved $17,000 in three months by reducing water usage in one plant, with no capital investment. Its wastewater treatment plant no longer needed to expand (Lagenwalter, 2006). The Collins Companies, a wood-products company founded in 1855, reclaimed heat from ovens that cure hardboard coating. It saved $118,000 in electricity cost per year by installing a single, 300hp electric motor to replace six motors. Altogether, it saved an estimated $1 million in the first year of implementing sustainability principles (Lagenwalter, 2006).

Nageswara Posinasetto (2014) posits that the link between green manufacturing and cost and lead time have not been clearly established. However he does not believe that the pursuit of green is contrary to a firm’s interests regarding cost and lead time. On a more assertive note, Koechlin and Müller (1992) states that, ‘…contrary to a common misconception, environmental management keeps costs down rather than jacking them up.’ Furthermore, apart from environmental benefits of green manufacturing, Fischer et al. (2016) believe that green manufacturing has a positive effect on other aspects by improving product quality, improving production lead time and reducing costs.

According to Singh and Vidyarthi (2005) cited in Rehman (2012), the unscientific management of wastes generated by commercial and industrial activities could lead to serious environmental problems. An immediate proper disposal planning is required. To achieve overall Green disposal, no release of toxic substances in product life, end-of-life (EOL) treatment (recycling), collection of equipment, use of biodegradable materials, packaging materials and their disposal should be environmentally friendly. For better housekeeping Sroufe (2002) in Rehman (2012) advocates various activities including segregation of waste, minimising chemicals and waste inventories and installing various devices. Employee training is one of the suggested improvements aimed at reducing waste (Amani et al., 2015).

With reference to the amount of residual waterworks sludge, Babatunde and Zhao (2007) in Rehman (2012) identified and examined four broad categories of uses, which included different ways in which this can be reused. They further stressed the advantages of such reuse options and identified knowledge gaps. Singh Ajit and Vidyarthi (2005) determined the ranking order of fuzzy numbers which can help a decision maker make a suitable decision for rating of a specific landfill site which is an indication of the feasibility of disposal of solid wastes at the site.

In general, green practices ultimately caters for the minimisation of environmental impact by the reduction of toxics, waste, pollution, the optimisation of the use of raw material and energy by the application of end of life (EOL), cradle to cradle and close loop approach (Rehman, 2012).

2.7 Research Hypothesis

A test of hypothesis is a statistical test that is used to determine whether there is adequate evidence in a data sample to infer that a given condition is true for the whole population. It is intended to determine whether there is a relationship between two or more variables.

Based on the sample data, the outcome of test determines whether the null hypothesis is either accepted or rejected. The null hypothesis is the statement being tested, usually a statement of "no effect" or "no difference". A p-value is used to make the determination. If the p-value is less than or equal to the level of significance, which is a defined ‘cut-off point’, then the null hypothesis can be rejected.

H_1: Competitiveness (cost reduction, lead time reduction and green waste reduction) is improved by a combination of appropriate LAG practices at PLC stages.

The hypothesis H_1 of this research is based on the understanding of LAG impacts. This hypothesis was tested with the aid of the following sub-hypotheses outlined herein.

Sub-hypothesis 1 (SH_1): That neither lean, agile nor green at paradigm level work at PLC.
Sub-hypothesis 2 (SH_2): That outcomes vary with a combination of practices.

Sub-hypothesis 3 (SH_3): Paradigm level adoption of lean, agile, green is inefficient for waste reduction.

The method of hypothesis employed here is the hierarchy of hypothesis (HoH) as discussed by Farji-Brener and Amador-Vargas (2014). HOH is a method that proposes partitioning a single major hypothesis in this case H_1 into a hierarchy of sub-hypotheses (sub-hypotheses 1, 2 and 3). The general hypothesis is placed at the top of the hierarchy, and it branches into more specific sub-hypotheses which may also branch into even more specific sub-hypothesis. In this way, HoH integrates broad ideas as well as specific ones, which unify empirical tests under a common framework.

2.8 Summary

The literature review has critically analysed literature in the areas of lean, agility and green and identified the limitations of each paradigm. It has also analysed literature/works that combined paradigms example, lean and agility; agility and green; lean and green; lean, agility and green; and identified their limitations based on a set of critical evaluation parameters.

In summary, the following has therefore been deduced:

- Competition and changing customer demands will continue unabated requiring innovative strategies to address them.
- Organisations' need for cost savings, lead time improvement and the delivery of quality are crucial drivers for adopting manufacturing practices
- The lean and agile paradigms have been adopted as manufacturing strategies both in singularity and as a combination.
- Sustainability issues are adding complexity to the already daunting task of managing businesses but it has not been adequately explored in combination with lean and agility.

- The life cycle of products have not been adequately considered in the development of manufacturing strategies; lean, agile and green paradigms.
- The life cycle stages of a product have different characteristics and companies will need a reassessment and repositioning in strategies to address the different attributes of the stages for instance low demand in the introduction stage, etc.
- It will present a challenge for companies to address the fluctuations in attributes as a product proceeds through its life cycle (with the lean and agile strategies in this case) while keeping up with their environmental obligations.

This research argues that none of the works in literature has presented an integrated LAG strategy for the issues facing businesses with a consideration of PLC. The systematic literature review spelt this gap out more clearly as presented, hence the need for this research. The part of the literature review discussing the impact of LAG on performance measures helped in the development of the research hypotheses which are analysed and the outcomes presented in CHAPTER FOUR.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The effect of research method on the possible outcome of a research endeavour cannot be overstated. Whenever research is undertaken, it is important to adopt the appropriate methodology in order for the research objectives to be met and the findings validated (Steele, 2000; Fellows and Liu, 2003, 2003 in Akadiri, 2011). This chapter discusses the research design and methodology including their strengths and weaknesses and highlights the general approach to the research. The choice of research methodology and the reasons for its selection are also provided and mapped out against research objectives and associated tasks. This chapter links the literature review of the contribution of LAG practices on competitiveness (Chapter 2) to the findings (Chapters 4 and 5) to achieve the objectives of the thesis (stated in Chapter 1).

Section 3.2 presents the research philosophies which have been considered. Section 3.3 presents the research approach and section 3.4 shows the research strategy. These theories were used to justify the research method used in this research. Section 3.5 presents management decision making tools which have been used in this research. Section 3.6 is a presentation of the adopted research methodology for this research, clearly presenting the research roadmap which links the research objectives and the research roadmap. Section 3.7 presents the methods of data collection and analysis used in this research, providing a rationale for the statistics used in data analysis. Section 3.8 summarises the chapter.

3.2 Research philosophy

Philosophies have an important and sometimes equivocal relationship with research. Patton (2002) suggests that good philosophy does not necessarily produce good research, nor necessarily help to make effective researchers, but it can enhance our ability to understand the social world. Creswell (1994, 2003) argue that, while there are several classifications used to differentiate research paradigms, most of them share three fundamental elements focusing on ontology, epistemology and methodology. Ontology deals with the nature and form of reality in the physical world; while epistemology concerns the nature of knowledge, or the ways of knowing. Finally, methodology concerns the rationales behind the procedures used to research what it is believed it is possible to be known (Creswell, 1994).

It is possible to locate the present study in relation to the five main research paradigms discussed by Denzin and Lincoln (2011): positivism, post-positivism, critical theory, participatory and constructivism. For this study, post-positivism is the most relevant and it was used as the research paradigm to shape this study. The five main research paradigms that are mainly based on Denzin and Lincoln (2011) and Heron and Reason (1997) are discussed as follows:

3.2.1 Positivism

Positivism views the world as ‘real’ (Denzin and Lincoln 2011). The findings of research conducted under this positivism are seen as ‘true’ and unbiased knowledge. The research takes place in a controlled setting where hypotheses can be verified through quantitative methods; the results are believed to be either true or false. Operations management studies, such as this one, are not so easily quantifiable. ‘Reality’ is not so clear; results are blurry and open to the researcher’s interpretation and, to some extent, bias. This is because management is socially constructed and ‘reality’ in management research context is dependent on the researcher’s perspectives. No matter how objective the researcher tries to be, there will always be a degree of preconceived notions of the world that will influence the research process and results. Therefore, in general, this research paradigm does not completely suit the nature of the research being conducted here.

3.2.3 Critical Theory

Critical theory perceives reality as shaped by the values of society, politics, culture, economy, ethnicity and gender. Knowledge is subjective because findings are dependent on such values Denzin and Lincoln (2011). The methodologies applied in studies conducted under critical theory try to confront the notions of a phenomenon commonly held by respondents. The data analysis takes place as a dialogue between researcher and researched. This paradigm is more suitable to studies on the views of groups that share a characteristic that define their self, such as an ethnic group or a group of people from the same gender, for example. It is a highly political approach to research.

3.2.4 Constructivism

Under constructivism, reality is relative. It is socially constructed and knowledge (research findings) is subjective Denzin and Lincoln (2011). Knowledge is created by the researcher and the participants. Respondents’ realities are subject to the researcher’s realities and vice versa. Constructivists claim that meaning is constructed by human beings when they engage with the world they are interpreting. Humans do not create meaning, rather they construct meanings instead. However, Burr (2015) notes that in the construction of meaning or truth, humans may respond differently, even in the same situation or in response to the same phenomenon. Methodologically, reality is reconstructed through informed consensus. Qualitative methods are, then, the main data collection tools for research taken under this paradigm.

3.2.5 Postpositivism

Postpositivism differs from the positivism paradigm in the sense that it perceives the world in a less naive, more critical, way. Although reality can be apprehended, it can only be done in a partial and probabilistic manner. Studies conducted under postpositivism can only indicate there is a probability that the hypotheses are true or false. It adds a more critical approach to the research. Although unbiased research is ideal, there is some influence of the researcher on the investigation. Qualitative methods may be used to some extent, but modified forms of experimental and manipulative methods (field studies) dominate the methodological approach to postpositivism research Denzin and Lincoln (2011).

This paradigm is more suitable to operations management studies than the previous one since there is a more critical understanding of the world. A mix of qualitative and quantitative methods can be used to interpret and quantify findings. To a study like this – which aims to get input from respondents, however, a more open-ended approach is necessary. The researcher is not looking for the probability of a hypothesis being true or false. Instead, the researcher is trying to make sense of the meanings of the respondents' opinions about a topic. For this reason, this paradigm was chosen to mould the most significant parts of this research.

3.2.6 Participatory

The participatory approach to enquiry is presented here to highlight the constant development of research paradigms and knowledge. Heron and Reason (1997) argue that, under this research paradigm, reality is subjective-objective. The approach involves a more extensive epistemology than the others since it engages with four different ways of knowing: experiential, presentational, propositional and practical. Methodologically speaking, the participatory paradigm suggests a collaborative form of enquiry. In such an approach, both the researcher and the researched work cooperatively as co-researchers and co-subjects.

This paradigm uses qualitative methods and tries to avoid researcher bias by transforming researcher to co-subject and subjects in co-researchers. Becoming co-researchers and co-subjects is a process that requires a relationship between the researcher and the researched.

3.3 Research approach

Once a research philosophy has been adopted as a basic belief containing assumptions about the way in which the researcher views the world, research approaches in which the researcher develops theory and hypothesis are then considered. The nature of a research topic, its aims and objectives and the resources available largely determine its design (Creswell, 2003). These criteria largely informed the research method developed for carrying out this research. This research phase was achieved through deductive reasoning combined with extensive and critical reviews of a large body of literature, attendance of seminars and workshops, internet discussion forums and expert focus group approach. These helped to build up a theoretical background to the subject area, provided a foundation for achieving the research aim and insight into many of the major issues concerning the concept of sustainable development. The literature review in chapter two has gone through the critical points of current knowledge, including substantive findings as well as theoretical and methodological contributions to facilitate the aim of the research. The literature review covered the need to adopt an integrated approach towards the application of lean, agile and green practices and the importance of incorporating the PLC.

The information provided in the literature review shows that an integrated approach towards the adoption of LAG practices could serve as a strong foundation to achieving competitiveness; and that the PLC provides a platform for addressing customer requirements and changing competitive priorities. These provide the platform for further research on selecting more appropriate LAG practices for improving competitiveness given the dynamics of the market environment. The objectives posed a number of questions including:

a. To what extent are managers aware/knowledgeable of the lean, agile and green paradigms?
b. To what extent are managers aware/knowledgeable about the product life cycle concept?
c. What are the main reasons for the adoption of lean, agility and green?
d. Has product life cycle been considered by companies in adopting lean, agile and green practices?
e. How important are lean, agile and green paradigms in achieving competitive advantage?
f. What are the contributions of lean, agile and green practices to the reduction in costs, lead time and waste?

g. Does the market performance of products affect production?
h. What is the overall performance of the company regarding lead time reduction, waste reduction and cost reduction?

As a result of the multiplicity of research questions and diversity in the types of sources of data required for answering these questions, it became apparent early in study that the data would be both qualitative and quantitative in nature.

Research is an active, diligent and systematic process (Rajasekar et al., 2006) conducted in the spirit of inquiry, which relies on facts, experience, data, concepts and constructs, hypotheses, conjectures, laws and principles (Akadiri, 2011). Research design is the logical sequence that connects the generated empirical data to the initial research objectives of the study and ultimately to its conclusions (Yin, 2003).

There is a wide range of research methods and each can be used to elicit a specific type of information or combined to support and complement one another (Frankfort-Nachmias and Nachmias, 1996; Kane, 1985). The review of research methodology indicated there are several research methods. Yin (2003) suggests experiment, case study, survey, archival analysis and history as research methods. These various research methods fall into two classical and distinctive epistemological positions, which are qualitative and quantitative research methods. The combination of the two approaches is termed triangulation. The next sub-section provides a brief description of these research methods.

3.3.1 Quantitative research

Quantitative research has been described as involving the collection of numerical data; demonstrating a view of the relationship between theory and research that is often deductive; having a proclivity for a natural science approach; and having an objectivist conception of social reality (Bryman, 2015). In this approach, there is no space for researcher bias. Quantitative enquiry places emphasis on the measurement and analysis of casual relationships between variables, not processes (Denzin, 2003).

A quantitative approach may be appropriate if researchers are interested in teasing out the relative importance of various causes of social phenomenon (Bryman, 2015). By doing so, quantitative researchers believe that they can measure the associations among variables of a phenomenon and fully understand the existing relationships. Since findings are defined by statistical procedures, results can be generalised to a whole population of the sample investigated. Types of quantitative research are randomised experiments, quasi-experiments, multivariate statistical analyses and surveys (Cook and Reichardt, 1979;SJI, 1999). The effectiveness of the selected types depends on the nature of the research. The survey technique is the most widely used method in social science and also the most relevant to this study. It typically involves cross-sectional and longitudinal studies using questionnaires or interviews to collect large amount of data. According to Rubin and Babbie, (2012), the most common techniques are mail, personal and telephone survey.

3.3.2 Qualitative research

Qualitative research is a naturalistic approach that seeks to gain an understanding of phenomena within their own context-specific settings. It involves the researcher gaining a deep and 'all-inclusive' overview of the context being studied, often involving interacting within the everyday lives of individuals, groups, commodities and organisations (Gray, 2014). Capturing information on the responses and perceptions of the players in the field of study requires being attentive, abandoning pre-conceived notions about a subject, approaching the research with an open mind and being empathetic to those being studied (Gray, 2014).

According to Gray, (2014) qualitative researchers often differ in the kinds claims that they make. Some seek to emulate the traditional science while others choose to conduct an 'authentic' study providing original and trustworthy results within a specific context. The data gathering tools and resources in qualitative research include semi-structured interviews, focus groups, observations and analysis of materials such as documents, photographs, video recordings and other media. Flick (2014) listed a few disadvantages of this method to include: it takes a great deal of time to collect data and the analysis requires some degree of interpretation, which may be subjected to bias and subjectivity.

3.3.4 Triangulation

Combining both quantitative and qualitative research methods has proven to be more powerful than a single approach (Moffatt et al., 2006) and very effective (Lee, 1991). Triangulation is a process of using more than one form of research method to test a hypothesis (Brannen, 2005). This approach offers researchers a great deal of flexibility, whereby theories can be developed qualitatively and tested quantitatively or vice versa. The main aim of using triangulation method is to improve the reliability and validity of the research outcomes. Brannnen (2005) drawing on the work of Denzin (1970) argued that triangulation means more than just one method and data collection but also includes investigators and theories. He then outlined four different types of triangulation as follows:

- Multiple methods: can be a triangulation between methods and within methods.
- Multiple investigators: that is research is undertaken through partnership or by teams instead of a single individual.

- Multiple data sets: the gathering of different sets of data through the use of the same method but at different times or with different sources.
- Multiple theories: can be used in a single research.

3.4 Research Strategy

There are a number of research strategies available in literature: Experiment, Active research, Ethnography, Grounded theory, Archival analysis, Survey and Case study (Saunders et al., 2009). Due to the nature of this research, the last three are applicable to this research and are discussed below.

3.4.1 Archival analysis

There is a wealth of literature on the lean, agility and green paradigms but to varying degrees of integration, quality and integration with the product life cycle concept. The review of literature was extensively and critically undertaken throughout the study to build up a solid theoretical base for the research area and a foundation for addressing the problems and achieving the research objectives. Archival analysis is the most efficient, effective and cheapest method for gathering the existing wealth of literature on the subject matter to form a thorough understanding of the paradigms and their combinations. The review helped to identify gaps in knowledge and formed the basis for developing the framework to aid the adoption of an integrated approach to applying LAG in product life cycle stages.

Information was sought from various sources including academic publications, institutions and university databases, the Internet and conference notes attended. Moreover, information and knowledge was also gained by attending relevant courses.

3.4.2 Survey

Survey is one of the most widely used methods in social sciences to provide a representative sample of an area of study and serves as an efficient and effective means of looking at a far greater number of variables than is possible with experimental approaches (Czaja and Blair, 1996; Galiers, 1992). Survey research involves acquiring required information from people by asking relevant questions and tabulating their answers (Leedy and Ormrod, 2012). It involves eliciting information from respondents which can be achieved through questionnaires for data collection, with the aim of generalizing from a sample to a population (Babbie, 1990; Creswell, 2003).

3.4.3 Case study

According to Robson (1993), a case study is a strategy for doing research which involves the empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence. Case study research is typically employed to explore real life events over which the researcher has little control, and where the boundaries between the context and events are not readily evident (Yin, 2003). Stake (1995) states that from the use of case studies, researchers can establish generalizations that are true in diverse situations. A case study approach can thus be used to provide models, frameworks, or theories, which can then be extended to other cases in similar situations. The major aim of this research is to develop conceptual framework and to apply this proposed framework in a developing company – in order to better understand the contribution of LAG practices to business performance. Case studies can be particularly valuable because they generate rich subjective data.

3.5 Research tools in management decision making

On the basis of the research objectives, scope and motivation, this PhD research focuses on practical dimensions such as decision making which is an important aspect of management.

One of the systematic decision making tools used by companies to deal with their complex environments is the Analytic Hierarchy Process (AHP). AHP is a tool widely used in solving complex problems (Saaty, 2005). In some situations where decision makings involve forecasting or non-existing knowledge, expert-based tools such as the Delphi method are recommended (Linstone et al., 1975). Companies need decision making tools to deal with these issues.

3.5.1 AHP in management decision making

The AHP presents an advantage in solving a complex problem by arranging a decision problem and its factors in a hierarchical structure. This concept helps decision makers to better understand the relationship amongst factors. Subsequently, they can select a proper alternative which contributes the most to the hierarchical factors. The pairwise comparison is a natural means of decision as a hierarchy. Comparing two elements at a time by using ratio scale has an advantage in separating two elements having closely important levels (Saaty, 2000); thus, it could provide a clear-cut rank of factors than rating the large number of factors. To obtain the global priorities, the AHP first transforms the series of pairwise comparisons into consistent matrices, and derives local priorities which are correlated to elements in the same levels of a hierarchy. The AHP is discussed in more detail in CHAPTER FIVE.

3.5.2 Delphi method in management decision making

Delphi is a group process which utilizes written responses as opposed to bringing individuals together (Delbecq et al., 1975). According to the authors, it's a means for aggregating the judgements of a number of individuals in order to improve the quality of decision making. Delphi does not necessarily require face-to-face contact; however, it is useful for involving experts, resource controllers or administrators who cannot physically come together (Delbecq et al., 1975). The Delphi process has been used in various fields of study such as program planning, needs assessment, policy determination, and resource utilization to develop a full range of alternatives, explore or expose underlying assumptions, as well as correlate judgments on a topic spanning a wide range of disciplines (Hsu and Sandford, 2007). Delphi is essentially a series of questionnaires; the first one asks individuals to respond to questions that might focus on problems, objectives, solutions or forecasts and each subsequent questionnaire is built upon responses to the preceding questionnaire. The process ends when consensus has been reached or when sufficient information exchange has been obtained (Delbecq et al., 1975).

3.5.2.1 Types of Delphi

The Delphi method has been classified into several types according to the nature of research problem, data collection method and time constraint etc. for example: Classical Delphi, Decision Delphi, Conventional Delphi, Real time Delphi and Policy Delphi (Hanafin, 2004; Linstone et al., 1975). In this research, classical Delphi has been selected as it is the most fundamental Delphi method which aims to collect the judgement of participants and analyse it to be used as a reference in the next round. In terms of the communication approach between the researcher and the participants, email services were adopted. This type of Delphi meet the demand of this research: to keep the entire process confidential and participants could provide the most correct and honest answer without hesitation.

3.5.2.2 Characteristics of Delphi

The characteristics which distinguish the Delphi technique and make it most suitable for the purpose of this study are:

Use of experts

This is the feature which is perhaps, most commonly associated with the Delphi process. The expert is someone who is demonstrably informed about the issue in question and selected for the process as a consequence of their expertise.

Anonymity

Participants' personal information e.g. gender, age, name and contact information are not divulged to any other organisation. Answers and relevant comments will not be shared with other individual or organisation. The idea behind this is that it encourages a genuine opinion unencumbered by group processes or other external factors (Hanafin, 2004; Delbecq et al., 1975)

Feedback

Feedback provides a function to help all participants to consider the average or median value of that particular factor's importance in previous rounds. Experts' opinions are collated and fed back to the participants to allow amendment to the original views if they wish to (Hanafin, 2004).

Iterations

The Delphi method provides participants with a second chance to reconsider their initial answer, as well as using the group's answer as a reference, which can help them to think twice for the most correct answer. Participants are kept informed of the current groups's opinions, and this may influence further refinement (Hanafin, 2004).

Aims of using Delphi

The main aim of adopting a Delphi technique in decision-making is to provide a structured approach to collecting data in circumstances where the only available alternative is likely an anecdotal or an entirely subjective approach (Broomfield and Humphris, 2001). The features of anonymity, iteration with controlled feedback, statistical group response and expert input can expedite unanimity where there is contradictory or insufficient information to make effective decisions (Goodman, 1987; Hasson et al., 2000). Other group approaches to reaching consensus have been examined but have been found to be less appropriate for the validation of the the elements of a decision framework. These include, for example, nominal groups (Carney et al., 1996); focus groups; analytic hierarchy process (AHP) (Dong and Saaty, 2014); as well as the establishment of working groups. The main disadvantages with each of these techniques is their risk of taking account only of the perceptions of the most outspoken or opinionated members of that group or of only focussing on interesting or controversial elements (Fein et al., 1997).

Sukcharoensin (2017) deployed the Delphi technique for indicator selection and the validation of a framework for benchmarking the strategic position of bond markets in a competitive environment. In this research, the aim of adopting Delphi is to select appropriate measures of competitiveness and validate the elements of the proposed decision support framework developed as part of this research. The Delphi has been chosen for this purpose for the following reasons:

- The feature of guaranteed anonymity in responding to individual questions is that it is likely to encourage opinions that are free of influences from others and is therefore more likely to have a high degree of accuracy (Goodman, 1987).
- The use of questionnaires have the capacity to capture a wide range of inter-related variables and multi-dimensional features (Gupta and Clarke, 1996, p. 186) and enable a geographically dispersed group of experts to provide their understandings (Rogers and Lopez, 2002). Respondents can complete the questionnaire in their own time and this reduces time pressures and allows for more reflection and contemplation of response Linstone and Turoff (1975) in Hanafin (2004)
- The advantages of using questionnaire, including reduced pressure regarding time and other participants may increase the number and quality of contributions and can decrease respondent burden by allowing participation at the participant’s convenience (Hanafin, 2004).
- The feature of iteration is also another appealing characteristic of the Delphi, ensures that the outcome is ‘true’.

Number of feedback stages

Rowe (1994) acknowledges that the Delphi method has traditionally consisted four stages, however, there is diversity in the number of stages/rounds applied in order to reach a consensus depending on the purpose of the research. Delbecq et al. (1975) suggest that two-round iteration is also sufficient. Gustafson et al. (1973) used a two-round Delphi to estimate almanac events in order to investigate Delphi accuracy; Duncan (1995) applied a two-round Delphi to identify and rank the critical elements of the flexibility of the infrastructure of information systems and Roberson et al. (2005) used a two-round Delphi to explain how the specificity of recruitment message influences job seeker attraction to companies. McKenna (1994) and Hsu and Sandford (2007) highlighted that the likelihood that response rates may drop with each round of the Delphi is worth considering.

Principle of consensus

Consensus forming is the essence of the Delphi method (Agumba and Haupt, 2015;Giannarou and Zervas, 2014). When analysing data from a Delphi study, decision rules must be established to gather and organize the judgments and insights supplied by the Delphi subjects (Hsu and Sandford, 2007; Agumba and Haupt, 2015). However, the type of criteria to adopt in defining and determining the consensus in a Delphi study is subject to interpretation. Murry and Hammons (1995) defined consensus as a congregation around median responses with minimal divergence. Miller (2001) believes that consensus on a topic can be decided if a certain percentage of the responses fall within a prescribed range. Several suggestions have been made regarding desirable level of consensus in Delphi. Loughlin and Moore (1979) in Rowe (1994) suggest that consensus should be set at 59% agreement among respondents while McKenna, (1994) suggested a simple majority of 51%. Ulschak (1983) suggests that consensus is achieved when 80% of participants' responses fall within two categories on a seven-point scale. Expert agreement on the 7-point Likert scale was defined as a median (mdn) ≥ 5, disagreement as a mdn ≤ 3, and a mdn = 4 was considered neutral (Boulkedid et al., 2011; von der Gracht, 2012 in Paquette-Warren et al. 2017). Chen (2015) used the median, suggesting that any criterion with a median less than 3 should be removed.

Some studies favoured the use of standard deviation or interquartile range (IQR) to measure consensus, according to Christie and Barela, (2005) the standard deviation should be less than 1.5. According to Kittell-Limerick, (2005) the IQR should be less than 2.5 or 1 (Raskin, 1994; Rayens and Hahn, 2000). It is clear that the statistical measures used in Delphi analysis and feedback are measures of central tendency and/or dispersion measures of dispersion, these measures are used to describe the most typical response. Grobbelaar, (2007) made a decision on the level of consensus reached by using the standard deviation as follows: high level of consensus ≅ 0 ≤ X < 1; reasonable level of consensus ≅ 1 ≤ X < 1.5; low level of consensus ≅ 1.5 ≤ X < 2 and no consensus ≅ 2 ≤ X.

Crisp et al. (1997) in Hanafin, (2004) notes that measures of central tendency (mean, median) may or may not be accompanied by a measure of dispersion (standard deviation). von der Gracht, (2012) advised researchers to use the median rather the mean as outliers can unrealistically 'draw' the mean. An example of Delphi consensus is presented below on the selection of competitive measures.

3.5.2.3 Delphi for competitive measures

Given that a critical challenge in the fast-moving consumer goods (FMCG) industry is to efficiently serve increasing customer demands, Farahani et al., (2013), Found and Rich (2007) and Aljunaidi and Ankrah, (2014) believe that manufacturers are pushed to focus on cost reduction, and that this issue is even more critical considering that customer loyalty is often very low in this industry, and that a high competitiveness means that this has to be achieved at minimal cost. Also, long lead times have been considered as barriers in FMCG industry (Farahani et al., 2013), reducing lead times could therefore improve competitiveness in the FMCG industry. Furthermore, given the inevitability of companies having to take responsibility for the impact of their management decisions on the environment and comply with environmental regulations, environmental waste reduction is a reasonable consideration.

The performance measures showing the highest consensus rates are corroborated in the Delphi output shown in table 3.1, where participants were asked to rate a number of potential competitive priorities by their adequacy in measuring competitiveness, on a 1 to 7 scale where 1 is very inadequate and 7 is very adequate.

Table 3.1: Adequacy of competitive measures

	Quality		Cost		Flexibility		Leadtime		Dependability		Waste	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Agreement												
Very inadequate	0%	0%	0%	0%	0%	0%	0%	0%	4%	10%	0%	0%
Mostly inadequate	2%	0%	0%	0%	6%	6%	0%	0%	21%	14%	0%	0%
Somewhat inadequate	11%	10%	5%	0%	10%	5%	2%	0%	24%	22%	6%	0%
Neither adequate nor inadequate	17%	19%	11%	10%	32%	27%	11%	10%	38%	35%	17%	13%
Somewhat adequate	24%	22%	25%	25%	33%	37%	25%	25%	8%	8%	19%	21%
Mostly adequate	27%	35%	30%	30%	13%	14%	19%	21%	3%	6%	30%	37%
Very adequate	19%	14%	29%	35%	6%	11%	43%	44%	2%	5%	27%	30%
Importance												
Median	5	5	6	6	5	5	6	5	4	4	6	6
Range	5	4	4	3	5	5	4	3	6	6	4	3
Mean	5.21	5.35	5.67	5.90	4.56	4.81	5.90	6.00	3.40	4.00	5.54	5.84
Rank	4	4	2	2	5	5	1	1	6	6	3	3
Standard deviation	1.334	1.20	1.15	0.99	1.22	1.27	1.13	1.05	1.23	1.50	1.24	1.00

For this study, the decision has been made to use the standard deviation as described by Grobbelaar (2007). By this criteria, though flexibility and quality fall within the same reasonable consensus level as waste and lead time after the second round of the Delphi, the later duo is observed to have less dispersion form their median responses (standard deviation of 1 for waste and 1.05 for lead time respectively as opposed to 1.27 for flexibility and 1.20 for quality). In other words, the group consensuses are better converged at lead time and waste than at flexibility and quality. Only cost is observed to have a high level of consensus. This shows that the experts agree that cost, waste and lead time are more adequate measures of competitiveness than flexibility, dependability and quality. Furthermore, considering only the scales: mostly adequate and very adequate, the two-round Delphi indicates that waste reduction received the highest agreement among participants on the second round with 67% of the respondents reaching a consensus. Lead time and cost share a consensus rate of 65% on the second round. These are reasonable levels of consensus judging by McKenna (1994)'s suggestion. This was followed by a consensus rate of 49% for quality.

The impacts of LAG on the cost, lead time and waste have been also been discussed in the literature review. Though the literature discusses the positive and negative impacts of lean, agile and green practices on lead time performance, waste and cost, it points out that that cost performance is positively related with set up time reduction, pull system, uniform workload, lot size reduction and preventive maintenance (Mackelprang and Nair, 2010); implementing small batch sizes would reduce lead time and that that green manufacturing has a positive effect on improving product quality, improving production lead time and reducing costs (Fischer et al., 2016).

3.6 Adopted research methodology

There is neither a fast rule to selecting research methods nor is there a best research method, as the use of each research method depends on the form of research question, the research objectives and contextual situation (Yin, 2003). The selection of the most suitable research method depends largely on the research objectives and the type of data needed for the research. Because of the broad scope of the study and the managerial context of the research, a wide range of research techniques was adopted to achieve the research aim and objectives.

This subsection discusses the overall research methods used for the study and justifies the reasons for using them. Table 3.2 presents the research road map, it maps the phases of the research with the research objectives and tasks as well as the various research methods adopted. In addition, the table shows the main research outputs, which consists of decision support framework and the PhD thesis.

The design of a research is largely determined by the nature of a research topic, its aims and objectives and the resources available (Creswell, 2003 in Akadiri, 2011).The research process followed in this study consisted of a number of stages which are mentioned herein and discussed in the subsequent sections and sub-sections. At the initial stage of the research, problems were identified from preliminary review of the literature. This process involved various stages of revisions of the original ideas until gaps were identified within the area of research interest.

The research aim was then identified based on the research gap, and the research objectives were derived from the aim, after several revisions. Then, to address the research aim, literature was further studied with focus on a number of areas. Firstly, lean, agility and green as well as their practices were researched, secondly, product life cycle perspective was researched, and finally, the performance measures cost, lead time and waste along with impact of the lean, agile and green on the measures. The next stages include questionnaire development, data collection and analysis and the development of the AHP and result generation.

Table 3.2: Research roadmap

PHASE	OBJECTIVES	TASKS	METHOD	CHAPTER
REVIEW	1. Desk research	1. A review of related literature on the paradigms	AA	Chapter 2
		2. Review the various combinations of lean, agility and green including practices		
		Identify lean, agile and green practices in consumer packaged goods		
		3. Review available literature on lean, agility and green with consideration of product life cycle		
		4. Investigate contribution of lean, agility and green including practices to the reduction of cost, lead time and environmental waste	AA	
SYNTHESIS	2. Field research	5. Identify lean, agile and green practices in consumer packaged goods industry through pilot and main survey questionnaires	S	Chapters 4 & 5
		6. Identify product life cycle stage matching to the lean, agile and green practices through pilot and main survey questionnaires		
		7. Identify mix of lean, agile and green practices used in company at product life cycle stage through pilot and main survey questionnaires		
		8. Investigate the contribution of lean, agile and green practices to the reduction of cost, lead time and environmental waste through main survey questionnaire		
APPLICATION	3. Develop decision support framework for selecting the right mix of lean, agile and green practices at PLC stages	9. Use main survey data to develop knowledge base of the framework	S	Chapters 5
		10. Develop decision support module of the framework using AHP		
		11. Develop the analysis and comparison module of the framework		
	4. To verify and validate the new decision support framework	12. Verify the framework using Delphi study	S	Chapters 6 & 7
		13. Validate the framework using face validity and case study research		

KEY: AA (Archival analysis) CS (Case study) S (Survey)

3.7 Method of data collection and analysis

3.7.1 Questionnaire Survey

A Questionnaire is a list of research questions delivered to participants to collect data by asking a set of relevant questions (Bryman, 2015; Leedy and Ormrod, 2012). Questionnaires were utilised as they are proficient and valuable in gathering information from a large population over a wide geographical area. Also, it is a relatively inexpensive data collection and processing method as suggested by (McQueen and Knussen, 2002). Although questionnaires have shortcomings such as low response rates (for questionnaire surveys) and the risk of bias, this strategy offers the opportunity to explore a broad range of issues such as those envisaged in this research. The survey research design was adopted to provide, as indicated by Creswell (2003), a quantitative description of trends, attitudes, or opinions of the population by studying a sample of that population. Specifically, a questionnaire survey of top level managers was conducted with the questionnaire designed to:

- Elicit information on the product life cycle stage based on expert knowledge and experience of respondents.
- Investigate the impact of LAG practices on cost, lead time and waste. In other words the contribution of LAG practices towards cost reduction, lead time reduction and waste reduction given product life cycle stage.

The accuracy and success of questionnaire surveys largely depend on the careful design of its content, structure and the response format. Hence, certain precautions must be taken in designing questionnaires (Hoinville et al., 1985): the questions must be clear and easily understood by the respondents; should be easy to be administer by the interviewer; the recorded answers can be easily edited, coded and transferred onto a computer file for statistical analysis; and its flow, length and structure must motivate respondents to complete the questionnaire. Considerable effort was therefore devoted towards this endeavour.

The traditional form of questionnaire survey is the postal questionnaire but the use of electronic mailed questionnaires over posted questionnaires is gaining momentum due to the increased speed and lower cost.

In order to achieve the objectives of this research, the questionnaire-survey was developed and delivered in three stages. In the first stage the questionnaire was designed and used to run a pilot study. The second stage which is the main questionnaire-survey involved the delivery of the questionnaire following the outcome of the pilot study. At the initial two stages, the questionnaire-survey was used to elicit information on the experience of respondents; their position in the company (ideally a production manager); awareness of the paradigms considered for this research (Lean, agile and green); their practices as well as their importance; type of company and awareness of the product life cycle.

Having learned about the expertise of the respondents, the third stage of the questionnaire-survey was then developed and used to elicit information based on product life cycle stage about the contribution of the LAG practices on cost reduction, lead time reduction and waste reduction. This was used for AHP and to rank the practices according to product life cycle stages. E-mail was used in the distribution of the questionnaires. The questionnaire-survey was anonymous; the participant names were not associated with their responses. Follow up email is a method of increasing the response rate of a survey (Sheehan & Hoy, 1999).

3.7.1.1 Pilot study and main questionnaire

The reason for conducting a pilot study prior to the main questionnaire survey in this research was to identify any particular issues that would be valuable to follow in more depth, or would form a particular barrier to the investigation. Pilot survey was used to assess the survey items' readability and clarity so that such issues can be addressed in the main survey. Professionals with experience in the fields under study participated in the pilot study.

The main survey was used to gather information that addresses the objectives of the research, such identifying the Lean, Agile and Green practices in the FMCG industry; identify the manufacturing strategy (mix of lean, agility and green practices) adopted for the products given their life cycle stage; investigate the contribution of lean, green and agility practices to cost reduction, lead time reduction and waste generated at PLC stages and identify the PLC stage of FMCGs.

3.7.2 Data Analysis Methods

Data analysis is of paramount importance in order to turn raw data into useful information by statistical and quantitative methods so that conclusions can be drawn. Various statistical techniques were employed some of which include descriptive statistics, correlation coefficient (mean ranking), regression analysis, correlation analysis and analytic hierarchy process. The data gathered was analysed with the aid of SPSS 20 applying a selection of statistical techniques which also include ANOVA.

3.7.2.1 Descriptive Statistics

This involved the use of frequencies, percentages and means (see appendix thirteen) for presenting descriptive findings of the survey. These techniques were employed for analysing data related to the characteristics of the respondents and their organisations. They were also used for the initial analysis of rating score data of the various research variables.

3.7.2.2 Analysis of Variance (ANOVA)

In statistics, one-way analysis of variance (abbreviated one-way ANOVA) is a technique used to compare means of three or more samples (using the F distribution), since the two groups case can be covered by a t-test. This statistical method was used to rank the level of the respondents awareness (how knowledgeable the respondents are) on lean, agility and green. The t-value column provides the individual significance of each independent variable in the regression equation and tells whether the variable is making statistically significant contribution. A variable must have a significant value of alpha less than 0.05 to make a significantly unique contribution.

3.7.2.3 Regression Modelling

Modelling in this case refers to the development of mathematical expressions that describe in some sense the behaviour of a random variable of interest (Rawlings et al., 2006). Regression analysis is a statistical tool for the investigation and modelling of relationships between variables (Montgomery and Peck, 1992). The basic idea of regression analysis is to obtain a model for the functional relationship between a response variable (often referred to as the dependent variable) and one or more explanatory variables (often referred to as the independent variables) (Ott and Longnecker, 2008). Usually, the investigator seeks to ascertain the causal effect of one variable on another (in this case the effect lean, agile and green practices on cost, lead time and waste). To explore such issues, the researcher assembles data on the underlying variables of interest and employs regression to estimate the quantitative effect of the causal variables upon the variable that they influence.

At the outset of any regression study, one formulates some hypothesis about the relationship between the variables of interest - lean, agile and green practices with cost, lead time and waste (Skyes, 2005).

The regression model for this research is formulated and fully explained in chapter five.

3.7.3 Rationale for statistical tests

Burns (2000) argues that there is no cast-iron rule for choosing an appropriate statistical test. Tests vary in the assumptions that they make, their power, and the types of research design for which they are appropriate (Burns, 2000). There are two main groups of statistical tests, they are non-parametric and parametric. Non-parametric tests are designed to be used in situations where available data are not normally distributed while parametric tests are used with numerical data (Saunders et al., 2009; Gray, 2014).

There has been some controversy regarding the power of tests among statisticians. However, Burns (2000), Saunders et al. (2009), Sullivan and Artino (2013) and Gray (2014) argue that parametric tests are considered more powerful as they are able to calculate variances as well as consider the rank order of scores. Also, in a test of hypothesis, a false null hypothesis is likely to be rejected with a non-parametric test than with a parametric test. In other words, parametric tests are more likely to reject the null hypothesis when it should be rejected (Burns, 2000; Gray, 2014).

Although parametric tests are considered more powerful, a number of assumptions about the data being analysed need to be satisfied in order to avoid spurious results. Saunders et al. (2009), Pagano (2012), Romano (1977) and Hamburg (1985) list the following:

I. Linearity: This examines the strength of the relationship between the independent and dependent variables.

II. Normality: All errors should be normally distributed. In other words, the data should be drawn from normally distributed populations. This can be tested evaluating the skewness, kurtosis and histogram plots.

III. Homoscedasticity: It is important to know whether the variance differs from sample to sample. Also referred to as the homogeneity of variance, this requirement expects all the variances of the residuals across all levels of the independent variables to be consistent. This implies that there is the same amount of variability around the regression line. This the most important assumption underlying regression and analysis of variance (Crawley, 2013). It is tested by plotting the residuals.

IV. Independence: The errors associated with one observation are not correlated with the errors of any other observation.

For this research, data has been collected based on likert responses, therefore the question arises as to whether this form of data could in fact fulfil the assumptions stated above. This is also a controversial issue in statistics as likert scales produce ordinal data where descriptive statistics such as means and standard deviations, have unclear meanings when applied to the responses from likert scales. However, Sullivan and Artino (2013) argue that parametric tests tend to give the right answer even when statistical assumptions such as that of normality are violated. Romano (1977) suggests that the method of least squares can be used to obtain estimates if these assumptions are not satisfied. Thus, parametric tests can be used with ordinal data, such as data from likert scales. The questionnaire data for this research was tested based on the assumptions for parametric tests and the results are presented herein.

3.7.3.1 Independence, Homoscedasticity and linearity

A plot of jackknife residuals versus predicted values indicates whether or not assumptions of homoscedasticity, independence, and linearity are violated. If a model is well-fitted, there should be no pattern or curvature to the residuals plotted against the predicted values. The plot in the figure 3.1 shows that scatter appears to be quite random with no evident funnelling or sinuous pattern. Therefore, assumptions of homoscedasticity, independence, and linearity are not notably violated.

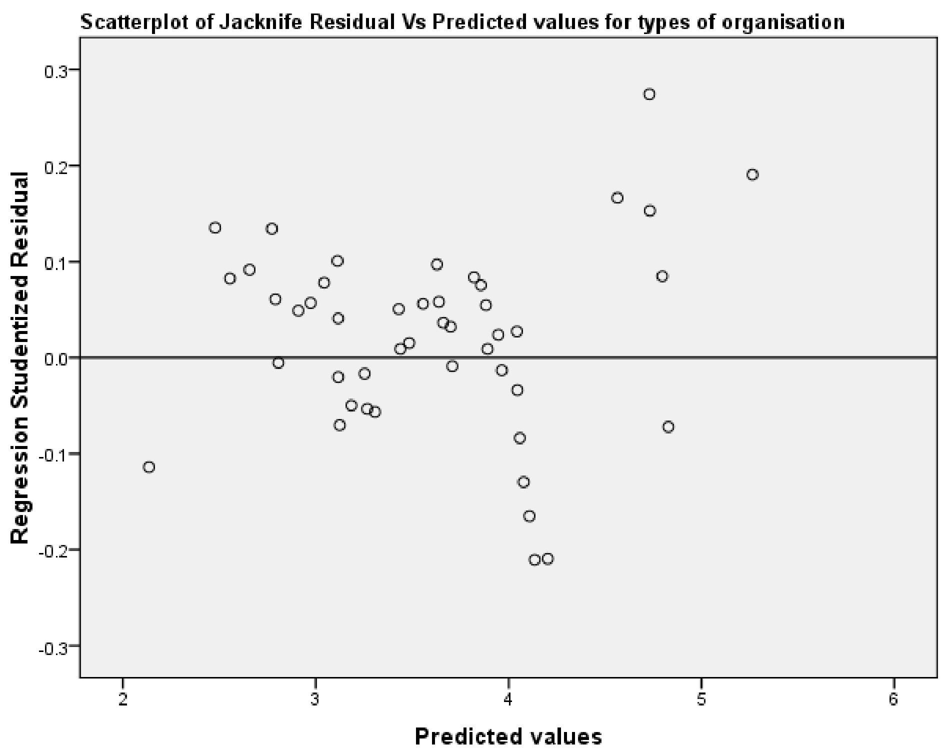

Figure 3.1: Scatterplot of residual against predicted values

3.7.3.2 Normality

A normal probability plot of Jackknife residuals figure 3.2 shows a graph of the ordered observations versus the normal order statistics means. If the sample follows a normal distribution, then this plot should manifest as a straight line at an estimated 45-degree angle. In the following normal probability plot figure, the dot sign do not generally seem to deviate strongly from the 45-degree reference line. Therefore the assumption of normality is satisfied.

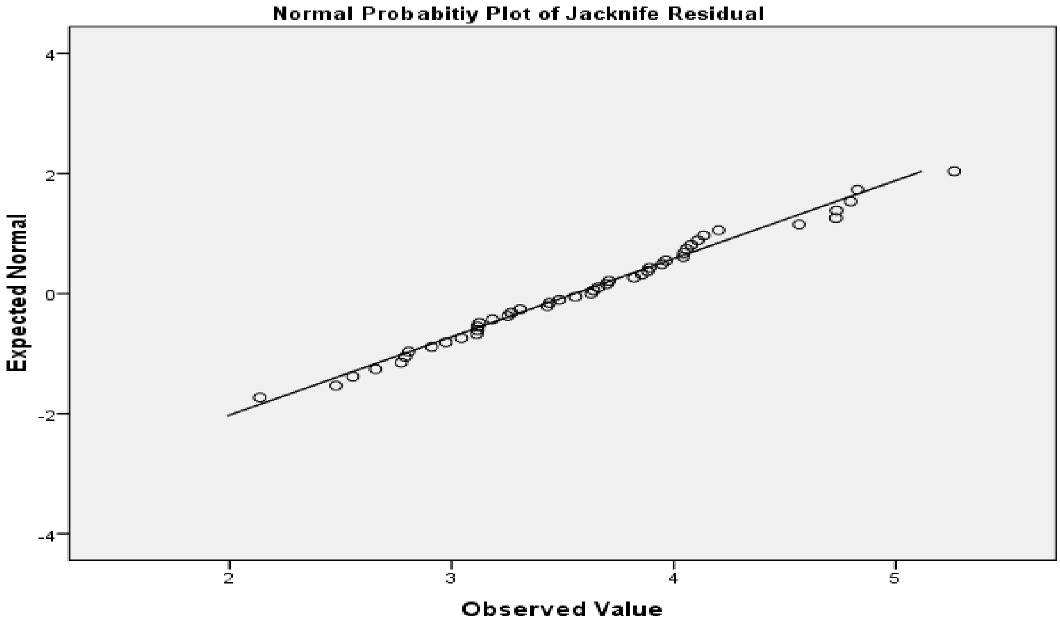

Figure 3.2: Normal probability plot of jacknife residuals

The test of normality table below further strengthens the satisfaction of normality assumption. The null hypothesis for this test is that the data are normally distributed. If the significance value for the standardized Residual under Shapiro-WilK is less than the p-value, then the null hypothesis that the data are normally distributed is rejected. However, the p-value (0.442) is greater than 0.05. Therefore, do not to reject H_0 and conclude that there is sufficient evidence to conclude that the data are normally distributed.

Table 3.3: Test for normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Predicted Value	.076	39	.200*	.981	39	.620
Standardized Residual	.077	39	.200*	.976	39	.442

a. Lilliefors Significance Correction

Another test of normality is the histogram generated from the Jackknife residuals assesses the distribution of the variable. A normal distribution is approximately symmetrical and should have a skew of zero as the histogram shown in figure 3.3 suggests through its appearance of symmetry and bell shape.

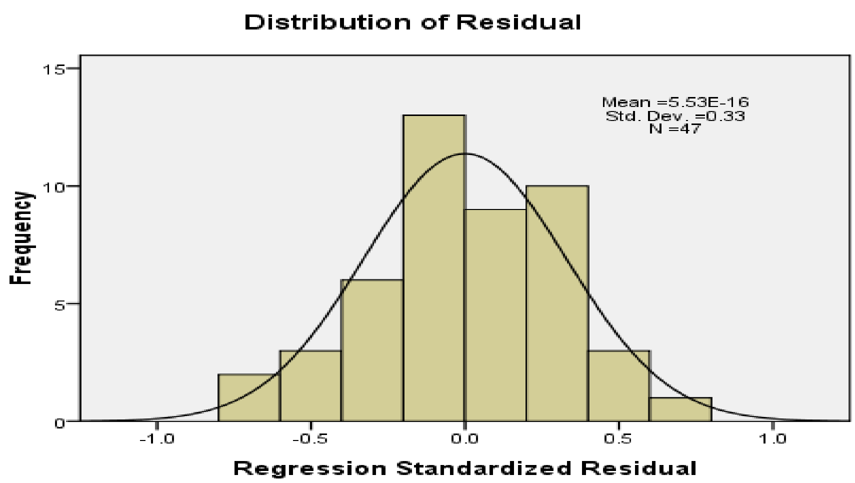

Figure 3.3: Distribution of residuals

3.8 Summary of Research Methodology

This chapter has provided the research methodology implemented in the course of this research. Combinations of approaches have been implemented to allow a comprehensive research of the lean, agile and green practices most suited to a given product life cycle stage in order to reduce costs, lead time and waste generated in the production process. These approaches helped in accomplishing the research aim and objectives as summarised in the research roadmap which links the research objectives with the research process.

This chapter also lays out the justification for the use of parametric tests in analysing the data as presented in CHAPTER FOUR. The data was shown to have been taken from a normally distributed population; that the variability around the regression line is consistent and assumptions of independence and linearity are satisfied. This goes a long way in showing that the outcomes of the analysis are reasonably accurate.

This section also presents the Delphi technique and outlines why it has been used in this research. The Delphi was used to show that the performance measures, cost, lead time and waste are appropriate measures of competitiveness for this research in the context of the fast moving consumer goods (FMCG) industry.

CHAPTER FOUR

PILOT AND MAIN SURVEY ANALYSIS

4.1 INTRODUCTION

This chapter reports the results of the pilot study, sample size determination, response rate and characteristics of the survey respondents. The results of hypothesis testing are also reported herein. The data were collected from professionals possessing knowledge of the lean, agility and green management paradigms who worked in the fast moving consumer goods industry. The survey was administered via e-mail delivery.

Section 4.2 presents the results of the pilot study, stating the objective of the pilot study. Section 4.3 discusses the development of the questionnaire which was then used for the main survey. The contents of the questionnaire are also highlighted therein. Section 4.4 presents the results of the main survey analysis including the outcome of the tests of hypotheses. The outcome of the tests of hypotheses practically demonstrates the need for this research as they confirm the inadequacy in adopting Lean, Agility and Green without practices, on their own, and that benefits are realisable in adopting Lean, Agility and Green practices. Section 4.5 presents the chapter summary.

4.2 Pilot Study

Saunders and Lewis (2011) believe that a pilot study is essential in providing a focus mechanism to clearly establish the research direction. Similarly, Munn and Drever (1999) believe that such test run surveys are crucial in revealing the methodological diligence and precision of a survey. The sample employed in this survey was obtained from the Institute of Operations management (IOM) in the United Kingdom. Overall, 30 individuals were randomly emailed questionnaires to complete, taking into consideration their experience and position in either their current or previous place of work.

Of the 30 pilot questionnaires sent out, 14 were returned indicating a response rate of 46.6%. This compares positively with the 33% response rate realised in Akadiri (2011)'s pilot study where 40 questionnaires were sent out and 13 returned. It also compare positively with the 20% response rate realised in the pilot survey stated in Xiao (2002). Mathers et al. (2007) also corroborate the sample size for the pilot study, stating that it is ideal to test the questionnaire on a small number of 5 to 50 respondents from the target population. The questionnaire was tested on the units in the population to evaluate its clarity and comprehensiveness. As a result of the analysis of the pilot questionnaire-survey, the questionnaire was put through an activity of amendments and modifications to ensure it is more appropriate for the main questionnaire-survey. This helped to detect short comings in the questionnaire. One of the short comings detected was that some of the questions were left unattended to. From the feedback provided by respondents, another short coming of the questionnaire is that on average it took a respondent 35 minutes complete. It was therefore considered necessary to reduce the overall number of questions in the questionnaire to make it shorter. Some of the questions were also re-worded as the feedback from the respondents seemed to suggest that they found them ambiguous. Having fulfilled the necessity to pre-test the questionnaire and having finalised the modification of the questionnaire, it was set for distribution and use in the main survey.

This chapter discusses the results of both the pilot and main survey analyses. The pilot survey was distributed to a random sample of 30 individuals with 14 returned. The pilot survey allowed for easy detection of obstacles and discrepancies in the main questionnaire. The problems identified were that some of the questions which are germane to the aim and objectives of the research were left unanswered and some of the respondents ticked more than one option in a question. The other problem was that the questionnaire took too long to complete and some of the questions were seen as ambiguous. As a result, some of the questions were restructured and it was clearly stated in the main survey questionnaire that only one option should be ticked.

Targeted at senior staff in the FMCG industry, the questions in the pilot survey bordered around the following:

i) Determination of the level of awareness of the lean, agile and green paradigms and it also determines the level of awareness of the product life cycle concept
ii) Determination of the reasons/motivations for adopting any of the paradigms
iii) Determination of the scale of importance of the various lean, agile and green practices in the product life cycle stage where they are adopted.

4.2.1 Summary statistics for Pilot Study

The summary statistics of the analysed variables for the level of awareness of the respondents regarding the lean, agile and green paradigms are presented in table 4.1. Table 4.1 gives a measure of how the overall model fits and how well the predictors are able to predict the dependent variable.

Table 4.1: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.501	0.251	0.001	1.091	1.995

a. Predictors: (Constant), Level of awareness; Green, Level of awareness; Agility, Level of awareness; Lean

b. Dependent Variable: Type of organisation

For multiple regression models, R is the correlation between the observed and predicted values of the dependent variable; it ranges from -1 to 1. Values very close to 1 suggest a high positive correlation. R^2 is the proportion of variance in the dependent variable which can be predicted from the independent variables; it is the square of this correlation (R) and it ranges from 0 to 1, if there is no linear relation between the dependent and the independents variable, R^2 is 0 or very small. If all the observations fall on the regression line, R^2 is 1. A linear regression model which may have more than one independent variable is an equation of a plane dimensional space which can be visualized geometrically. Table 4.1 shows that 25.1% of the total variance in the dependent variable can be explained by the independent variable. It is also called the coefficient of determination. The adjusted R-square attempts to yield a more accurate to estimate for the value of R-squared for the population; in other words, it is a modified version of the R-squared. The value of Adjusted R-square is 0.001. The standard error of the estimate also referred to as the root mean square error, is the standard deviation of the error term, and is the square root of the Mean Square Residual (or Error); it is a measure of the differences between values (sample and population values). The Durbin Watson statistic is used to test for the presence of serial correlation among the residual. The value of the Durbin Watson statistic ranges from 0 to 4. As a general rule of thumb, the residuals are uncorrelated if the Durbin Watson statistic is approximately 2. A value close to 0 indicates strong positive correlation while a value of 4 indicates strong negative correlation. In other words, the Durbin Watson statistic is used to detect the presence of auto-correlation (a relationship between values separated from each other by a given time lag) in the residuals (prediction errors).

Table 4.2 (coefficients) presents the summary of the levels of awareness (LOA) for lean, agility and green. None of the attributes make statistically unique contribution to level of awareness at 95% confidence level (A variable must have a significant value of alpha less than 0.05 to make significantly unique contribution). The standardized beta coefficients which provide the order of importance (or relative contribution to the level of awareness) show that the level of awareness figure for green makes the largest contribution, followed by lean, then agility.

The multiple regression equation which relates the level of awareness to the organisation is given by the constant and the coefficients of the unstandardized beta as:

LOA = β + βLean + βAgility + βGreen

Table 4.2 LOA Coefficients

	Unstandardized coefficients		Standardized coefficients		
Model	B	Std. error	Beta	t	sig
Constant	0.555	2.907		0.191	0.853
Level of awareness: Lean	0.855	0.824	0.343	1.037	0.327
Level of awareness: Agile	-0.227	0.698	-0.103	-0.326	0.752
Level of awareness: Green	0.727	0.537	0.433	1.354	0.209

Dependent variable: Type of organization. R^2=0.251(25.1%). F-statistics=1.005(P>0) Durbin Watson=1.995

LOA (level of awareness) = 0.555 + 0.855Lean - 0.227Agility + 0.727Green

The equation above shows that lean and green levels of awareness are positively correlated to the type of organisation. Hence the conclusion can be made that the lean and green levels of awareness are highly positively correlated, the higher the correlation, the better the paradigms and their practices are at achieving improved competitiveness. The equation shows that the level of awareness for agility is low, this could have an impact on the questionnaire and results as respondents are less aware of agility. This is also reflected in literature as one of the limitations of agility is that lack of understanding is the reason for low adoption of agility.

The t-value column in table 4.2 provides the individual significance of each independent variable in the regression equation and tells whether the variable is making statistically significant contribution. A variable must have a significant value of alpha less than 0.05 to make significantly unique contribution.

The F statistic shown in table 4.3 is used to test the hypothesis that the slope is equal to zero; the linear relation is highly significant if the p value for the F is less than 0.0005. The F-value is the Mean Square Regression (1.197) divided by the Mean Square Residual (1.191), yielding F=1.005. The p-value associated with this F value is very small (0.0000). These values are used to answer the question "Do the independent variables reliably predict the dependent variable?" The p-value is compared to the alpha level (typically 0.05) and, if smaller, the conclusion is "the independent variables reliably predict the dependent variable". That is that lean, agility green can be used to reliably predict the type of organisation the respondents works (the dependent variable). If the p-value were to be greater than 0.05, then the independent variables does not show a statistically significant relationship with the dependent variable (that is they do not reliably predict the dependent variable).

Table 4.3: Analysis of variance (ANOVA)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.590	3	1.197	1.005	.434[a]
	Residual	10.718	9	1.191		
	Total	14.308	12			

4.3 Questionnaire Development

Questionnaire is a measuring instrument comprising close-ended (respondents choose from a given set of answers) and/or open-ended questions (respondents record their views and opinion in full). The literature review in CHAPTER TWO helped in the formulation of the questionnaires which has been used in this research.

4.3.1 Contents of the Questionnaire

The questionnaire was divided into five sections for easy analysis and reporting.

(A) Background of respondent: It is crucial that the respondents have a high enough position within the company they either work in or have worked as this would ensure that they are aware of the lean, agile and green practices adopted and the circumstances under which they were adopted (for example product life cycle stage). The production manager position was especially preferable and targeted because the responsibilities attached to it includes but is not limited to: overseeing the production process, drawing up a production schedule; ensuring that the production process is cost effective; ensuring that the products are produced in good time; working to implement the company's policies and goals; estimating, negotiating and agreeing budgets and timescales with clients and managers (Target, 2012; Prospects, 2016).

(B) General Information: This part of the questionnaire is included especially to ensure that the company from which the respondents' information is coming are in the fast moving consumer goods (FMCG) industry.

(C) Awareness of lean, agile and green: This part explores the level of awareness of the respondents on the concepts of lean, agility and green (LAG). It is also for the respondents to indicate their reasons for adopting LAG and to rank those reasons.

(D) Product life cycle awareness: This section deals with product life cycle (PLC) and how knowledgeable the respondents are on its stages and whether products can be identified within those stages. A high rating would indicate that the respondent has good knowledge of the PLC concept and hence can authoritatively answer the next section E

(E) Lean, Agility and Green practices employed for the specific Life Cycle stages and their importance: This section is for exploring the importance of the specific LAG practices for each life cycle stage. Here the respondents identify the practices they have adopted, the product life cycle stage where they were adopted and rate the importance of the practices for that PLC stages. The section also explores the need for the consideration of the PLC in developing LAG practices to be adopted.

4.3.1.1 LAG practices used in questionnaire development

Literature on the lean, agile and green production concepts have been the subject of several studies and case studies, reviews in academia as well as in the manufacturing industry. However, it is rare to find practices as adopted in the Fast Moving Consumer Goods (FMCGs) industry.

Literature review revealed that there are many lean, agile and green practices available for companies to utilise in improving operational efficiencies, adding value, becoming flexible and environmentally responsible. However, in practice, all the lean, agile and green practices cannot be used in a specific application of one methodology (Alaskari et al., 2016). In this study, practices were selected through literature with whole or partial focus on the fast moving consumer goods (FMCG) sector either through examples, case studies, research survey or otherwise (Abbasi and Hassan, 2013; Agarwal et al., 2006; Aljunaidi and Ankrah, 2014; Apple, 2014; El-Tawy and David, 2012; El-Tawy and Gallear, 2012; Found and Rich, 2007; Kirkwood and Walton, 2012; Lowson and Robert, 2001b; Marwan M. Al-Nsour et al., 2012; Mohankumar and Shivaraj, 2010). The commonly used practices adopted and used in the development of the questionnaire are therefore presented in tables 4.4, 4.5 and 4.6.

Table 4.4: Lean practices in FMCG industry

Lean Practices	Explanation	Source(s)
Time based competition (JIT)	Speed in developing new products and in responding to customer demands	(Sahin, 2000; Lowson and Robert, 2001; Lowson and Robert, 2001; Zsidisin et al., 2005; Daisy 2011; Han et al., 2013)
Reengineered process	Radically redesigned production processes	(MacDuffie and Helper, 1997; Shah and Ward, 2003)
Cycle time reduction	Strategy for lowering total process completion time	(Shah and Ward, 2003; Han et al., 2013; Diaby et al., 2013)
Set up time reduction	Lowering the time it takes to change from the last item of previous order to the first good item of the next order	(Fullerton and McWatters, 2001; Cruz, 2012; Kakish and Yousef, 2012)
Continuous flow production	Method of production without interruption	(Shah and Ward, 2003)
Cellular manufacturing	Work place design model that groups similar processes in the 'cells'	(Shah and Ward, 2003; Cruz, 2012; Kakish and Yousef, 2012)
Lot size reduction	Lowering of product quantity made in a production run or of materials ordered for delivery.	(Shah and Ward, 2003)
Bottle-neck removal	Removal of processes that slow down or stop production	(Shah and Ward, 2003)
Focused factory	Focused factory production systems involves concentrating the plant resources on a limited manufacturing task closely related to the business strategy	(Fullerton and McWatters, 2001; Shah and Ward, 2003)
Concurrent engineering	Development of products by running the different stages simultaneously.	(Cruz, 2012)
Group technology	Assembling similar machines or family of parts together in production.	(Fullerton and McWatters, 2001)
Planning and scheduling	Optimal allocation of raw materials and production capacity to meet demand	(Shah and Ward, 2003; Cruz, 2012)
Total quality control	Applying quality principles from design to delivery	(Fullerton and McWatters, 2001; Shah and Ward, 2003)
Quality circles	Regular employee meetings on ways of solving problems and improving productivity	(Fullerton and McWatters, 2001; Shah and Ward, 2003)

Lean Practices	Explanation	Source(s)
Continuous improvement	Making small incremental improvements to improve efficiency and quality	(Shah and Ward, 2003)
Process capability analysis	Statistically measuring of the ability of the production process to deliver output within (specified) control limits	(Shah and Ward, 2003)
Pull system/kanban	Producing only to actual demand from customers/ resource control by replacing only what has been consumed.	(Fullerton and McWatters, 2001; Shah and Ward, 2003; Cruz, 2012)
Uniform workload	Minimisation of fluctuations in daily workload (number of products made)	(Fullerton and McWatters, 2001)
Maintenance optimisation	Ensuring that machines are working at most efficient levels	(Shah and Ward, 2003)
Preventive maintenance	Avoidance of equipment failure through proper use and regular servicing (including replacement of worn parts)	(Fullerton and McWatters, 2001; Shah and Ward, 2003; Kakish and Yousef, 2012)
Multifunction employees	Cross-training of employees on the operation of different machinery as well as other functions. Staff capable of performing several different roles.	(Fullerton and McWatters, 2001; Cruz, 2012; Shah and Ward, 2003)
Self-directed work teams	Employees capable of working with minimal managerial supervision.	(Shah and Ward, 2003)

Table 4.5: Agile practices in FMCG industry

Agile Practices	Explanation	Source(s)
R&D for NPD	Research and development for new product development	(Vázquez-Bustelo and Avella, 2006)
Rapid reconfiguration	Quickly adapt production processes for the task at hand	(Cruz, 2012)
Mix/model flexibility	Flexibility in product mix and product model i.e. Capability to vary products	(Mohankumar and Shivaraj, 2010)
Flexible production lines	Creation of flexible production lines	(Vázquez-Bustelo and Avella, 2006)
Flexible employees	Flexible employees operating work cells with greater responsibility and control	(Vázquez-Bustelo and Avella, 2006)
Virtual organisation	Formation of temporary alliances to share skills and manage competencies in order to respond better to opportunities. Not particularly requiring a physical facility	(Lowson and Robert, 2001; Steve, Denning, 2012)
Strategic postponement	Delay of final production (assembly) or distribution of product until order is received.	(Lowson and Robert, 2001)
Temporary alliances	Formation of temporary alliances to share complimentary resources or information	(Vázquez-Bustelo and Avella, 2006)
Demand flexibility	Strategically prepared to respond to fluctuations in demand by Shifting production/distribution to some other time, preferably when orders have been received	(Cruz, 2012)
Large/small batches	Production in large or small batches as required	(Cruz, 2012)
Strategic outsourcing	Outsourcing of some production processes to focus on core competencies	(Lowson and Robert, 2001; Vázquez-Bustelo and Avella, 2006)
Innovation culture	Development of a culture of innovation and market orientation	(Vázquez-Bustelo and Avella, 2006; (El-Tawy and Gallear, 2012)
Process management	Development of process management model consolidate links between departments	(Vázquez-Bustelo and Avella, 2006)
Internal communication	Encouragement of internal communication	(Vázquez-Bustelo and Avella, 2006)
Supplier partnership	Strong partnership with core suppliers	(Vázquez-Bustelo and Avella, 2006)
Storage facilities	Location of storage facilities/warehouses near production areas	(Vázquez-Bustelo and Avella, 2006)

Agile Practices	Explanation	Source(s)
Quick decision making	Facilitation of quick decision making at all levels	(Lowson and Robert, 2001)
Speed in NPD	Speed in new product development and time to market capacity	(El-Tawy and Gallear, 2012; Cruz,2012)
Information capture	Capture of demand information quickly	(El-Tawy and Gallear, 2012; Cruz,2012)

Table 4.6: Green practices in FMCG industry

Green Practices	Explanation	Source(s)
Site selection	Selection of sites and warehouses away from general population	(Abbasi and Hassan, 2013)
Large doors/windows	Installation of large doors and windows for proper lighting and ventilation	(Abbasi and Hassan, 2013)
Temperature control	Installation of temperature control devices	(Abbasi and Hassan, 2013)
Low energy lighting	Use of low energy lighting when needed	(Kirkwood and Walton, 2012; Abbasi and Hassan, 2013)
Weather monitoring	Installation of weather monitoring systems such as irrigation systems that are triggered by the weather conditions (example rise in temperature)	(Apple, 2014)
Water re-use	Cooling system that re-uses water	(Kirkwood and Walton, 2012; Apple report, 2014; AME, 2007)
Non-hazardous materials	Use of non-hazardous materials in production and packaging	(Handfield et al., 2005; Abbasi and Hassan, 2013; Apple report, 2014)
Supplier survey	Survey of suppliers to support accurate environmental reporting	(Apple report, 2014)
Outsourcing to 3PLs	Outsourcing operations/activities to third party logistics providers	(Abbasi and Hassan, 2013)
Supplier monitoring	Monitor suppliers’ and partners’ compliance to set standards	(Handfield et al., 2005; Apple report, 2014)
Durable products	Development of durable and long lasting products	(Handfield et al., 2005; Apple report, 2014)
Energy production	Onsite energy production	(Apple report, 2014)

Green Practices	Explanation	Source(s)
Renewable energy	Powering facilities with renewable energy	(Abbasi and Hassan, 2013)
Use of alternative fuels	Less use of fossil-derived energy sources (even in movement of staff and materials)	(Apple report, 2014)
Smaller packaging	Use of smaller, thinner and lighter packaging	(Apple report, 2014)
Use of less material	Production with less material	(Apple report, 2014)
Waste processing	Processing of waste in the region where it is collected	(Apple report, 2014)
Product take-back	Participation in product take-back	(Handfield et al., 2005; Abbasi and Hassan, 2013)
Recycling programme	Introduction of/participation in recycling programs for products at end of life	(Handfield et al., 2005; Kirkwood and Walton, 2012)
Recyclable materials	Products made with/use of recyclable packaging or materials	(Handfield et al., 2005)
Re-usability/reverse logistics	Reuse of materials/products where possible	(Abbasi and Hassan, 2013)
Use of PLC analysis	Use of a comprehensive product life cycle analysis that measures the carbon footprint of products throughout their life	(Handfield et al., 2005; Kirkwood and Walton, 2012)
Environmental laboratory	An environmental testing lab built to examine products for harmful substances and working with suppliers on this	(Apple report, 2014)
Supporting green efforts	Supporting environmental efforts in the host community	(Apple report, 2014)
Employee training	Training employees on environmental sustainability and initiatives introduced or used by the enterprise	(Abbasi and Hassan, 2013)
Collaboration to reduce carbon emissions	Inter-organisational collaboration aimed at reducing CO2 emissions	(Theissen et al., 2014)

4.3.2 Sample Size Determination for Main Survey

The sample size was calculated using the sample size method applied in Esan (1994). Responses from the pilot study on whether product life cycle should be considered in the adoption of LAG strategies was used to arrive at a suitable sample size for the main survey as depicted below. This method has been applied in Braganca et al. (2014) and Shaikh et al. (2014).

$$n \geq N\left(1+\frac{d^2(N-1)}{4PQK^2_{\alpha/2}}\right)^{-1}$$

Where,

n is the sample size

N is the population size

P is the proportion of respondents who says product life cycle should be topmost priority in the adoption of lean, agile and green practices

Q is the proportion of respondents who says product life cycle should not be topmost priority in the adoption of lean, agile and green practices

d is the width of the confidence interval

$K_{\alpha/2}$ is the value of z-distribution corresponding to 95% confidence interval

$N=150$ $K_{\alpha/2}=1.96$ $Q=1-P$

Where P is got from the pilot survey carried out

$$P=\frac{14}{30}=0.47$$

Hence, $Q=1-0.47=0.53$

$d=0.21$

$$n \geq N\left[1+\frac{d^2(N-1)}{4PQK_{\alpha/2}^2}\right]^{-1}$$

$$n \geq 2000\left[1+\frac{(0.21)^2(2000-1)}{4(0.47)(0.53)(1.96)^2}\right]^{-1}$$

$$n \geq \frac{2000}{24.03}$$

$$n \geq 83.23 \approx 83$$

This implies that 83 or more questionnaires can be sent out for this survey. Random sampling was utilised in the survey; this is where each member of a population has a non-zero probability of being involved in the sample. It was utilised because of its low cost, quicker data collection. Most of the questions require a simple check of a check-box (see appendixes three and four).

Collecting questionnaire responses was a challenge as some respondents did not respond to the questionnaire. For the initial and second stages of the questionnaire-survey, follow-ups were sent to respondents which eventually yielded results.

4.3.3 Implementation of the questionnaire

The unit of analysis for this research was the individual, and preferred target respondents were senior level managers who have worked or are currently working within the FMCG industry with knowledge of the lean, agile and green paradigms, and direct involvement in operational and strategic decision making. A non-experimental survey methodology was used for data collection (Kerlinger and Lee, 1999). A web-based survey approach was deemed suitable as the population of interest is individuals who have worked in or are working in businesses and coverage issues are minimized due to high rates of computer use (Dillman, 2000). The sample employed in this survey was obtained from the Institute of Operations management (IOM) in the United Kingdom. A total of one hundred and fifty questionnaires accompanied with an attached letter explaining the purpose and objective of the survey and guidance notes for completing the questionnaire were e-mailed out to participants for purpose of this survey. Two reminders spaced one week apart followed the initial.

Respondents were asked to select and rate the importance of LAG practices given product life cycle stage on a five point likert scale where 1=Not important at all, 2=Slightly important, 3=Moderately important, 4=Very important, 5=Extremely important. Again, the respondents were required to select and rate their reason for adopting LAG practices on a five point Likert scale. The main part of the second questionnaire required respondents to rate LAG practices contribution to cost reduction, lead time reduction and waste reduction; again based on product life stage where the practices are applied. It is also worth mentioning that following the pilot study which had a total of 66 LAG practices, the number of practices was reduced 41. Practices which were a cause for ambiguity were removed; others were reworded for clarity. As earlier stated, the length of time it tool to complete the questionnaire was also reduced as a result of the reduction in the number of LAG practices. The LAG practices which became part of the main framework are: *Time based competition, Cycle time reduction, Set up time reduction, Cellular manufacturing, Bottle-neck removal, Focused factory, Planning and scheduling, Total quality control, Quality circles, Quality circles, Continuous improvement, Pull system/Kanban, Preventive maintenance, Self-directed work teams, Research for new product, Rapid reconfiguration, Virtual organisation, Strategic postponement, Demand flexibility, Large/small batches, Strategic outsourcing, Innovation culture, Internal communication, Supplier partnership, Storage facilities, Speed in NPD, Quick decision, Information capture, Site selection, Large doors/windows, Temperature control, Non-hazardous materials, Supplier survey, Outsourcing to 3PLs, Durable products, Smaller packaging, Use of less material, Waste processing, Recyclable materials, Recycling programs, Use of PLC analysis and Environmental lab*. These LAG practices are also ranked higher in the pilot survey than the ones which have been removed.

Three steps were followed in administering the survey to encourage a good response. The first involved e-mailing of an advance-notice to all the members of the sample notifying them of the questionnaire-survey they were about to receive; solicit and encourage their participation. The second step involved delivering the second stage of the questionnaire-survey (the main survey) and the final step involved delivering the third stage of the questionnaire. This was also undertaken, as recommended by (Creswell, 2003). Single source bias was minimised in this research by ensuring that the sample included mid to senior level managers with significant levels of relevant knowledge.

4.4 Main Survey Results

Presented herein are results of the main survey and test of hypothesis.

4.4.1 Level of Awareness of lean, agile and green (LAG)

In addressing this question, data on the level of awareness for LAG in the questionnaire was analysed using percentages. The lean paradigm takes the largest share and was rated high over agility and green in times of expertise of the respondents. The table 4.7 shows further insights to the analysis.

Table 4.7: Level of Awareness for LAG

Level of Awareness	Expert	%	VA	%	MA	%	SA	%	NA	%
Lean	52	54.2	37	38.5	2	2.1	5	5.2	-	-
Agility	4	4.2	19	19.8	33	34.4	20	20.8	20	20.8
Green	5	5.4	8	8.6	47	50.5	20	21.5	13	14.0

4.4.2 Reasons for Adopting LAG

The purpose of this question is to discover the reason why each of the individual paradigms is adopted in the fast moving consumer goods (FMCG) industry.

Lean Adoption

Table 4.8: Rated Scale for lean adoption

	VL	%	L	%	N	%	H	%	VH	%
Minimise Cost	51	53.1	29	30.2	4	4.2	7	7.3	4	4.2
Improve lead time	8	8.3	31	32.3	20	20.8	23	24.0	12	12.5
Improve operations	67	69.8	23	24.0	2	2.1	3	3.1	1	1.0
Improve env. performance	49	51.0	35	36.5	3	3.1	9	9.4	-	-
Coordinate processes	8	8.3	23	24.0	36	37.5	11	11.5	18	18.8
Increase market share	10	10.4	19	19.8	33	34.4	11	11.5	21	21.9
Improve customer	58	60.4	27	28.1	4	4.2	4	4.2	2	2.1
satisfaction	6	6.2	33	34.4	22	22.9	28	29.2	5	5.2
Others										

VL=Very Low, L=Low, N=Neutral, H=High, VH=Very High

Agility Adoption

Table 4.9: Rated scale for agility adoption

Level of Awareness	VL	%	L	%	N	%	H	%	VH	%
Minimise Cost	76	79.2	11	11.5	3	3.1	4	4.2	2	2.1
Improve lead time	42	43.8	34	35.4	2	2.1	9	9.4	9	9.4
Improve operations	3	3.1	18	18.8	28	29.2	20	20.8	25	26.0
Improve env.(waste)Performance	5	5.2	7	7.3	40	41.7	21	21.9	19	19.8
Coordinate processes	42	43.8	26	27.1	4	4.2	9	9.4	12	12.5
Increase market share	8	8.4	25	26.0	18	18.8	29	30.2	13	13.5
Improve customer satisfaction	56	58.3	21	21.9	8	8.3	8	8.3	1	1.0
Others	45	46.9	35	36.5	6	6.9	9	9.4	-	-

Green Adoption

Table 4.10: Rated scale for green adoption

	VL	%	L	%	N	%	H	%	VH	%
Minimise Cost	1	1.0	16	16.7	36	37.5	19	19.8	23	24.0
Improve lead time	5	5.2	12	12.5	38	39.6	18	18.8	21	21.9
Improve operations	54	56.2	22	22.9	6	6.2	6	6.2	6	6.2
Improve env. performance	3	3.0	32	33.3	23	24.0	28	29.2		
Coordinate processes	71	74.0	6	6.2	4	4.2	9	9.4	9	9.4
Increase market share	8	8.3	17	17.7	34	35.4	17	17.7	6	6.2
Improve customer satisfaction	53	55.2	28	29.2	8	8.3	3	3.1	18	18.8
Others	5	5.2	29	30.2	20	20.8	33	34.4	1	1.0
									8	8.3

VL=Very Low, L=Low, N=Neutral, H=High, VH=Very High

It can be observed form the tables 4.8, 4.9 and 4.10 above that the respondents varied in their ratings for reasons of adoption of the paradigms lean, agility and green. The green paradigm came off comparatively better than lean and agility in terms of adoption for the sake of cost reduction and lead time improvement. The green paradigm showed comparatively better figures for improving environmental performance than the lean and agile paradigms. Below is a summary table for the leading paradigms for the reasons considered.

Table 4.11: Summary of tables 4.8, 4.9, 4.10

CONCEPTS	LEADING PRACTICE
Minimize cost	Green
Improve lead time	Green
Improve operation	Agile
Improve environmental (waste)performance	Green
Coordinate processes	Lean
Increase market share	Lean
Improve customer satisfaction	Lean
Others	Green

The result of the analysis as shown in table 4.11 is quite interesting as it indicates that green comes top for reducing cost and minimizing lead time; cost and lead time are widely thought to come within the territory of lean. However, the pursuit of green is not contrary to a firm's interests regarding cost and lead time (Posinasetto, 2014). The notion that the pursuit of green increases costs is not supported by Koechlin and Müller, (1992) and AME, (2007) who believe that environmental management keeps costs down rather than jacking them up. Also, Fischer et al., (2016) believe that apart from the environmental benefits of green manufacturing, it also has a positive effect on other aspects by improving production lead time and reducing costs.

4.4.3 Tests of Research Hypothesis

H_1: Competitiveness (cost, lead time and waste) is improved by a combination of appropriate LAG practices at PLC stages.

In order to find out the outcome of LAG adoption at both paradigm and practices levels and at PLC stages, this research tests the research hypothesis H_1 in three stages by the following three arguments:

Argument 1: That neither lean, agile nor green at paradigm level work at PLC.

Argument 2: That outcomes vary with a combination of practices.

Argument 3: That neither lean, agile nor green at paradigm level work to reduce waste.

4.4.3.1 Sub-hypothesis 1 (SH_1)

The first sub-hypothesis is that neither the lean, agile nor green paradigms work to improve competitiveness (cost, lead time and waste) at PLC stages.

LAG Test for Introduction Stage (SH_1a)

(I)

H_0: Firm competitiveness is positively associated with the lean practices applied in the introduction stage of the PLC.

H_0: P = 0.5

H_1: P < 0.5

P is the overall proportion of the respondents who rated lean practices applied in the introduction phase of PLC.

P is estimated by $\hat{P}$

where n' is the number of respondents who rated lean practices adoption at the introductory phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{341}{1248}=0.27$$
$$\hat{q}=1-\hat{p}=1-0.27=0.73$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.27\times0.73}{96-1}$$
$$\hat{V}(\hat{p})=0.2004$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.27-0.5|}{\sqrt{0.2004}}=0.512$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o<Z_\alpha$. We accept H_0 .

That is, firm competitiveness is positively associated with Lean practices used in the introduction phase of the PLC.

(II)

H_0: Firm competitiveness is positively associated with the agile practices applied in the introduction phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated agile practices applied in the introduction phase of PLC.

P is estimated by $\hat{P}$

where n' is the number of respondents who rated Agile practices adoption at the introductory phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{429}{1344}=0.32$$
$$\hat{q}=1-\hat{p}=1-0.32=0.68$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.32\times0.68}{96-1}$$
$$\hat{V}(\hat{p})=0.0022$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.32-0.5|}{\sqrt{0.0022}}=3.84$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with agile practices applied in the introduction phase of the PLC.

(III)

H_0: Firm competitiveness is positively associated with the green practices applied in the introduction phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated Green practices used in the introduction phase of PLC.

P is estimated by $\hat{P}$

where n' is the number of respondents who rated Green practices adoption at the introductory phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{348}{1344}=0.26$$
$$\hat{q}=1-\hat{p}=1-0.26=0.74$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.26\times0.74}{96-1}$$
$$\hat{V}(\hat{p})=0.0019$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.26-0.5|}{\sqrt{0.0019}}=5.51$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o > Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the green practices applied in the introduction phase of the PLC.

LAG Test for Growth Stage (SH_1b)

(I)

H_0: Firm competitiveness is positively associated with the lean practices applied in the growth phase of the PLC.

H_0: P = 0.5

H_1: P < 0.5

P is the overall proportion of the respondents who rated Lean practices applied in the growth phase of PLC.

P is estimated by $\hat{P}$

where n' is the number of respondents who rated lean practices adoption at the growth phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{284}{1248}=0.23$$
$$\hat{q}=1-\hat{p}=1-0.23=0.77$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.23\times0.77}{96-1}$$
$$\hat{V}(\hat{p})=0.0018$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.23-0.5|}{\sqrt{0.0018}}=6.36$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the lean practices applied in the growth phase of the PLC.

(II)

H_0: Firm competitiveness is positively associated with the agile practices applied in the growth phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated agile practices applied in the growth phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Agile practices adoption at the growth phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{347}{1344}=0.26$$
$$\hat{q}=1-\hat{p}=1-0.26=0.74$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.26\times 0.74}{96-1}$$
$$\hat{V}(\hat{p})=0.0019$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.26-0.5|}{\sqrt{0.0019}}=5.51$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence , $Z_o > Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with agile practices applied in the growth phase of the PLC.

(III)

H_0: Firm competitiveness is positively associated with green practices applied in the growth phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated Green practices applied in the growth phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Green practices adoption at the growth phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{375}{1344}=0.28$$
$$\hat{q}=1-\hat{p}=1-0.28=0.72$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1},f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.28\times0.72}{96-1}$$
$$\hat{V}(\hat{p})=0.0020$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.28-0.5|}{\sqrt{0.0020}}=4.92$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o > Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with green practices applied in the growth phase of the PLC.

LAG Test for Maturity Stage (SH_1c)
(I)

H_0: Firm competitiveness is positively associated with the adoption of lean in the maturity phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated Lean practices applied in the maturity phase of PLC.

P is estimated by $\hat{P}$

where n' is the number of respondents who rated lean practices adoption at the maturity phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{218}{1248}=0.15$$
$$\hat{q}=1-\hat{p}=1-0.15=0.85$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.15\times0.85}{96-1}$$
$$\hat{V}(\hat{p})=0.0013$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.15-0.5|}{\sqrt{0.0013}}=9.71$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence, $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the lean practices applied in the maturity phase of the PLC.

(II)

H_0: Firm competitiveness is positively associated with the adoption of agility in the maturity phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated agile practices implemented in the maturity phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Agile practices implementation at the maturity phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{262}{1344}=0.12$$
$$\hat{q}=1-\hat{p}=1-0.12=0.88$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.12\times0.88}{96-1}$$
$$\hat{V}(\hat{p})=0.0011$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.12-0.5|}{\sqrt{0.0011}}=11.45$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence , $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the agile practices applied in the maturity phase of the PLC.

(III)

$H_0:$ Firm competitiveness is positively associated with the adoption of Green in the maturity phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated green practices implemented in the maturity phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Green practices adoption at the maturity phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{332}{1344}=0.25$$
$$\hat{q}=1-\hat{p}=1-0.25=0.75$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1},f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.25\times0.75}{96-1}$$
$$\hat{V}(\hat{p})=0.0019$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.25-0.5|}{\sqrt{0.0019}}=5.74$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence , $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the green practices applied in the maturity phase of the PLC.

LAG Test for Decline Stage (SH_1c)

(I)

H_0: Firm competitiveness is positively associated with the lean practices applied in the decline phase of the PLC.

$$H_0:P=0.5$$
$$H_1:P<0.5$$

P is the overall proportion of the respondents who rated lean practices applied in the decline phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated lean practices adoption at the decline phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{367}{1248}=0.29$$
$$\hat{q}=1-\hat{p}=1-0.29=0.71$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.29\times0.71}{96-1}$$
$$\hat{V}(\hat{p})=0.0021$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.29-0.5|}{\sqrt{0.0021}}=4.59$$

$$Z_\alpha=Z_{0.05}=1.64$$ (Single tailed test)

Hence , $Z_o > Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the lean practices applied in the decline phase of the PLC.

(II)

H_0: Firm competitiveness is positively associated with the adoption of agility in the decline phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated the agile practices applied in the decline phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Agile practices adoption at the decline phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{265}{1344}=0.20$$
$$\hat{q}=1-\hat{p}=1-0.20=0.80$$
$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$
$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.20\times0.80}{96-1}$$
$$\hat{V}(\hat{p})=0.0016$$
$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.2-0.5|}{\sqrt{0.0016}}=7.5$$

$Z_\alpha=Z_{0.05}=1.64$ (Single tailed test)

Hence , $Z_o>Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the agile practices implemented in the decline phase of the PLC.

(III)

H_0: Firm competitiveness is positively associated with the adoption of green in the decline phase of the PLC.

$$H_0: P=0.5$$
$$H_1: P<0.5$$

P is the overall proportion of the respondents who rated green practices applied in the decline phase of PLC.

P is estimated by $\hat{p}$

where n' is the number of respondents who rated Green practices adoption at the decline phase of PLC.

n is the total number of respondents sample

$$\hat{p}=\frac{234}{1344}=0.17$$

$$\hat{q}=1-\hat{p}=1-0.17=0.83$$

$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}\hat{q}}{n-1}, f=\frac{n}{N}$$

$$\hat{V}(\hat{p})=\left(1-\frac{96}{2108}\right)\frac{0.17\times 0.83}{96-1}$$

$$\hat{V}(\hat{p})=0.0014$$

$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|0.17-0.5|}{\sqrt{0.0019}}=7.57$$

$$Z_\alpha=Z_{0.05}=1.64$$ (Single tailed test)

Hence , $Z_o > Z_\alpha$. We reject H_0 .

That is, firm competitiveness is not positively associated with the green practices applied in the decline phase of the PLC.

4.4.3.2 Sub-hypothesis 2 (SH_2)

The second sub-hypothesis states that outcomes vary with a combination of practices. This tests the association of LAG with cost performance (reduction of costs) and lead time (reduction of lead time). The tests for the association of lean and agility with cost performance are performed followed by tests for lead time improvement.

Cost Reduction

Lean

The coefficients table 4.12 presents the summary of cost performance associated the lean practices adopted. The standardized beta coefficients provide the order of importance or relative contribution of the practices to cost performance. It can be observed that bottle neck removal makes statistically unique contribution to the cost performance at 95% confidence level as it has the highest value. The null hypothesis is accepted.

Table 4.12: Regression analysis for hypothesis test (Lean Coefficients)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.434	1.258		.345	.732
LEAN PRACTICES Time based competition(L_1)	.088	.120	.094	.731	.468
Cycle time reduction(L_2)	.245	.125	.271	1.961	.055
Set up time reduction(L_3)	.001	.126	.002	.011	.991
Cellular manufacturing(L_4)	-.127	.129	-.138	-.985	.329
Bottle-neck removal(L_5)	.278	.119	.311	2.341	.023
Focused factory(L_6)	-.008	.136	-.008	-.058	.954
Planning and scheduling(L_7)	-.116	.119	-.140	-.977	.333
Total quality control(L_8)	.056	.121	.062	.459	.648
Quality circles(L_9)	.002	.175	.002	.011	.992
Continuous improvement(L_{10})	-.129	.132	-.134	-.975	.334
Pull system/Kanban(L_{11})	.176	.201	.129	.878	.384
Preventive maintenance(L_{12})	.106	.150	.101	.704	.485
Self-directed work teams(L_{13})	-.220	.151	-.194	-1.457	.151

Dependent Variable: Scale rating for Lean adoption: Minimise cost

R^2 = 0.246 (24.6%); F- Statistics = 1.253 (P > .000); Overall Sig. value = 0.275

The multiple regression equation that relates the cost performance to the lean practices adopted is given by the constant and the coefficients of the unstandardized beta as:

CP (Cost performance) = $0.434 + 0.088L_1 - 0.245L_2 + 0.001L_3 - 0.0127L_4 + 0.278L_5 - 0.008L_6 - 0.116L_7 + 0.056L_8 + 0.002L_9 - 0.129L_{10} + 0.176L_{11} + 0.106L_{12} - 0.220L_{13}$

The equation shows that time base competition, setup time reduction, bottle neck removal, total quality control, quality circle, pull system/kanban and preventive maintenance are positively correlated to Cost performance.

Agile

The coefficients table 4.13 presents the summary of cost performance associated the agile practices. The standardized beta coefficients provide the order of importance or relative contribution of the practices to cost performance. It can be observed that none of the practices make any statistically unique contribution to cost performance at 95% confidence level. The overall significance figure 0.66 implies agile practices are not positively associated with cost reduction. Hence the null hypothesis is rejected. The standardized beta coefficients provide the order of importance or relative contribution of the practices to cost reduction.

The multiple regression equation that relating cost performance with the agile practices is given by the constant and the coefficients of the unstandardized beta as:

CP (Cost performance) = $1.192 - 0.116A_1 + 0.154A_2 + 0.023A_3 – 0.100A_4 + 0.022A_5 – 0.118A_6 – 0.038A_7 - 0.085A_8 + 0.012A_9 + 0.113A_{10} - 0.023A_{11} + 0.180A_{12} + 0.125A_{13} – 0.024A_{14}$

The equation shows that Virtual organisation, demand flexibility, internal communication, supplier partnership and speed in new product development are positively correlated to Cost reduction.

Table 4.13: Regression analysis for hypothesis test (Agile Coefficients)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.192	.659		1.810	.075
AGILE PRACTICES Research for new product(A_1)	-.116	.108	-.144	-1.079	.285
Rapid reconfiguration(A_2)	.154	.120	.171	1.280	.205
Virtual organisation(A_3)	.023	.119	.029	.196	.845
Strategic postponement(A_4)	-.100	.111	-.116	-.897	.373
Demand flexibility(A_5)	.022	.153	.021	.145	.885
Large/small batches(A_6)	-.118	.140	-.122	-.843	.402
Strategic outsourcing(A_7)	-.038	.168	-.032	-.227	.821
Innovation culture(A_8)	-.085	.130	-.090	-.655	.515
Internal communication(A_9)	.012	.102	.016	.114	.909
Supplier partnership(A_{10})	.113	.139	.108	.815	.418
Storage facilities(A_{11})	-.023	.158	-.021	-.146	.884
Speed in NPD(A_{12})	.180	.130	.194	1.382	.172
Quick decision(A_{13})	.125	.097	.154	1.280	.205
Information capture(A_{14})	-.024	.089	-.036	-.276	.783

Dependent Variable: Scale rating for Agile adoption: Minimise cost.

R^2 = 0.145 (14.5%); F- Statistics = 0.802 (P > .000); Overall Sig. value = 0.66

Green

The coefficients table 9C below is a summary of green practices adopted and cost performance. None of the attributes make any statistically unique contribution to reducing costs at 95% confidence level.

Table 4.14: Regression analysis for hypothesis test (Green Coefficients)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	3.398	.867		3.918	.000
GREEN PRACTICES: Site selection(G_1)	.121	.107	.146	1.133	.261
Large doors/windows(G_2)	-.116	.127	-.119	-.917	.362
Temperature control(G_3)	-.160	.181	-.135	-.883	.380
Non hazardous materials(G_4)	-.088	.153	-.081	-.579	.565
Supplier survey(G_5)	.171	.163	.130	1.052	.296
Outsourcing to 3PLs(G_6)	.021	.145	.017	.141	.888
Durable products(G_7)	.353	.186	.255	1.896	.062
Smaller packaging(G_8)	-.168	.140	-.144	-1.200	.234
Use of less material(G_9)	.032	.127	.035	.251	.803
Waste processing(G_{10})	-.090	.171	-.069	-.523	.603
Recyclable materials(G_{11})	-.223	.172	-.192	-1.294	.200
Recycling programs(G_{12})	.152	.137	.135	1.104	.273
Use of PLC analysis(G_{13})	.012	.123	.012	.100	.921
Environmental lab(G_{14})	.129	.108	.144	1.202	.233

Dependent Variable: Scale rating for Green adoption: Minimise cost

The multiple regression equation that relates the cost performance to the practices adopted is given by the constant and the coefficients of the unstandardized beta as:

CP (Cost performance) = 3.398 + $0.121G_1$ - $0.116LG_2$ - $0.160G_3$ – $0.088G_4$ + $0.171G_5$ + $0.021G_6$ + $0.353G_7$ - $0.168G_8$ + $0.032G_9$ – $0.090G_{10}$ - $0.223G_{11}$ + $0.152G_{12}$ + $0.012G_{13}$ + $0.129G_{14}$

The equation shows that Site selection, supplier survey, outsourcing to 3pls, durable product, use of less material, recycling programs, use of PLC analysis and environmental laboratory are positively correlated to Cost performance. However, the overall significance figure 0.626 means that the null hypothesis is rejected at 95% level.

Lead time Reduction

Lean

The coefficients table 4.15 is the summary of lead time performance associated the lean practices. The standardized beta coefficients provide the order of importance or relative contribution of the practices to cost performance.

Table 4.15: Regression analysis for hypothesis test (Lean Coefficients)

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
Constant	-.287	1.056		-.272	.787
Leans Practices:					
Time based competition	.094	.101	.129	.930	.357
Cycle time reduction	.084	.105	.118	.798	.428
Set up time reduction	.098	.106	.135	.927	.358
Cellular manufacturing	.175	.108	.246	1.619	.112
Bottle-neck removal	-.022	.100	-.031	-.217	.829
Focused factory	.082	.115	.105	.712	.480
Planning and scheduling	-.019	.100	-.029	-.187	.853
Total quality control	.102	.102	.145	1.003	.321
Quality circles	.024	.147	.027	.162	.872
Continuous improvement	.041	.111	.054	.366	.716
Pull system/Kanban	.110	.168	.104	.652	.517
Preventive maintenance	.058	.125	-.071	-.460	.647
Self-directed work teams	-0.22	.126	.025	-.174	.863

Dependent Variable: Scale rating for Lean adoption: Reduce lead time

It can be observed that cellular manufacturing makes the most statistically unique contribution to lead time reduction at 95% confidence level as it has the highest value. The null hypothesis is rejected as the overall significance value as shown in appendix eleven is 0.922. Hence lean practices are not positively associated with lead time reduction.

Lead time reduction = $-0.287 + 0.094L_1 + 0.084L_2 + 0.0980L_3 + 0.175L_4 - 0.022L_5 + 0.082L_6 -0.019L_7 + 0.102L_8 + 0.024L_9 + 0.041L_{10} + 0.110L_{11} - 0.058L_{12} - 0.022L_{13}$

The equation shows that time based competition, cycle time reduction, set up time reduction, cellular manufacturing, focused factory, total quality control, quality circles, continuous improvement, and pull system/kanban are positively correlated to lead time reduction.

Agile

From the table 4.16, it can be observed that the agile practice speed in new product development makes the most statistically unique contribution to lead time reduction at 95% confidence level compared to the other practices.

Table 4.16: Regression analysis for hypothesis test (Agile Coefficients)

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
Constant	4.356	.828		5.262	.000
Agile Practices:					
Research for new product	.030	.133	.028	.225	.823
Rapid reconfiguration	.005	.149	.005	.036	.971
Virtual organisation	.059	.148	.054	.398	.692
Strategic postponement	.150	.143	.131	1.054	.296
Demand flexibility	-.276	.193	-.196	-1.432	.157
Large/small batches	.096	.173	.075	.553	.582
Strategic outsourcing	-.161	.213	-.104	-.753	.454
Innovation culture	-.226	.162	-.181	-1.392	.196
Internal communication	-.183	.127	-.193	-1.443	.154
Supplier partnership	.228	.175	.165	1.308	.195
Storage facilities	-.216	.195	-.152	-1.106	.273
Speed in NPD	.239	.161	.195	1.480	.144
Quick decision	.034	.121	.032	.283	.778
Information capture	-.207	.110	-.229	-1.881	.065

Dependent Variable: Scale rating for Agile adoption: Reduce lead time

Lead time reduction = $4.356 + 0.030A_1 + 0.005A_2 + 0.059A_3 + 0.150A_4 - 0.276A_5 + 0.096A_6 -0.161A_7 - 0.226A_8 - 0.183A_9 + 0.228A_{10} - 0.216A_{11} + 0.239A_{12} + 0.034A_{13} - 0.207A_{14}$

The agile practices which are positively correlated to lead time reduction are research for new product, rapid reconfiguration, virtual organisation, strategic postponement, production in large/small batches, supplier partnership, quick decision making and speed in new product development. Though some agile practices have not been shown to be positively associated with lead time reduction, the null hypothesis is accepted at 95% significance level as the overall significance value as shown in appendix eleven is 0.114.

Green

From the table 4.17 it is observable that the green practice environmental laboratory makes the most statistically unique contribution at 95% confidence level. Even though some green practices such as large/small windows, supplier survey, use of PLC analysis among others are not positively correlated with lead time reduction; the hypothesis is accepted as the overall significance value as shown in appendix eleven is 0.004. Hence green practices are positively associated with lead time reduction.

Table 4.17: Regression analysis for hypothesis test (Green Coefficients)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	2.138	.895		2.388	.020
GREEN PRACTICES: Site selection	-.038	.108	-.040	-.351	.727
Large doors/windows	-.005	.128	-.004	-.038	.970
Temperature control	.032	.185	.023	.171	.865
Non hazardous materials	.097	.154	.078	.633	.529
Supplier survey	-.074	.165	-.049	-.451	.653
Outsourcing to 3PLs	-.243	.147	-.172	-1.656	.102
Durable products	-.193	.191	-.121	-1.012	.315
Smaller packaging	.159	.140	.119	1.134	.261
Use of less material	-.265	.129	-.256	-2.064	.043
Waste processing	-.167	.173	-.112	-.962	.340
Recyclable materials	.690	.179	.507	3.864	.000
Recycling programs	.098	.141	.076	.696	.489
Use of PLC analysis	-.335	.127	-.274	-2.649	.010
Environmental lab	.184	.109	.177	1.682	.097

Dependent Variable: Scale rating for Green adoption: Lead time reduction.

4.4.3.3 Sub-hypothesis 3 (SH_3)

Paradigm level adoption of lean, agility, green is inefficient for the reduction of waste.

We test:

H_0: Waste generation is reduced by a combination of appropriate lean, agile and green practices.

$H_0: P = 0.5$
$H_1: P < 0.5$

P is the overall proportion of the respondents who confirmed waste generation is reduced by combination of appropriate lean, agile and green practices.

P is estimated by $\hat{P}$

Where n' is the number of respondents who confirmed waste generation is reduced by combination of appropriate lean, agile and green practices.

n is the total number of respondents

PWR_L is the proportion of students who confirmed waste generation is reduced by combination of appropriate lean.

PWR_A is the proportion of students who confirmed waste generation is reduced by combination of appropriate agile.

PWR_G is the proportion of students who confirmed waste generation is reduced by combination of appropriate green.

P is estimated by $\hat{P}$

$$\hat{P}WR_L = \frac{n'}{n} = \frac{90}{96} = 0.94 \qquad \hat{Q}WR_L = 1 - \hat{P}WR_L = 1 - 0.94 = 0.06$$

$$\hat{P}WR_A = \frac{n'}{n} = \frac{91}{96} = 0.95 \qquad \hat{Q}WR_A = 1 - \hat{P}WR_A = 1 - 0.95 = 0.05$$

$$\hat{P}WR_G = \frac{n'}{n} = \frac{93}{96} = 0.97 \qquad \hat{Q}WR_G = 1 - \hat{P}WR_G = 1 - 0.97 = 0.03$$

$$\hat{V}(\hat{p})=(1-f)\frac{\hat{p}wr_l}{n-1}+(1-f)\frac{\hat{p}wr_a}{n-1}+(1-f)\frac{\hat{p}wr_g}{n-1}$$

$$\hat{V}(\hat{p})=\left(1-\frac{96}{1248}\right)\frac{0.94\times0.06}{96-1}+\left(1-\frac{96}{1344}\right)\frac{0.95\times0.05}{96-1}+\left(1-\frac{96}{1344}\right)\frac{0.97\times0.03}{96-1}$$

$$\hat{V}(\hat{p})=0.00061$$

$$Z_0=\frac{|p-p_0|}{\sqrt{\hat{V}(\hat{p})}}=\frac{|2.82-0.5|}{\sqrt{0.00061}}=93.93$$

$Z_\alpha=1.64$ (Single tailed test)

Hence, $Z_o>Z_\alpha$. We reject H_0 .

That is, waste generation is not reduced by a combination of appropriate lean, agile and green practices.

4.5 Chapter Summary

This chapter presents the results of questionnaire-survey and the tests of hypotheses. The hypothesis was tested with the aid of three sub-hypotheses referred to in this chapter as 'arguments'. The hypothesis tested in this chapter is in support of the argument that no one paradigm is enough to achieve competitiveness and that each of the paradigms need to be considered down to individual practices in order to take full advantage of their strengths. They also show that considering LAG at paradigm level on the platform of the PLC in the FMCG industry yields different outcomes as each PLC stage poses different and unique challenges. Therefore as LAG considered individually and on the PLC platform does not guarantee competitiveness, a combination of all three may help to achieve competitiveness. The test result shows that combining LAG as a group does not work for waste reduction as the hypothesis is shown to be rejected. However, this is at the paradigm level, there may yet be some individual LAG practices that can be combined to reduce waste. Summary tables of the outcomes of the test of hypothesis are presented.

Table 4.18: Summary table for Hypothesis

PARADIGMS	COST REDUCTION	LEAD TIME REDUCTION
Lean	*Accepted*	*Rejected*
Agile	*Rejected*	*Accepted*
Green	*Rejected*	*Accepted*

Table 4.19: Summary table for Hypothesis

PARADIGMS	**COMPETITIVENESS**			
	INTRODUCTION	GROWTH	MATURITY	DECLINE
Lean	*Accepted*	*Rejected*	*Rejected*	*Rejected*
Agile	*Rejected*	*Rejected*	*Rejected*	*Rejected*
Green	*Rejected*	*Rejected*	*Rejected*	*Rejected*

In the following chapter, a framework is developed for combining all three paradigms at the practices level with the overall aim of achieving competitiveness by reducing cost, lead time and waste generated.

CHAPTER FIVE

CONCEPTUAL FRAMEWORK

5.1 INTRODUCTION

In CHAPTER TWO it was established that the LAG paradigms individually do not provide all the solutions to address the conditions of the business environment (Hasanian and Hojjati, 2016). Therefore, in order to meet the needs of the currently competitive market characterised by changing customer demands, unpredictability and environmental sustainability obligations, LAG are integrated to facilitate management decision-making in the selection of appropriate practices from the paradigms and in product life cycle stages.

This chapter focuses on addressing the challenge of manufacturing managers selecting the appropriate LAG practices to reduce costs, lead time and environmental waste, as competitive priorities change throughout the product life cycle of products. A recap of the revelation of the literature review is that, of the frameworks integrating lean, agile and green, though some have provided a multi-criteria problem solving approach for the selection problem, none of them have considered the product life cycle. This research therefore develops a decision support framework that integrates lean, agile and green practices with the following components:

- A multi-criteria method that ranks practices based on their contributions to cost reduction, lead time reduction and waste reduction at each of the four PLC stages
- A method of analysis for LAG practices that compares outcomes
- Decision on whether to adopt a new set of LAG practices or keep the current set depending on outcomes

Section 5.2 introduces the conceptual framework, explaining the development of its different parts. Section 5.2 also includes background information on multi-criteria decision making (MCDM) methods, and an explanation of why AHP was chosen to be part of the framework. It also discusses the limitations of the AHP and the implications of its limitations to this research. Section 5.3 presents the process view of the framework, which explains the functional view in more detail using a total of 10 steps. For steps 1 to 5, a background is presented prior to applying each of the steps for better understanding of what is being applied and how. Section 5.5 briefly describes how steps 6 to 8 are represented; it involves gathering and analysing information from a company. Section 5.6 describes how steps 9 and

10 are represented; it involves comparing outcomes in order to make a determination on better outcome and hence a decision on adopting the practices that produced the better outcome. Section 5.7 discusses how this framework compares to existing frameworks, explaining similarities, and section 5.8 summarises the chapter.

5.2 Introduction to Conceptual Framework

Framework is an analytical process comprising a number of distinct and interconnected phases (Huberman and Miles, 2002). Frameworks can be rudimentary or detailed, theory-driven or logical, descriptive or casual (Miles and Huberman, 1994). Although systematic and disciplined, framework depends on the conceptual and innovative ability of the researcher to determine meaning, uncover connections and identify important features (Huberman and Miles, 2002). It often involves working through a series of steps and returning to reconsider and perhaps rework previous steps.

The overall aim of the framework is to enable managers to identify the most appropriate lean, agile and green practices that would bring about improved competitiveness in terms of cost reduction, lead time improvement and waste reduction.

The robustness of this framework is demonstrated by: the integration of lean, agility and green at practices level rather than at the paradigm level; the incorporation of product life cycle in the decision support process through identification of the lean, agility and green practices that are best suited for specific life cycle stages; and the use of performance measures of cost, lead time and waste.

In order to aid understanding, this framework has been broken into three parts (identified as Part 1, Part 2 and Part 3 in figure 5.1. These parts reflect the stages of development of the framework). Part 1 involves data collection; Part 2 is the decision support module which was developed with the aid of the Analytic Hierarchy Process (AHP) while Part 3 is the analysis and comparison module which was demonstrated with a case study which obtained and analysed information from a company and making comparison between actual case study outcome and expected outcome. These parts are fully explained in the following sub-sections and with the aid of figure 5.1.

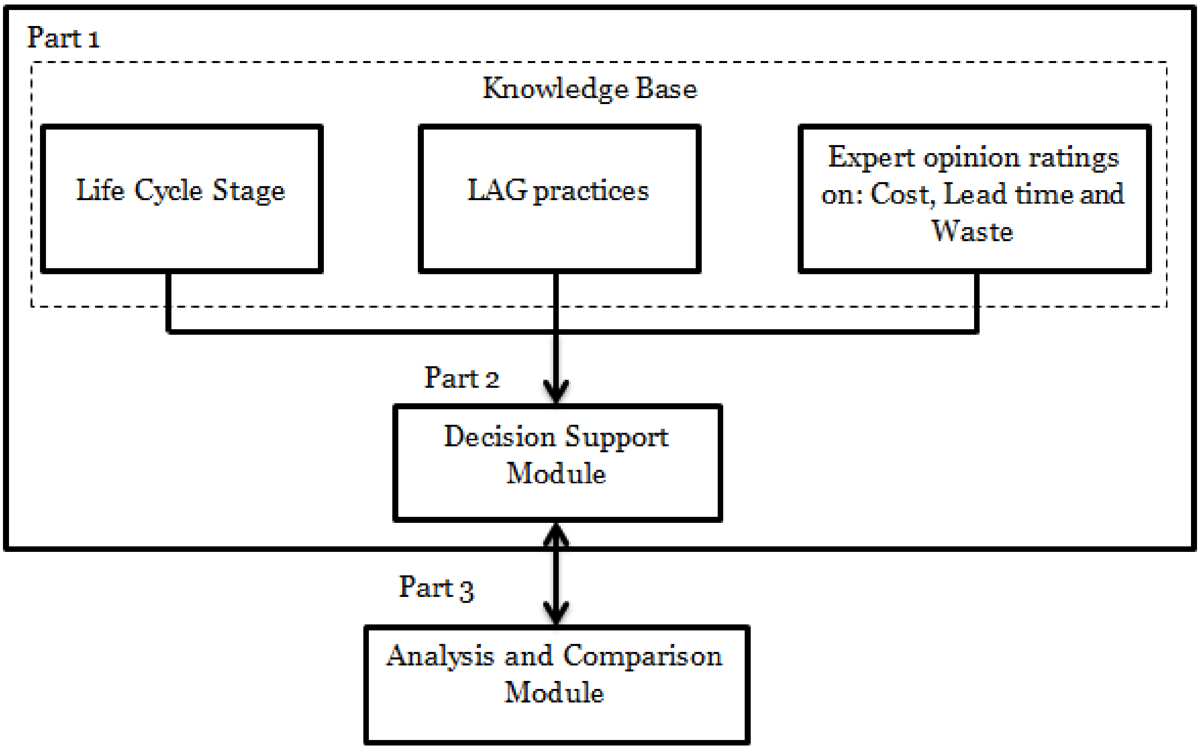

Figure 5.1: Functional view of conceptual framework

5.2.1 Part 1: knowledge base

This part involves questionnaire data collection. The data collected in this part is based on the questionnaire developed in CHAPTER THREE. The information required to develop the AHP are the life cycle stage of products, LAG practices, ratings of based on the contribution of LAG practices to cost reduction, lead time reduction and waste reduction. Also needed are paired comparisons on LAG and on life cycle stages. The snippets of the questionnaire that captured these are shown in figures 5.2, 5.3 and 5.4.

LIFE CYCLE STAGE	INTRODUCTION ☐	GROWTH ☐	MATURITY ☐	DECLINE ☐
EXPLANATION	*High costs* *Low sales and* *Low profits*	*Rising sales* *Increasing Profits* *and* *Reduction in costs*	*Reduction in costs* *Intense competition* *Low sales*	*Low profits* *Low sales* *Low costs*

Figure 5.2: Questionnaire snippet: PLC stage

Agility

		Cost reduction							**Lead time reduction**						
Agile practices		**0**	**1**	**2**	**3**	**4**	**5**	**NS**	**0**	**1**	**2**	**3**	**4**	**5**	**NS**
Research for new products	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rapid reconfiguration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Virtual organisation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Strategic postponement	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Demand flexibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Large/small batches production	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Strategic outsourcing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Innovation culture	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Internal communication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 5.3: Questionnaire snippet: practices selection and ratings

	Extremely		Very Strongly		Strongly		Moderately		**Equally**		*Moderately*		*Strongly*		*Very Strongly*		*Extremely*	
A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**B**
Lean	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Agile
Agile	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lean
Green	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lean
Agile	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Green

Figure 5.4: Questionnaire snippet: LAG pairwise comparison

5.2.2 Part 2: Decision Support Module

This part involves the development of a decision support module. To accomplish this, research was carried out into multi-criteria decision making methods (MCDM) available in literature. Based on this review, the analytic hierarchy process (AHP) was chosen as the most appropriate for this research. The details of this review and the justification for choosing AHP are presented in the next section 5.3. Section 5.4 also presents details of the development and implementation of the AHP.

It is note-worthy, that steps 1 to 5 of the process view (figure 5.5) which corresponds to part 1 of the functional view (figure 5.1) of the framework are the steps of a of a the AHP method which are explained in detail section 5.4 and applied in section 5.4.

Suffice to say that to develop the AHP; first a structural hierarchy is created which shows how the decision problem is reduced into a hierarchy of levels with the main objective at the top of the hierarchy. With the AHP, the LAG practices are ranked according to how much they contribute to achieving the overall objective of achieving competitiveness.

5.5.2.1 Background to Multi-Criteria Decision Making

Decision-making techniques range from reliance on chance (such as coin flipping, reading of tea leaves or tarot cards) to the adoption of more structured and organised decision-making tools. Good decision-making involves evaluating all important factors. In literature, there are several multi-criteria decision making (MCDM) tools to aid decision making. MCDM tools support decision makers in understanding their preferences (through criteria) and expand the set of alternatives. Some of the MCDM methods include but are not limited to the following examples:

- The VIKOR method
- Technique for order preference by similarity to an ideal solution (TOPSIS) method
- Data envelopment analysis (DEA)
- Multi-attribute utility theory (MAUT)
- Value engineering (VE)
- Analytic network process (ANP)
- New approach to appraisal (NATA)

- Fuzzy ANP (FANP)
- Multi-attribute analysis (MAA)
- Analytic hierarchy process (AHP)

The VIKOR method of compromise ranking developed for multi-criteria optimization of complex systems determines a compromise solution, providing a maximum ‘‘group utility’’ for the ‘‘majority’’ and a minimum of an individual regret for the ‘‘opponent’’. The VIKOR method focuses on the ranking and selection from a set of alternatives in the presence of contradictory criteria. It introduces the multi-criteria ranking index based on the particular measure of ‘‘closeness’’ to the ‘‘ideal’’ solution (Opricovic, 1998 in Opricovic and Tzeng, 2002).

TOPSIS (technique for order preference by similarity to an ideal solution) method is presented in Chen and Hwang, (1992); Olson, (2004) with reference to Hwang and Yoon (1981). The basic principle is that the selected alternative should have the smallest distance from the ideal solution and the farthest distance from the negative-ideal solution (Opricovic and Tzeng, 2002). According to Olson (2004), only limited subjective input is required from the decision makers.

Potentially one of the success stories in operations research, data envelopment analysis (DEA) deals with the evaluation of the performance of decision making units (DMUs). DEA relies on a linear programming based technique (LP) and does not have to introduce any form of subjective or economic parameters (ranks, prices and so on), DEA provides a measure of efficiency for each DMU and allows efficient to be separated from non-efficient (Bouyssou, 1999).

The methods identifiable as MAUT consist of grouping the different criteria into a function, which has to be maximized. The mathematical conditions of aggregations are thereby examined. MAUT allows complete compensation between criteria, that is, the gain on one criterion can compensate for the inadequacies on another (Keeney and Raiffa, 2008).

Value Engineering is an effective problem solving method that uses function analysis, team-work and creativity to improve value (Rajak and Shalendra Kumar, 2015).

The analytic network process (ANP) is a generalization of the analytic hierarchy process. The ANP is a methodology for multi-criteria decision making used to derive priorities of the compared elements in a network hierarchy, where the dependences and feedback within and between the elements can be considered (Zhu et al., 2015). It is used where in decision problems that cannot be structured hierarchically because they involve the interaction and dependence of higher level elements in a hierarchy on lower level elements (Gorener, 2012).

NATA is the name given to a MCDM involving a body of advice, software and data products that the UK department for transport provides to support those developing business cases for government funding or approval. The analytical tools ensure that transport projects are assessed in a comparable and consistent manner (Department for Transport, 2009).

The fuzzy-ANP decision model was made necessary as a result of the ineffectiveness of the shortcomings of the conventional ANP decision model in dealing with inherent vagueness, imprecision and uncertainty in judgement during the pairwise comparison process (Dağdeviren et al., 2008; Zhou, 2012). Although the use of the 1-9 scale in representing the verbal judgment in pairwise comparisons has the advantage of simplicity, it does not take into account the uncertainty associated with the mapping of one’s judgment to a number. In real-life decision-making situations, the decision makers or stakeholders could be uncertain about their own level of preference, perhaps due to incomplete information, complexity and uncertainty within the decision environment (Zhou, 2012). Such situations will occur for example when selecting and evaluating an optimal project. Therefore, it’s better to make project selection and assessment with consideration of fuzzy conditions (Dağdeviren et al., 2008; Zhou, 2012). A major contribution of the fuzzy decision model is its capability to represent vague data.

The multi-attribute analysis (MAA) technique facilitates decision making in being able to evaluate predetermined decision alternatives and indicate optimum choice in respect of the same objectives (Holt et al., 1994).

Thomas Saaty developed AHP in the 1970s when faced with the problem of dealing with high costs and a host of other considerations along with many other factors that conflicted with each other or were not easily identified when he was consultant with the Arms Control Disarmament Agency and professor at the Wharton School of Business. He developed it as a way of dealing with weapons trade-offs, resource and allocation of assets and decision-making.

5.2.2.2 Analytic hierarchy process

Since its development by Saaty, the AHP has been a tool at the hands of decision makers and academics, and is believed to be one of the most widely used multiple criteria decision-making tools (Vaidya and Kumar, 2006;Tahriri et al., 2008; Govindan et al., 2015). AHP is a multi-criteria decision making procedure that is capable of expressing the general decision structure by decomposing a complicated problem into a multilevel hierarchical structure of objective, criteria and alternatives (Sharma et al., 2008 in Gorener, 2012; Tahriri et al., 2008; Alexander, 2012). According to Gorener, (2012), AHP is an effective decision making tool especially where subjectivity is present. It can perform paired comparisons in order to derive the relative importance of the variables in each level of the hierarchy and/or appraise the alternatives in the lowest level of the hierarchy in order to choose the best option.

The AHP performs paired comparisons to derive the relative importance of the variable in each level of the hierarchy and/or assesses the alternatives in the lowest level of the hierarchy so as to make the best decision among alternatives. The AHP is an effective decision making method particularly when subjectivity exists and it is very useful to solve problems where the decision criteria can be organized in a hierarchical way into sub-criteria (Semih and Seyhan, 2011).

AHP can be thought of as helping to answer the questions: “Which ones do we choose?” or “Which ones are the best?” by selecting the best alternative that matches all of the decision makers’ criteria.

AHP has been discussed and applied in several disciplines including management, supplier selection, material selection and so on in order to solve decision problems. Seyed et al., (2013) discussed decision making in a management context, describing it as challenging when appropriate alternatives should be selected from among various selections based on some criteria. In developing the analytic hierarchy process (AHP), lean tools assessment was considered by the authors as criteria to select the best decision among various options.

Observing the uncertainty in management, Govindan et al., (2015) noted the preponderance of fuzzy analysis in the approaches developed by researchers to solve the green supplier evaluation and selection problem. The authors observed that the most widely adopted individual approach was the Analytic Hierarchy Process (AHP). However, Govindan et al., (2015) noted that the literature review highlighted that the implementation of green issues within the supplier selection process is limited as relatively few papers have been identified to discuss the issue.

5.2.2.3 Limitations and Variants of the AHP

Although AHP has been applied in many applications across the public and private sectors, Hartwich (1999) in Melvin Alexander, (2012) noted several limitations. One of the criticisms against the AHP is that it does not provide sufficient guidance about structuring the decision problem to be resolved, forming the levels of the hierarchy for criteria and alternatives, and aggregating group opinions when team members are geographically dispersed or are subject to time constraints. Again, as the levels of hierarchy increase, so does the difficulty and time it takes to synthesize weights Melvin Alexander, (2012).

Malczewski and Rinner, (2015) outlines the criticisms of the AHP to include: that there is ambiguity in the meaning of the relative importance of one element of the decision hierarchy when compared to another element; the number of comparisons for large size problems; and the use of 1-9 scale. Malczewski and Rinner, (2015) and Youngsik, (2011) argues that for large problems, the number of pairwise comparisons required would be too many. For this reason Youngsik, (2011) recommends factoring the decision to make it manageable, examining only the relevant aspects.

As a result of the shortcomings mentioned above, different forms of the AHP have been developed and applied in academia and industry in a bid to mitigate some of the limitations.

In a bid to drastically reduce the number of pairwise comparisons, Kallas, (2011) proposed a transformation of the likert scale to approximate Saaty's pairwise comparison. In this alternative approach, likert scale was used to collect the required data on a direct valuation of attributes and levels using a nine-point likert scale; where "1 = not important" and "9 = very important". The result of each valuation score as obtained from the likert scale valuation was then transformed in a subsequent step to simulate pairwise comparison.

Ashutosh and Ido, (2011) demonstrating how the AHP can be used to assess the risk of managerial fraud used a rating model where for each lowest level criterion in the hierarchy, possible ratings were specified. The rating intensities employed range from 'No red flag' to 'very significant'. The ratings here are such that the user goes through an elicitation process with established numerical values that reflect the subjective relative intensity attached to each rating.

Begum et al., (2012) demonstrates a method for transforming qualitative data into quantitative data with scale-5 likert using commensurate units. The data transformations table using likert-5 is available in Begum et al., (2012).

In M. Asad et al., (2015)'s multi-criteria decision making (MCDM) application using AHP, the preference criterion is measured using questionnaire interview. During the evaluation, pairwise comparison was carried out among the criterion while the sub-criteria rating were measured using likert scale. This implies that different evaluation methods were used for different levels of the hierarchy-pairwise comparisons for criteria and direct evaluation, on a likert scale for sub-criteria as echoed in Ishizaka et al., (2012).

A multiple-item method could be employed in developing a questionnaire for measuring the performance indicators in AHP with each item based on five point likert scale ranging from "very low" to "very high"(Theriou et al., 2004). Similarly, Muralidharan et al., (2002) adopted a five point likert scale for the individuals to rate alternatives on each of the attributes in the hierarchy.

5.2.2.4 Implications of limitations

The involvement of multiple participants working on this method, their different opinions about the weight of each criterion and sub-criterion might have complicated matters. Also the participants may have found the pairwise comparisons and ratings of practices time consuming and cumbersome as there are more than 30 practices to consider. This could have had an impacted the accuracy of their responses and that of the framework presented. A major implication is therefore that there are chances of bias when giving relative weightage to different criteria and sub-criteria since the rating scale used in the AHP analysis is conceptual. This could affect the usefulness of the framework.

In the event that a LAG practice is included or removed , the "rank reversal" problem could arise i.e., changes in the importance ratings whenever criteria or alternatives are added-to or deleted-from the initial set of alternatives compared. This could also affect the usefulness of the framework.

5.2.2.5 Strengths of the AHP

AHP has been adopted as a decision-making method for the following reasons:

1. *Formal structuring of the problem*: It allows complex problems to be decomposed into sets of simpler judgments and presented in a hierarchy of levels. It allows the decision maker to define as many levels as needed depending on the problem being tackled(Goodwin and Wright, 1991). Bratianu et al., (2011) state that the structure of managerial decision making is vertical and the alternatives for each decision are shown horizontally.

2. *Simplicity of pair-wise comparisons*: The use of pair-wise comparisons allows the decision maker to concentrate, in turn, on each small portion of the problem as only two options have to be considered at a time(Goodwin and Wright, 1991).
3. *Subjectivity and inconsistency*: It offers the possibility to measure the consistency in the decision maker's judgment (Koorosh, 2013). AHP is an effective tool especially when subjectivity exists (which can result in inconsistent judgments) and can help to

eliminate the inconsistencies. In other words, AHP does not require the very strong assumption that the stakeholders make absolutely no errors in providing preference information. The ability to deal formally with judgment error is distinctive of the AHP method (Saaty, 2007).

4. *Designed for multi-criteria*: It offers a solution when a decision maker is faced with multiple objectives (Goodwin and Wright, 1991). It allows the decision maker to consider all the criteria and organise them in a hierarchy of levels. The AHP method has the ability to structure complex, multi-person, multi-attribute and multi-period problem hierarchically (Tahriri et al., 2008).
5. *Widely adopted and proven*: The analytic hierarchy process (AHP) has found widespread application in decision making problems and that is evidence of its versatility (Goodwin and Wright, 1991;Tahriri et al., 2008).
6. AHP has the capability to integrate both qualitative and quantitative information (Koorosh, 2013).
7. The respondents in an Analytic hierarchy process survey may carry out rating items individually or as a group (Melvin Alexander, 2012).
8. It allows users to gather all the relevant elements of the problem into one model and work out their interdependencies and their perceived consequences (Asma, 2006).

5.2.2.6 Reasons for Choosing AHP for this research

Achieving competitiveness through cost reduction, lead time and waste reduction at different stages of the product life cycle presents a multi-criteria decision problem. The complexity of this decision problem can be eased by breaking it down into sub-issues where the hierarchy can easily be explained to the participants. Therefore, one very obvious advantage is the hierarchical structuring of the decision problem, i.e. the nature of the decision problem necessitated the use of AHP. AHP allows the consideration of multiple criteria and multiple alternatives without which, managers might base their decisions on only a subset of important criteria while not understanding their relative importance

Considering that the participants are sufficiently knowledgeable, being experts, the use of the AHP could better ensure that the outcome of the analysis is generally acceptable because of the possibility of combining the input from participants, which helps in calculating the geometric mean. This helps in obtaining a consolidated AHP input. This is helpful as there are several lean, agile and green practices.

The AHP allows for the ranking of criteria and sub-criteria, which in this research is required in order to achieve the objective of selecting the most appropriate LAG practices. The final outcome, resulting from the consolidated input is also generally acceptable as the process is widely adopted and proven.

Also, because it is easier to handle all AHP calculations with a spread sheet program, this process can easily be delivered and explained to users with minimal usage issues.

5.2.3 Part 3: Analysis and comparison module

This part of the framework involves obtaining real data from a company, analysing the data with the multiple regression model which would have been developed at this stage. The data is then analysed according to cost, lead time and waste as obtained. The top ranked practices for achieving the objectives of cost reduction, lead time reduction and waste reduction are selected and analysed with the same regression model and their outcomes compared against each other. At this stage the decision making is such that if the company's practices prove to be better they are fed back into the system. However if the company's practices fail to yield an improved outcome and those of the proposed model does, the practices of the proposed model are suggested to the company.

The conceptual framework is fully explained with the aid of the process view shown in figure 5.5. The process view of the framework explains the parts of the functional view (figure 5.1) in the following way:

- Steps 1 to 5 explains part 2 of the functional view (Decision module)
- Steps 6 to 10 illustrates part 3 of the functional view (Analysis and comparison module)

5.3 Framework - The process view

With the aid of the diagram in figure 5.5, the process view of the framework and the implementation of the AHP are represented in a number of steps. Steps 1 to 5 will be fully presented in the remainder of this chapter, while steps 6 to 10 will be presented in CHAPTER 6.

As mentioned earlier, steps 1 to 5 correspond to the steps of the AHP method. In applying the AHP for this research, the method by Muralidharan et al., (2002), Theriou et al., (2004) and Ishizaka et al., (2012) where different evaluation methods were used for different levels of the hierarchy were adopted. In this case, pairwise comparisons have been used to appraise the criteria and alternative levels, while the evaluation for the sub-criteria has been done with a likert scale. The reason for that is because for the 41 practices in the sub-criteria level there would be 820 pairwise comparisons to be performed for each performance measure (cost reduction, lead time reduction and waste reduction), which would be cumbersome and could generate a lot of inconsistencies. The criteria level in the hierarchy for this research is treated the same as the overall objective.

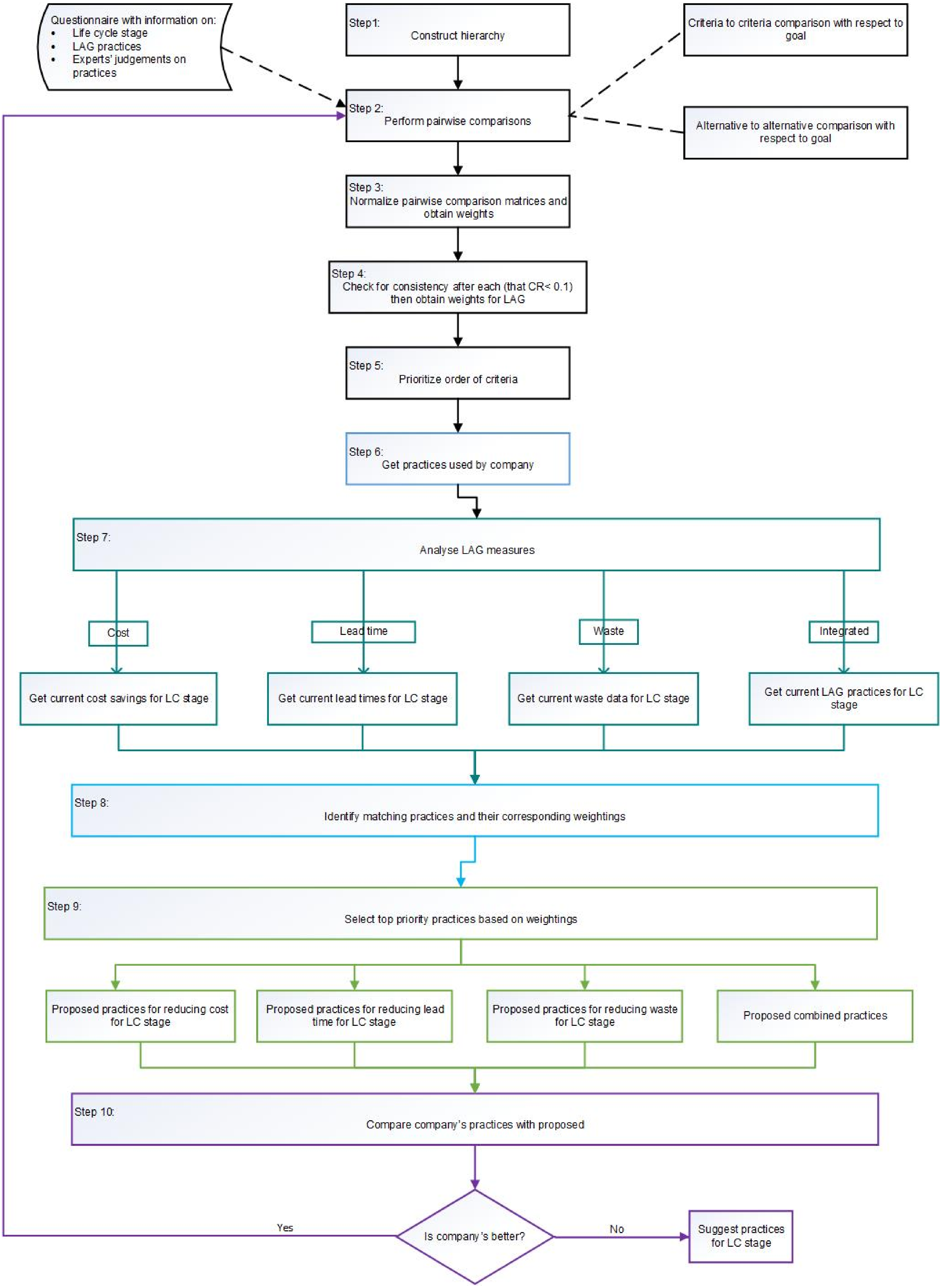

Figure 5.5: Process view of conceptual framewor

5.3.1 Background to structural hierarchy of the AHP

The decision problem is reduced to a hierarchy of levels as shown in figure 5.6. Constructing the hierarchical structure is the most important step in AHP. The hierarchy should be constructed such that elements occupying the same level are of the same magnitude and must be capable of being related to some or all elements in the next higher level. In a typical hierarchy, the alternatives are at the bottom; the next higher level would consist of the criteria for judging the alternatives. In other words, the highest level corresponds to the overall objective. The lowest level is formed by a set of strategies (in this case practices) by which the objective can be achieved. The intermediary levels could be composed of hierarchical criteria levels which measure the objective achievement.

The decision criteria could be grouped within high-level criteria, where the groups would be linked to the top single element, which is the objective or overall goal. It begins by considering the achievement competitiveness of by taking into account the four stages of the product life cycle as a decision making problem with *M* alternative practices to choose from and *N* criteria. The criteria and sub-criteria contributing to the decision are represented at the intermediate levels.

Zahedi (1986) comments that the structure of the hierarchy depends upon the nature or type of design decision. Also, the number of the levels in a hierarchy depends on the complexity of the problem being analysed and the degree of detail of the problem that an analyst requires to solve (Zahedi, 1986).

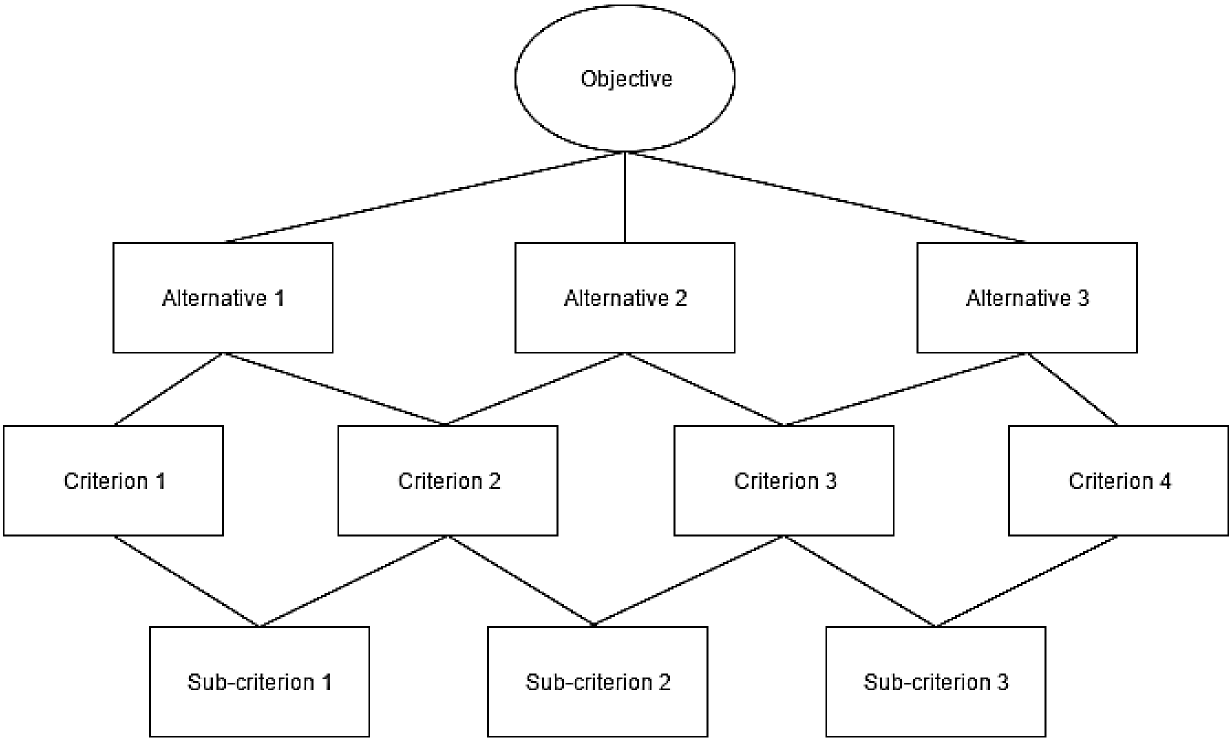

Figure 5.6: Hierarchical Approach of AHP

5.3.1.1 Step 1: Application of the Structural Hierarchy

Since practices from several paradigms (lean, agile and green) can be applied in a production system, a value should be obtained based on performance measures and PLC stage in order to identify and pick the most appropriate ones given the life cycle stage. This should help determine which paradigm and which practices should have priority in a given circumstance (In this case life cycle stage). Therefore a proper decision has to be made based on the afore-mentioned using AHP as shown in figure 5.7. In order to select the most appropriate alternatives, the consideration is about which alternative could be the best choice to meet the objective given all criteria. The goal being to select the most appropriate practices to improve competitiveness (this is placed at the top of the hierarchy).

The items for this hierarchy were chosen based on consideration of literature. The hierarchy descends from the more general criteria in the second level to the alternatives and sub-alternatives in the third and fourth levels. The criteria level involves the key performance indicators (or measuring factors); that is what needs to be achieved in order to achieve the overall objective- cost reduction, lead time reduction and waste reduction; they are for lean, agile and green.

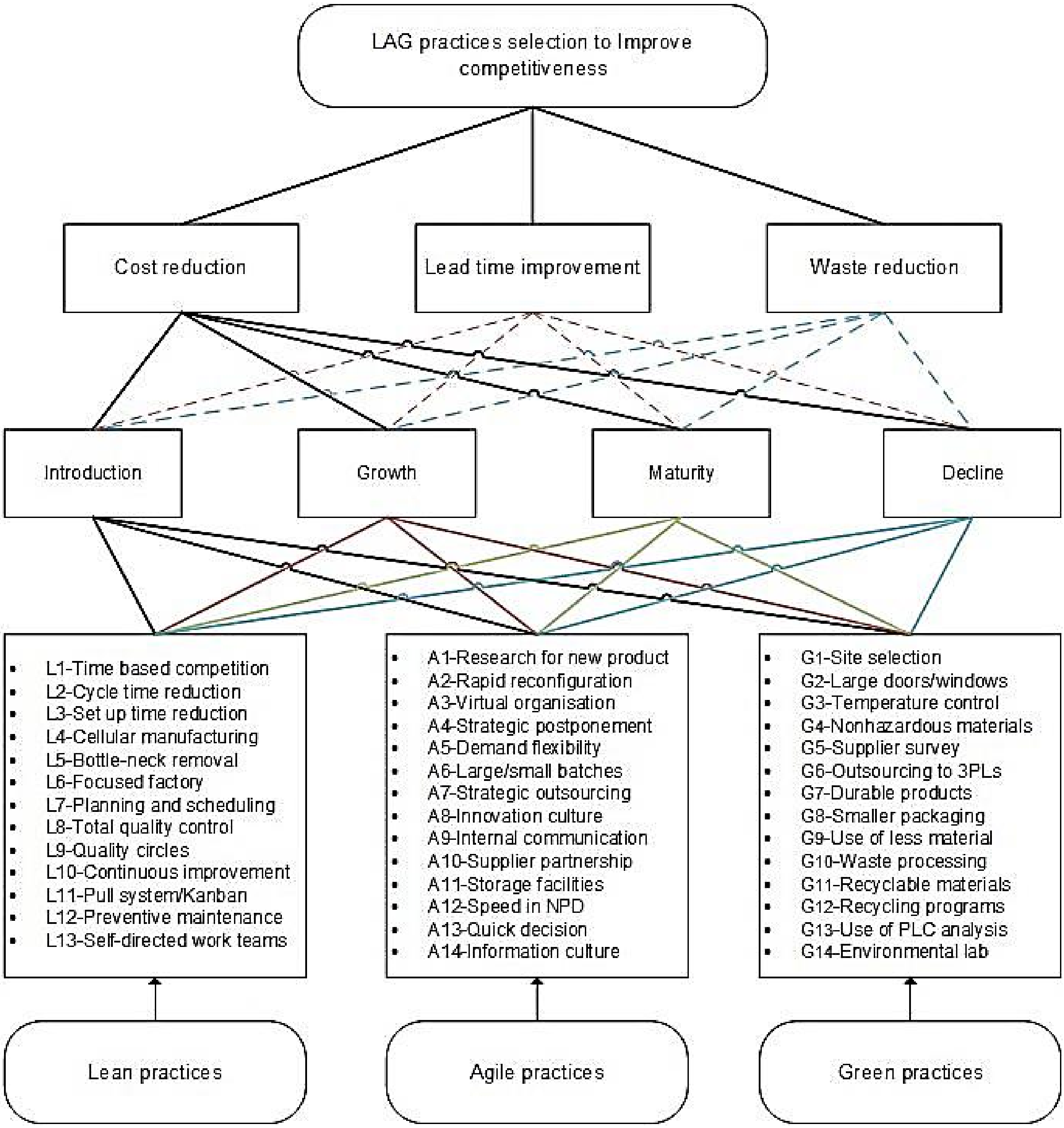

Figure 5.7: Hierarchy of the Decision Problem

5.3.2 Background to pairwise comparisons

After the problem has been arranged in a hierarchical form, the next step is to determine the relative importance of each criteria and sub-criteria, using the pairwise comparison technique (Saaty, 1986).

The elements of any level are subjected to a series of paired comparisons on the Saaty's scale (ranging from 1/9 to 9/9) as shown in table 5.1 and a paired comparison matrix is built. Comparisons are performed between pairs of elements within each branch of each level of the hierarchy to determine the relative worth of one element as compared with another in relation to the element directly above.

Table 5.1: Preference scale for pairwise comparisons

Definition	Intensity of Importance (a_{ij})	Reciprocal (decimal)
Equal Importance	1	1
Equally to moderately	2	1/2 (0.500)
Moderately Importance	3	1/3 (0.333)
Moderately to strong	4	1/4 (0.250)
Strong Importance	5	1/5 (0.200)
Strongly to very strong	6	1/6 (0.167)
Very strong Importance	7	1/7 (0.143)
Very strong to extremely	8	1/8 (0.125)
Extreme Importance	9	1/9 (0.111)

The pairwise comparisons are entered into a matrix and used to determine a vector of priority weights. Only those elements that pertain to a common objective are compared against one another. Breaking a complex system into a set of pairwise comparisons is a major feature of AHP.

This research uses the following notation:

w_i = weight for attribute *i*, *i* =1... *n* where *n* = number of attributes

a_{ij} = w_i / w_j = the result of a pairwise comparison between attribute *i* as compared to attribute *j*

A = matrix of pairwise comparison values, a_{ij}

A set of pairwise comparisons can therefore be represented as:

$$A \text{ ¿ } \begin{matrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_n} \\ . & . & . \\ . & . & . \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_n} \end{matrix} \quad \text{.............................5.1}$$

where $\frac{w_1}{w_2}$ is the importance of attribute *1* as compared to attribute *2*. Since the direct result of a pairwise comparison is a_{ij}, where a_{12} is equal to $\frac{w_1}{w_2}$, matrix A becomes:

$$A = \begin{matrix} a_{11} & a_{12} & .. & a_{1n} \\ a_{21} & a_{22} & .. & a_{2n} \\ . & . & . & . \\ . & . & . & . \\ a_{n1} & a_{n1} & .. & a_{nn} \end{matrix} \quad \text{.....................................5.2}$$

The goal of AHP is to uncover the underlying scale of priority values w_i. In other words, given a_{ij}, find the “true” values of w_i and w_j.

This A matrix has some special properties. First, A is of rank one. If we look at each column of A, we have:

$$A = \frac{w_1}{w_{1^{-1}}} \text{¿} \frac{w_1}{w_2} \text{¿} \frac{w_1}{w_{2^{-1}}} w \text{¿}_2 \text{¿} w_{n^{-1}} \text{¿} w_2 \text{¿.¿¿.¿¿.¿.¿¿.¿¿.¿} w_n \text{¿¿} w_n \text{¿¿} w_n \text{¿}$$

............................5.3

Each column of A differs only by a multiplicative constant, w_i^{-1}. If the matrix A is consistent, only one column is required to determine the underlying scale (w_j ,..., w_n). The same evaluation could be undertaken in a row-wise fashion with the same result.

Secondly, if B is x times more important than C, then it follows that C is $\frac{1}{x}$ times as important as B. In other words, a_{ji} is the reciprocal of a_{jj} such that a_{jj} = $\frac{1}{a_{jj}}$.

This assumes the decision maker is consistent with respect to individual pairwise comparisons and is a fundamental assumption made by the AHP. With this assumption, matrix A is be reduced to:

$$A = \begin{matrix} 1 & a_{12} & a_{13} & .. & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & .. & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & .. & a_{3n} \\ . & . & . & . & . \\ . & . & . & . & . \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & .. & 1 \end{matrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.4$$

As seen in Equation 5.4, when a criterion is compared with itself each criterion has equal weight. This makes the diagonals equal to unity (i.e. $\frac{w_1}{w_1}$ = 1). The entries below the diagonal are a reciprocal of those entries above the diagonal.

5.3.2.1 Step 2: Application of pairwise comparisons

Following the construction of the hierarchy, pair-wise comparisons were systematically performed to include all the combinations of alternative relationships. Prior to the analysis, the actual implementation of this model required that a group of decision makers get together in a brainstorming session and arrive at a consensus about each of these value judgments. But this was not possible as there were differences in the schedule and availabilities of respondents. Hence, the questionnaire (appendix four) was distributed to the decision makers.

The responses from the respondents were elicited in such a way that they had to rate the contribution of the practices according to the performance indicators taking life cycle stage into account. All the information were then gathered and aggregated.

As shown on table 5.1, the paired comparison scale between the comparison pair (a_{ij}) of two items i and j is as follows:

(Item i) 9-8-7-6-5-4-3-2-1-2-3-4-5-6-7-8-9 (item j)

The preference scale for pair-wise comparisons of two items ranges from the maximum value 9 to 1/9 (0.111 in decimal form). Let aij represent the comparison between item-i (left) and item-j (right). If item-i is 5 times (strong importance) more important than item-j for a given criteria or product, then the comparison $a_{ji} = \frac{1}{a_{ij}}$ = 1/5 (0.200) or the reciprocal value for the paired comparison between both items.

The responses were analysed using Statistical package for social sciences (SPSS) to calculate the consistency ratio (CR) and the consistency vectors of the criteria and alternative. Pair-wise comparison matrices are combined using the geometric mean approach to obtain the corresponding consensus pair-wise comparison matrices. The matrices are then translated into the corresponding largest eigenvalue problem and solved to find the normalised and unique priority weights for each criterion.

According to Saaty (1980) in Tahriri et al., (2008) the judgment of a respondent is accepted if CR ≤ 0.10. The mean values of the Eigenvector comparisons were calculated. If the result of any of the respondents is not consistent the inconsistencies in the results should be communicated back to the evaluators to go through the comparison again, but this time with the researcher. They would be requested to carefully evaluate the criteria until consistency was achieved.

The priorities, (obtained in exact form by raising the matrix to large powers and summing each row and dividing each by the total sum of all the rows, or approximately by adding each row of the matrix and dividing by their total) are shown at the bottom of the table along with the true values expressed in relative form by dividing the stage of the product life cycle by the sum of the stages of the product life cycle.

Table 5.2: Criteria with respect to objective

	Introduction	Growth	Maturit y	Decline
Introduction	1	1/2	3	1/2
Growth	2	1	3	1/4
Maturity	1/3	1/3	1	1/7
Decline	2	4	7	1
Total	$5^{1}/_{3}$	$5^{5}/_{6}$	14	$1^{25}/_{28}$

Table 5.3: Criteria with respect to objective (decimal representation)

	Introduction	Growth	Maturit y	Decline
Introduction	1	0.5	3	0.5
Growth	2	1	3	0.25
Maturity	0.333	0.333	1	0.143
Decline	2	4	7	1
Total	5.333	5.833	14	1.893

Table 5.4 shows the pairwise comparison matrix of the for the alternative with respect to the main objective.

Table 5.4: Pairwise comparison of alternative with respect to objective

	Lean	Agile	Green
Lean	1	0.33	0.25
Agile	3	1	0.5
Green	4	2	1
Total	8	3.33	1.75

5.3.3 Background to normalization and Derivation of Criteria Weights

Once pairwise comparisons have been carried out, the next step is the computation of a vector of priorities in the matrix or weighting of elements. In other words, given a_{ij} , find w_i and w_j . Because of the “random” error inherent in human judgment, even professional judgment, it cannot be expected the true values of w_i and w_j can be found. The user will need to be content instead with good estimates of w_i and w_j (Fichtner, 1986). Several methods have been proposed to estimate weights from matrices of pairwise comparisons. The two most common methods of deriving attribute weights are the eigenvector and the logarithmic least squares methods.

It can be shown by algebraic manipulations of the pairwise definitions that attribute weights can be obtained by finding the eigenvector corresponding to the largest eigenvalue of the A matrix. The eigenvector method was originally proposed by Saaty (1980) and is one of the most popular methods of calculating preferences from inconsistent matrices of pairwise comparisons. Equation 6.0 showed a consistent matrix of pairwise comparisons. When this matrix is consistent it is of rank one, meaning that only one column or one row is necessary to derive the underlying scale w_i , of weights. When inconsistency is introduced into pairwise comparisons, more than one row or column of A is desired in order to derive a good estimate of the underlying scale of weights. The largest eigenvalue of A, λmax, is used in consistency calculations (discussed below in Consistency) and its corresponding eigenvector, normalized such that its components sum to one represents the vector of attribute weights.

In the next step, elements of the eigenvector are normalized to sum to one as opposed to setting the largest element of the eigenvector equal to one. In order to do that (normalize each column to sum to one), the elements of that column are divided by the total of the column and summed up. Finally, the elements in each resulting row are added and the sum divided by the number of elements in the row to get the average**.**

This is required in order to give the potential for equal weighting between branches of the hierarchy where the number of elements being compared may be different. This normalization ensures the weights within each branch of the hierarchy sum to one no matter the number of elements or the relationships between the elements of a branch.

From the definition of $a_{ij} = w_i/w_j$ and $a_{ij}=1/a_{ji}$

$$a_{ij}a_{ji} = a_{ij}\frac{1}{aij} = a_{ij}\frac{1}{\frac{wi}{wj}} = a_{ij}\frac{wi}{wj} = 1 \text{ ……………………5.5}$$

It then follows that in the consistent case:

$$\sum_{j=1}^{n} aij \frac{wj}{wi} = n \quad i = 1 \text{ to } n \text{ ……………………………5.6}$$

Multiplying both sides of the equation 5.6 above through by w_i

$$\sum_{j=1}^{n} aij\, wj = n \quad w_i \quad i = 1 \text{ to } n \text{ ……………………5.7}$$

These statements are equivalent to the matrix notation A*w* = *nw*. If the goal is, given a positive reciprocal matrix A, to find *w*, the problem becomes (A - *nI*) *w* = 0. This is a classical eigenvector problem and is non-trivial if and only if *n* is an eigenvalue of A. This method for deriving a vector of weights from a positive reciprocal matrix of pairwise comparisons uses the largest eigenvector, also termed the principal right eigenvector, and its corresponding eigenvalue.

5.3.3.1 Step 3: Application of normalisation

Normalising pair-wise comparison matrix of the criteria with respect to objective

Table 5.4 shows paired comparisons of each factor with respect to each other that forms a comparison matrix with calculated weight, synthesising judgement to obtain the set of overall weights for achieving the objective

Table 5.5: Normalized matrix of criteria with respect to objective

	Intro	Growth	Maturity	Decline	**Criteria Weights (W)**
Intro	0.187512	0.085719	0.214286	0.264131	0.187911907
Growth	0.375023	0.171438	0.214286	0.132066	0.223203256
Maturity	0.062441	0.057089	0.071429	0.075541	0.066625105
Decline	0.375023	0.685753	0.5	0.528262	0.522259732
Total	1	1	1	1	

The table 5.5 indicates an interesting outcome, which is that the decline stage ranks highest in order of importance compared to other PLC stages. It is noteworthy that the respondents were asked to indicate relative importance with respect to achieving reduced costs, lead time and waste. One of the characteristics of the decline PLC stage is that costs are lower, hence a product is cheaper to produce at this stage; this implies that a company may be able to make profits at this stage provided that costs are low.

Table 5.6: Normalized matrix of alternative with respect to objective

	Lean	Agile	Green	**Alternative Weights (W)**
Lean	0.125	0.099099	0.142857	0.122318747
Agile	0.375	0.3003	0.285714	0.320338195
Green	0.5	0.600601	0.571429	0.557343057
Total	1	1	1	

The Priority column (alternative weights) in table 5.6 is the relative ranking of the alternative produced by dividing each element of the matrix with the sum of its column. Next, the average across the rows is computed. The sum of priority criteria vector is one. The largest value in the priority weight is the most important criterion, green = 0.5573. This outcome is consistent with the outcome shown in table 4.11 in CHAPTER FOUR which shows that green comes top for cost reduction and lead time reduction.

5.3.4 Background to measurement of consistency

Deviations from both ordinal and cardinal consistency are considered, and to a certain extent allowed, within AHP. Ordinal consistency requires that if *x* is greater than *y* and *y* is greater than *z*, then *x* should be greater than *z.* Cardinal consistency is a stronger requirement stipulating that if *x* is 2 times more important than *y* and *y* is 3 times more important than *z*, then *x* must be 6 times more important than *z*. If A is cardinally consistent, then $a_{ij}a_{jk} = a_{ik}$. Using the previous definition of *aij* we can see that this is true:

$$a_{ij}\, a_{jk} \;=\; \frac{wi}{wj} \quad \frac{wj}{wk} \;=\; \frac{wt}{wk} \qquad \text{……………………………….5.8}$$

If the relationship $a_{ij}a_{jk} = a_{ik}$ does not hold than A is said to be cardinally inconsistent. AHP has been designed to deal with inconsistent matrices (both cardinal and ordinal inconsistency), thus the problem becomes:

$$\frac{wt}{wj}\ \varepsilon_{ij} \bullet \ \frac{wj}{wk}\ \varepsilon_{jk} = \ \frac{wt}{wk}\ \varepsilon_{tk} \text{…………………………………………………5.9}$$

where $\varepsilon_{ij} > 0$ and represents some perturbation causing A to be inconsistent, producing an A matrix that looks like the following:

$$A = \begin{matrix} 1 & \varepsilon_{12}a_{12} & \varepsilon_{13}a_{13} & \cdots & \varepsilon_{1n}a_{1n} \\ \frac{1}{\varepsilon_{12}a_{13}} & 1 & \varepsilon_{23}a_{23} & \cdots & \varepsilon_{2n}a_{2n} \\ \frac{1}{\varepsilon_{13}a_{13}} & \frac{1}{\varepsilon_{13}a_{13}} & 1 & \cdots & \varepsilon_{3n}a_{3n} \\ .. & .. & .. & \cdots & .. \\ \frac{1}{1_{na}a_{1n}} & \frac{1}{2_{na}2_{n}} & \frac{1}{\varepsilon_{3n}a_{3n}} & \cdots & 1 \end{matrix} \qquad \text{…………………….6.0}$$

Various methods have been devised to deal with inconsistency. Saaty (1977) suggests using the following consistency index (CI):

$$CI = \frac{(\lambda max - n)}{(n-1)} \qquad \text{……………………………………….6.1}$$

where λmax is the largest eigenvalue of A and n is the number of elements within a branch being compared. If A is perfectly consistent (cardinally) than λmax will be at a minimum and equal to n, producing a CI equal to zero. As inconsistency increases λmax will become increasingly large, producing a larger value of CI. This consistency index can also be expressed as a consistency ratio:

$$CR = \frac{CI}{RI} \qquad \text{………………………………………….......6.2}$$

where RI is a known random consistency index obtained from a large number of simulation runs and varies depending upon the order of matrix.

The consistency ratio (C.R.) is calculated to determine the acceptance of the priority weighting. The consistency test is one of the essential features of the AHP method which aims to eliminate the possible inconsistency revealed in the criteria weights, through the computation of consistency level of each matrix. The software system called Expert Choice is used to determine the normalized priority weights. The consistency ratio (CR) was used to determine and justify the inconsistency in the pair-wise comparison made by the respondents. Based on Saaty's (1980) empirical suggestion that a C.R. = 0.10 is acceptable, it is concluded that the foregoing pair-wise comparisons to obtain attribute weights are reasonably consistent. If the CR value is lower than the acceptable value, the weight results are valid and consistent. In contrast, if the CR value is larger than the acceptable value, the matrix results are inconsistent and are exempted for the further analysis.

5.3.4.1 Step 4: Application of consistency measurement

To check the consistency of our judgement, we need to calculate the Consistency Ratio as described earlier, noting that CR has to be less than 0.1. The following sub-steps are followed;

1. Weight sums vector $W_s = C * W$ where C = Comparison matrix in table 5C, W= Criteria weight i.e average of the normalised matrix
2. Consistency Vector = $W_s * (1/W)$
3. Find the average of the Consistency vector = λ
4. Determine the Consistency Index i.e $CI = \frac{\lambda - n}{n-1}$

The Consistency Index (CI) measures the degree of logical consistency among pair-wise comparisons.

5. Check Random Index (RI) table value for $n*n$ matrix

The Random Index (RI) is the average CI value of randomly-generated comparison matrices using Saaty's preference scale sorted by the number of items being considered.

6. Calculate the Consistency Ratio, $CR = CI/RI$

Consistency Ratio (CR) indicates the amount of allowed inconsistency (0.10 or 10%). Higher numbers mean the comparisons are less consistent. Smaller numbers mean comparisons are more consistent. CRs above 0.1 means the pair-wise comparison should be revisited or revised.

These sub-steps are carried out for the criteria with respect to objective (i.e. first comparison) and for alternative with respect to objective (i.e. second comparison matrix).

Table 5.7: Checking for consistency of judgement

Weight sums (Ws)	Consistency vector
0.760519	4.047209
1.00005	4.480445
0.27821	4.175747
2.257272	4.322126

The values under the weight sums column are obtained by applying the sub-step 1 i.e. multiplying the first comparison matrix with values under the criteria weights in table 5E while the values under the consistency vector column are obtained by applying the sub-step 2.

i.e. 1(0.187911907) + 0.5(0.223203256) + 3(0.066625105) + 0.5(0.522259732) = 0.760519

Average λ= 4.256382

The value for λ is obtained by finding the average of the values under the consistency vector column in table 5.7 above

Consistency Index (CI) = 0.085461

CI is obtained by applying sub-step 4 where n = 4

Table Random Index Value=0.9

Consistency Ratio (CR) =0.094956 which is obtained after the application of sub-step 6

Since CR<0.1, the rankings are consistent

Checking for consistency for second comparison matrix (alternative with respect to objective)

Table 5.8: Checking for consistency of judgement (alternative and objective)

Weight sums (Ws)	Consistency vector
0.126656	1.035455
0.301308	0.940594
0.572036	1.026363

Average λ=3.002411

Consistency Index (CI) =0.001206

Table Random Index Value=0.58

Consistency ratio (CR) = 0.002079

Since CR<0.1, it follows that the rankings are consistent.

Lambdamax (λ_{max}) (3.0024) is an eigenvalue scalar that solved the characteristic equation of the input comparison matrix. Ideally, the λ_{max} value should equal the number of factors in the comparison (n=3) for total consistency.

5.3.5 Step 5: Prioritize order of criteria.

The aim of this step is to prioritize the practices based on cost, lead time and waste for specific life cycle stages. LAG practices have been applied and used as dependent variables as they are used to predict the outcome of the measuring factors (Cost reduction, lead time reduction and waste reduction) here applied as the independent variables, the weightings for each of the practices (lean, agile and green) are generated by applying the collinearity phenomenon. The table 5.9 shows the practices and their weightings for cost, lead time and waste.

Based on this table, it is easy to prioritize the practices according to their cost reduction, lead time reduction or waste reduction capabilities depending on business requirement. If the focus is on cost reduction, the top practices will be ranked differently than if the focus is solely on lead time or waste reduction.

Maturity stage

Table 5.9: Weightings of LAG practices for maturity stage

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
LEAN				
Time based competition	2.07	1.16	2.43	1.89
Cycle time reduction	2.35	1.27	3.21	2.28
Set up time reduction	2.80	1.82	1.00	1.87
Cellular manufacturing	2.41	1.21	1.88	1.83
Bottle-neck removal	2.59	1.63	1.82	2.01
Focused factory	3.55	1.47	1.06	2.03
Planning and scheduling	2.31	1.27	1.76	1.78
Total quality control	2.32	1.40	1.13	1.62
Quality circles	2.31	2.54	2.00	2.28
Continuous improvement	1.72	1.10	1.12	1.31
Pull system/Kanban	1.64	1.83	3.00	2.16
Preventive maintenance	4.79	1.65	1.00	2.48
Self-directed work teams	2.82	3.20	1.00	2.34

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
AGILE				
Research for new product	2.00	2.47	3.94	2.80
Rapid reconfiguration	1.88	2.18	3.88	2.65
Virtual organisation	2.47	2.40	1.72	2.20
Strategic postponement	2.06	2.87	4.14	3.02
Demand flexibility	2.24	3.74	2.48	2.82
Large/small batches	2.00	3.09	3.72	2.94
Strategic outsourcing	2.12	4.01	3.38	3.17
Innovation culture	2.24	4.38	3.99	3.53
Internal communication	2.35	3.01	3.30	2.89
Supplier partnership	2.47	4.41	3.19	3.35
Storage facilities	2.71	4.19	4.19	3.70
Speed in NPD	2.18	1.97	3.57	2.57
Quick decision	2.41	2.54	3.39	2.78
Information capture	2.35	3.10	3.10	2.85
GREEN				
Site selection	3.36	2.94	2.83	3.04
Large doors/windows	1.24	1.41	2.13	1.59
Temperature control	2.92	1.95	2.79	2.55
Non hazardous materials	3.21	3.36	3.70	3.42
Supplier survey	2.43	1.89	2.75	2.36
Outsourcing to 3PLs	1.77	1.57	1.95	1.76
Durable products	2.28	4.32	2.04	2.88
Smaller packaging	2.46	3.92	1.83	2.74
Use of less material	1.24	3.27	2.02	2.18
Waste processing	1.71	3.67	3.06	2.81
Recyclable materials	2.63	3.71	1.88	2.74
Recycling programs	2.85	4.54	1.81	3.07
Use of PLC analysis	3.21	2.26	2.01	2.49
Environmental lab	1.25	1.13	2.48	1.62

5.4 Representation of the analysis and comparison module

This part of the framework representing steps 6 to 10 of the process is part of the validation process. For better illustration and explanation, part 3 of the functional framework and associated steps are presented as part of CHAPTER SIX. The following are involved in fulfilling this part:

- Obtaining data from a company on the PLC stage and LAG practices used
- Obtaining data on the company's cost, lead time and waste performance
- Identifying the company's LAG practices which match with the ones from this research
- Selecting the LAG practices with the highest priority weightings for each performance measure

- Analysing and comparing company's outcomes with those of the proposed top ranked LAG practices from this research

At this stage the decision making is such that if the company's practices prove to be better they are fed back into the system. However if the company's practices fail to yield an improved outcome and those of the proposed model does, the practices of the proposed model are suggested to the company.

5.5 Similarity with existing frameworks/methods

In this section twelve frameworks have been judged to be closely related to the proposed framework in this research due to similarities in their problem solving approach and the components of the framework.

Amin and Karim (2013) presented a methodology to quantitatively evaluate the contribution of lean strategies selected to reduce identified lean wastes within the manufacturers' time constraints. The authors posit that appropriate lean strategies must be selected to eliminate wastes or improve the performance in the manufacturing process within their limited implementation time, and that it would be preferable to select the lean strategies that have the most impact overall on the identified wastes or performances, according to manufacturers' priority. This links to the proposed framework in this research as it proposes the selection of practices based on their contribution towards the reduction of wastes, similar to this current research, on method to select LAG practices based on their contribution towards cost reduction, lead time reduction and waste reduction.

Aitken et al. (2003) acknowledged that there is no one strategy that is applicable to all products types, and that each stage of the product life cycle has significant impact on supply chain strategy. Therefore, by monitoring a product as it proceeds through its product life cycle, it can be matched to the most appropriate strategy. The authors reviewed the way in which order winner (OW) and market qualifier (MQ) characteristics change during a product's life cycle at a UK lighting company and it was found that the company could not compete on the basis of cost alone; therefore, very short lead times are the only other competitive avenue. Some of the supply chain strategies that products could be matched to include the lean, agile and leagile paradigms. Aitken et al. (2003)'s work is linked to the current research in proposing that products be monitored throughout their life cycles and matched to lean, agile or a combination of the two; and in using cost and lead time as competitive paths.

Madu et al. (2002) acknowledges that environmental consciousness is increasingly, becoming a fundamental part of the overall corporate culture and is helping to reshape corporate strategies. While the concern for environmental issues may not be new, however, the wave of environmental consideration in corporations is certainly new, perhaps as a consequence of increasing environmental legislations and the public concerns about the use of limited natural resources and the degradation of the environment due waste accumulation. The authors also recommend that environmental processes are front-end integrated rather than 'end-of-pipe reactive' in the strategic planning and decision making of firms. Consequently, Madu et al. (2002) proposed a hierarchic framework for environmentally conscious design that integrates product designers and stakeholders in evaluating product features and its environmental burden. The analytic hierarchy procedure (AHP) was used to develop priority indices for customer requirements to highlight key features that must be present in the product. Madu et al. (2002)'s call to integrate green processes in decision making to reduce the accumulation of environmental waste and the use of the MCDM method AHP to develop priority scales is consistent with the spirit of this current research in integrating green with lean and agile decision making and using MCDM method priority determination.

In proposing an integrated approach for supplier portfolio selection, Abdollahi et al. (2015) explains that firms must be flexible to be agile for quick response to the changes in business environment and lean in order to eliminate waste to promote efficiency and be competitive by satisfying customer requirements. Produced items must be at a good level of cost and quality. Hence, for being competitive in the market, Abdollahi et al. (2015) believes that these concepts must be considered simultaneously because lean works best in high volume, low variety and predictable environments while agility is needed in less predictable environments. The authors explains that one of the reasons for their research is that most published focus only supplier's lean manufacturing perspectives, and only a few papers have focused on the supplier's agile manufacturing perspective while no paper was found that pays attention to these two factors at the same time. They further explain that the supplier selection problem is better solved by applying a combination of MCDM methods due to a multiplicity of suppliers. The criteria in this method involves lean and agile.

Abdollahi et al. (2015) applied the MCDM method in resolving the selection and evaluation problem where there are multiple suppliers considering lean and agile criteria in decision making. This supplier selection framework is therefore linked to this research in the acknowledgement of the deficiencies of lean and agility and the need to combine them; it also adopts a MCDM approach in dealing with multiple alternatives to choose from, as this research does in choosing lean, agile and green practices in order to prioritize and choose the most appropriate one for a given criterion.

Similarly, Agarwal et al. (2006) uses a MCDM method to evaluate the influence of various performance dimensions on specific objectives of the supply chain, such as lead time reduction. The proposed MCDM model serves as an aid to managers in arriving at prudent decision when faced with the complexities of decision variables and multi-criteria decision environment make their decision task complicated. The research explores the relationship among lead-time, cost, quality and service level as well as the leanness and agility of a case supply chain in fast moving consumer goods business; and used for selecting the appropriate paradigm for improved performance of a case company.

Sorli et al. (2012) acknowledged the lack of a systematic way to use eco-design methods and tools in new product development (NPD) and developed a set of structured activities that can successfully combine green in NPD. The framework provided by authors enables industry to balance green concerns with lean principles to be considered and incorporated from the beginning of product design and development and covering the entire product lifecycle. The link between Sorli et al. (2012)'s framework and this research is in integrating paradigms, in this case lean and green.

5.5.1 Most similar frameworks

Frameworks/methodologies/models for selecting appropriate lean/agile/green practices using MCDM methods are considered the ones most similar to the current research framework. One of those as shown in figure 5.9 is the modified VIKOR method proposed by Anvari et al., (2013) which addresses group decision making involving multiple criteria for lean practices selection. The authors developed a model to help practitioners improve their ability to solve problems when the possible solutions have their own individual criteria. Though Anvari et al. (2013)'s method considers only the lean paradigm and is limited in the number of lean practices involved, it provides a method for prioritizing a set of alternatives; in this case lean practices.

Similarly, Alaskari et al. (2016) developed a methodology that supports decision-making and selection of the most appropriate lean practices for a company experiencing difficulties in adopting lean tools. The methodology shown in figure 5.10 was designed by integrating the influence value (I.V.) of factors affecting KPIs, and the strength of the relationship (relative strength) between these factors and lean tools using a selection matrix. The lean practices selected by Alaskari et al. (2016) based on a variety of benefits that can be gained from each tool are 5S, Kanban, Poka-Yoke and SMED (Single-minute Exchange Dies). They are considered against performance measures quality, flexibility, time delivery and cost.

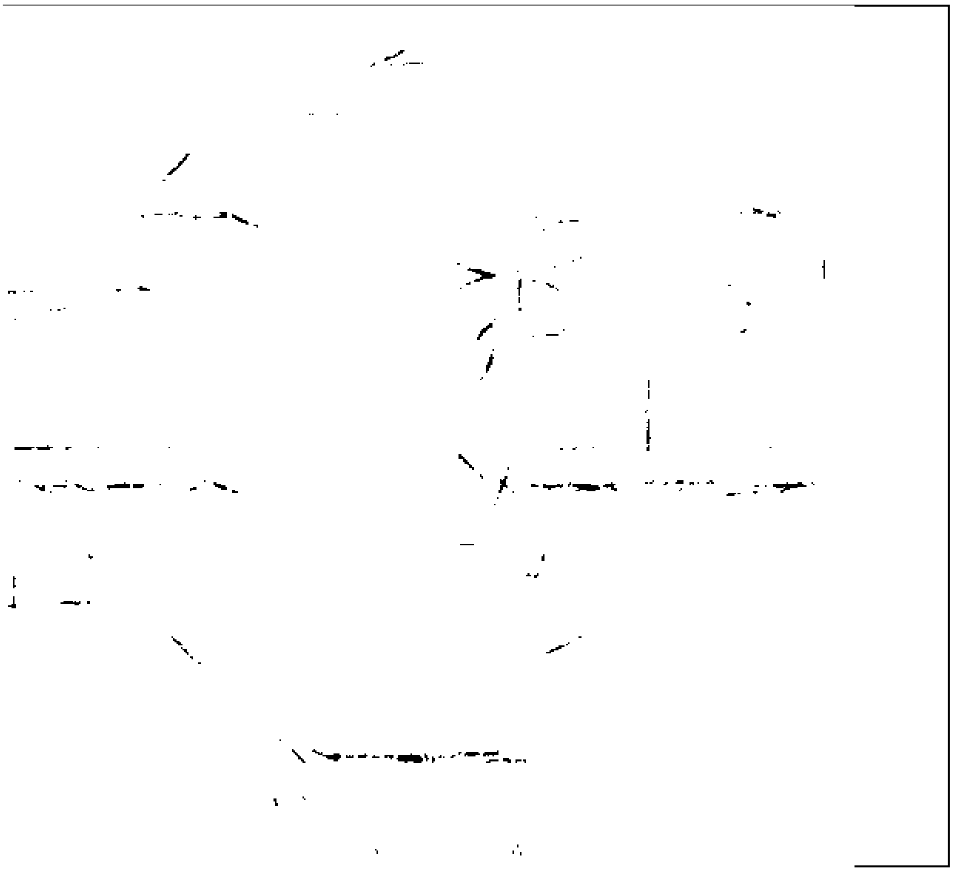

Figure 5.8: Management tool selection. Cabral et al. (2012)

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Figure 5.9: Anvari et al (2013)'s modified VIKOR method

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Figure 5.10: Alaskari et al (2016)'s methodology to assist manufacturing SMEs

In order to promote supply chain competitiveness, Espadinha-Cruz et al., (2011) proposed a model to evaluate the overall business interoperability in LARG approaches in particularly in the automotive industry and establish what measures can reduce interoperability problems in the supply chain. Based on MCDM, the model helps in the identification of practices for the reduction of parameters that make the supply chain operate less than seamlessly.

Similarly, as shown in figure 5.8, Cabral et al., (2012) proposed an integrated LARG model based on the analytic network process (ANP) to support managers in selecting the most appropriate practices and performance measures to be implemented by companies. The authors recognize that some practices have a positive impact on some paradigms and a negative impact on others. Thus, it is important to find a balance between the practices implementation, considering the strategy defined by the company.

Hasanian and Hojjati, (2016) proposed a framework based on literature review and fuzzy set theory for supplier selection criteria in LARG supply chain. Because different suppliers offer different incentives, companies have to consider these when evaluating supplier performance; suppliers who can provide products at the lowest prices, may not be the best for quality or delivery time. This makes supplier selection a multi-criteria problem requiring a MCDM method. The fuzzy method is used to evaluate suppliers, based on the determined criteria and characteristic weights.

Azevedo et al., (2012) proposed a conceptual model to explore the relationships between LARG practices and business performance. The model proposed a set of management practices that are related to an improvement in inventory levels, quality of products, environmental costs, costs and time. According to Azevedo et al., (2012), the model is an attempt to propose a set of management practices to assist manufacturing companies in becoming simultaneously more lean, agile, resilient, and green, and also to explore the relationships between these kinds of practices and supply chain’s performance.

Having considered the above frameworks, the following inferences can be drawn:

- No one paradigm or set of practices (lean, agile and/or green) is applicable to all product types because: (i) each PLC stage has significant impact on business strategy and; (ii) paradigms and/or sets of practices may have positive impact on some competitive priorities and negative impact on others.

- Considerations of what practices to adopt, under what circumstances to adopt them and what effects they have under those circumstance creates a multi criteria decision making problem which should be addressed accordingly.

5.6 Chapter Summary

This chapter has presented parts 1 and 2 of the functional framework with focus on steps 1 to 5 of the process view. The optimal practices selection framework as discussed in this section presents a holistic approach to decision making. It uses the concept of multi-criteria decision making where the respondents' inputs (pairwise comparisons) have been shown to be consistent and the lean, agile and green practices ranked according to how they are believed by the respondents to contribute to cost reduction, lead time reduction and waste reduction.

The identification of optimal LAG practices for a production business as presented herein would be beneficial for business improvement. The next chapter will discuss parts 2 and 3 of the functional view of the framework focusing on steps 6 to 10 of the process view. Steps 6 to 10 are represented and fulfilled with the aid of a case study.

CHAPTER SIX

VERIFICATION AND VALIDATION

6.1 INTRODUCTION

Validation is an important part of framework development process which increases confidence in the model and make it more valuable and reliable (Burns, 2000). Consequently, the developed decision support framework for the selection of appropriate LAG practices in the preceding chapter was put through a validation process. This chapter reports on the validation process and its findings, and is structured as follows: section 6.2 presents an overview of various validation techniques and the justification for selecting face validity and case study which are presented in sub-sections 6.3 and 6.4 respectively.

6.2 Validation Techniques

There are several perspectives about the importance of validation in research, its definition, terms to describe it and its methods (Creswell and Poth, 2017). From modelling point of view, validation is the process of defining whether the model is a meaningful and accurate representation of the real system in a particular problem domain (Borenstein, 1998). Unlike model verification, which is concerned with the accuracy of the model, validation is concerned with developing the right model (Gass, 1983). It therefore attempts to establish how closely the model mirrors the perceived reality of the model user/developer (Gass, 1983). (Sargent, 2013) argues that a model is developed for a specific purpose; therefore its validity should be determined with respect to that purpose. The main purpose of validation is to get a better understanding of the model's capabilities, limitations and appropriateness in addressing the situation for which it was created (Macal, 2005). These insights are often used to improve the model to an acceptable standard. In addition, they enable the modeller to address certain criticisms of the model such as omissions and assumptions used; and help instil confidence in the model's output (Gass, 1983). However, it is often too costly and time-consuming to determine that a model is *absolutely* valid over the complete domain of its intended applicability (Sargent, 2013). Perhaps, this is because models are inherently unable to totally reproduce or predict the real environment (Gass, 1983). Thus, the validation process is often not aimed at achieving absolute validity but rather confined to checking for *Operational Validity*. This validity concerns the process of establishing that the model's output behaviour has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability (Sargent, 2013). Other elements that concern operational validity include establishing whether the model (Gass, 1983): (i) offer a reasonable improvement in terms of net cost savings (ii) is robust enough that a user would find it difficult to make it yield an ostensibly wrong solution.

There are various methods for validating a model, each of which can be used either subjectively or objectively, the latter referring to the use of some type of statistical or mathematical procedures (Sargent, 2013; Qureshi et al., 1999). The basic idea behind any of these methods is the build-up of evidence regarding the credibility and applicability of the model by an independent, interested party (Gass, 1983). It is not uncommon to use a combination of the techniques when validating a model. Brief descriptions of these methods, as defined in literature (Gass, 1983; Sargent, 1998; McMillan et al., 2016 Burns, 2000; Gray, 2014), are presented herein.

Animation*:* Watching a visual or graphical animation of the model's operational behaviour and comparing this with how the actual system behaves.

Comparison to Other Models*:* The output of the model being validated is compared to the results of other valid models of the actual system. This is applicable if such valid models are already available.

Degenerate Tests*:* The model behaviour is known to degenerate at certain situations. The model can be tested to see if it degenerates as expected by simulating such situations in the model using appropriate selection of values of the input and internal parameters.

Extreme Condition Tests: Similar to the degeneracy tests, the model can be tested by running it under extreme conditions to see if the model would behave as would be expected.

Event Validity: This technique is by comparing the "events" of occurrences of the model being validated to those of the real system to determine if they are similar.

Face Validity: This is by asking people who are knowledgeable about the system whether the model and/or its features are reasonable. This method can be used in determining if the logic in the conceptual model is correct and if a model's input output relationships are reasonable.

Delphi: The Delphi method uses a multistage self-completed questionnaire with individual feedback, to determine consensus from a group of expert participants. The Delphi has often been used in validating frameworks/models in academia and in practical situations (Culley, 2011; Fernández-Llamazares et al., 2013; McMillan et al., 2016). The objective of adopting a

Delphi technique in decision-making is to provide a structured approach to collecting data in circumstances where the only available alternative is likely an anecdotal or an entirely subjective approach (Broomfield and Humphris, 2001). The features of anonymity, iteration with controlled feedback, statistical group response and expert input can expedite unanimity where there is contradictory or insufficient information to make effective decisions (Goodman, 1987; Hasson et al., 2000).

Fixed Values: By using fixed values for various model input and internal variables and parameters, the results of the model can be checked against easily calculated values.

Historical Data Validation: If historical data exist (or if data are collected on a system for building or testing the model), part of the data is used to build the model and the remaining data are used to determine (test) whether the model behaves as the system does.

Internal Validity: This is by running several replications of the model to determine the amount of internal variability in the model. A high amount of variability is an indication of a lack of steadiness and this may cause the model's results to be questionable. The internal validity question revolves around the concern of how far the constructions of the researcher are grounded in the constructions of those being researched. If typical of the problem entity, may question the appropriateness of the policy or system being investigated.

Sensitivity Analysis: This technique consists of changing the values of the input and internal parameters of a model to determine the effect upon the model's behaviour and its output. The same relationships should occur in the model as in the real system. Those parameters that are sensitive, i.e., cause significant changes in the model's behaviour or output, should be made sufficiently accurate prior to using the model. This may require iterations in model development.

Predictive Validation: This method involves the wish to forecast, by means of assessment, the performance of a system based on some criterion or a set of criteria. It involves using the model to forecast the behaviour of the system, and then comparing the system's behaviour and the framework's forecast to determine if they are the same.

Turing Tests: People who are knowledgeable about the operations of a system are asked if they can discriminate between system and model outputs. Inability to discriminate between these outputs is an indication that the model is valid.

Case study: Case study enables a researcher to closely examine data within a specific perspective. Case study research allows the exploration and understanding of complex issues through reports of past studies (Zainal, 2007). Case study is often used in validating models in academic research (Oduyemi, 2015) and in other fields. There are several categories of case study. There are three categories to case study research, namely exploratory, descriptive and explanatory case studies (Yin, 2013). Exploratory case studies explore any phenomenon in data which serves as a point of interest to the researcher. Descriptive case studies explain the natural phenomena which occur within the data in question. Explanatory case studies on the other hand are deployed in causal studies where 'pattern-matching' can be used to investigate certain phenomena in very complex and multivariate cases. Yin and Moore (1987) in Yin (2013) note that these complex and multivariate cases can be explained by knowledge-driven, problem-solving and a social-interaction theories.

This research has selected Delphi, face validity and case study to enable a three-stage validation process. Face validity will help to ascertain the logic of the conceptual framework, its usefulness, feasibility and utility, and if a framework's input output relationships are reasonable. The face validity used in this research targeted mainly industry experts; this was done to ascertain its suitability for industry managers. The Delphi method was used in this research to ensure that the framework and its components/methods are reasonable and correct, contributing to the achievement of its stated aim. Case study will help to estimate the output of the framework in a real environment, given a set of input and conditions. Gass (1983) believes that the appropriate method to use in the validation of a framework depends mainly on the real world aspect being analysed and the type of model being used. Sections 6.3, 6.4 and 6.5 present the applications of Delphi, face validity and case study respectively to the validation of this research.

6.3 Delphi study

The two-round Delphi method was chosen in this study because it allows for flexibility and participation of a greater number of experts, and because direct communication between the experts was not required (Fernández-Llamazares et al., 2013). The Delphi method used in this study involves requesting individual, anonymous information from each expert on the topic of the framework validation by means of a structured written questionnaire, which was sent by email in this case. Items that do not obtain consensus in the first round are repeated individually in a second questionnaire. Participants are informed of the results obtained in the first questionnaire and of their individual comments. This allows the experts to reconsider their points of view and allows for convergence of contrasting opinions, thus obtaining maximum possible consensus.

6.3.1 Delphi preparation: questionnaire design and validation

The first questionnaire was prepared based on the conceptual framework already developed through literature review. This questionnaire was drafted with the aim of validating the aspects that make up the framework. The first four questions are dichotomous questions focusing on the findings/inferences/interpretations from literature review which led to the development of the framework and the tool used as part of the framework. Questions involved the justification of the use of AHP, the practicality of adopting management practices based on properties of each product life cycle stage. A seven-point likert adequacy scale was used to measure the strength of a respondent's conviction on the adequacy of using any of lead-time, waste, dependability, flexibility, cost and quality in measuring competitiveness. A seven-point likert scale was also used to measure the extent of the respondents' belief on appropriateness of each step of the framework for achieving competitiveness (question 7). The last but one question was another dichotomous one about the including a feedback channel as part of the framework for update purposes.

The questionnaires were designed using the word processor 'Microsoft word'. The respondents were provided with a checkbox to fill out their responses for each statement and textbox for comments should they wish to elaborate on their answers. The comments along with the statistical results were used to formulate the second questionnaire and the latter was fed back to the respondents as summaries. The latter presents the same statements as before, together with both the individual respondent's rating and the median rating from the entire panel. After considering the group median and comments, respondents re-rate the statements, by either giving the same rating as before or an amended rating. Respondents are free to give further comments about the statements if they wish. The number of survey rounds is usually decided in advance and is dependent upon the level of dissension expected. In most studies, two rounds are used but occasionally, only a single round has been run (McMillan et al., 2016). More than two rounds increases panel attrition, so this is rarely done.

In order to improve Delphi response rate, this study adopts approaches advocated by Hsu and Sandford (2007) which include:

Assistance from endorsed individuals: The use of expert recommendation to help in identifying other experts. A list of expert participants was drawn and validated by 3 experts in this study.

Initial contact: An initial contact was undertaken prior to the delivery of the first round of Delphi. The selected and approved experts were contacted and the research objectives explained to them. At this stage the experts can decline from participating in the Delphi study.

Close-ended questions: Close ended questions were used with specific statements, which is viewed as an advantage by Hsu and Sandford (2007). The authors believe that from the point of view of a participant, if a questionnaire is easy to respond to and less time-consuming, the participant is more likely to complete and return the questionnaire.

Dealing with non-respondents: Being an iterative method and sequential, the problem of how to accelerate the process of data collection poses a great challenge for Delphi researchers. Reminders were sent using telephone contact and e-mail with an explanation of the level of urgency of the process. The respondents were persuaded to complete and return the questionnaires at their earliest convenience.

6.3.2 Selection and contact of experts

Since Delphi technique focuses on eliciting expert opinions, the selection of expert panel is generally dependent upon the disciplinary areas of expertise required research. Skulmoski et al. (2007) states that the Delphi participants should meet the following expertise requirements:

- knowledge and experience with the issues under consideration;
- capacity and willingness to participate;
- sufficient time to participate in the Delphi technique;
- effective communication skills

Concerning the sample size, the representation is assessed by the qualities of the experts rather than number; this is because the Delphi technique does not call the expert panels to be representative samples for statistical purpose (Nordin et al., 2012). Also as earlier stated, the Delphi should not be affected by the location of the participants or their discipline as it requires participants to be selected from a diversity of industries, cities, disciplines as well as level in the organisation. Optimal sample size of respondents using Delphi technique has not been established. However, literature has published research based on samples that vary from 3 and 171 as indicated by Skulmoski et al. (2007).

Therefore, focusing mainly on the expertise of the participants, table 6.1 and figure 6.1 below describes the demographic information and qualifications of the 62 participants approached for this study. These 62 experts were identified and contacted with the assistance of 3 other research colleagues in line with Hsu and Sandford (2007)'s suggestion for improving response rate. 50 of them took part in the two rounds of the Delphi consultation.

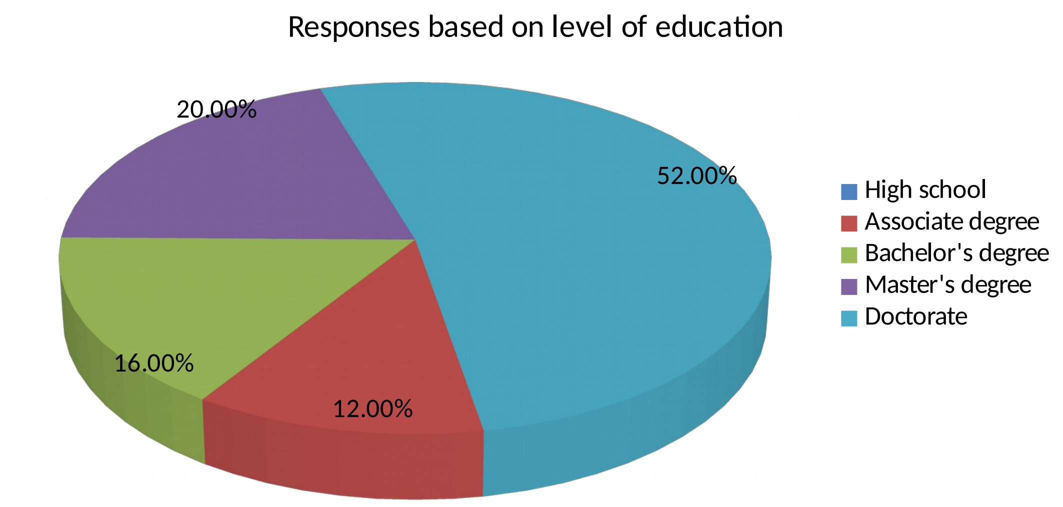

Figure 6.1: Educational qualification of experts

Figure 6.2 represents responses based on current position and figure 6.3 represents the years of experience and expertise of the participants.

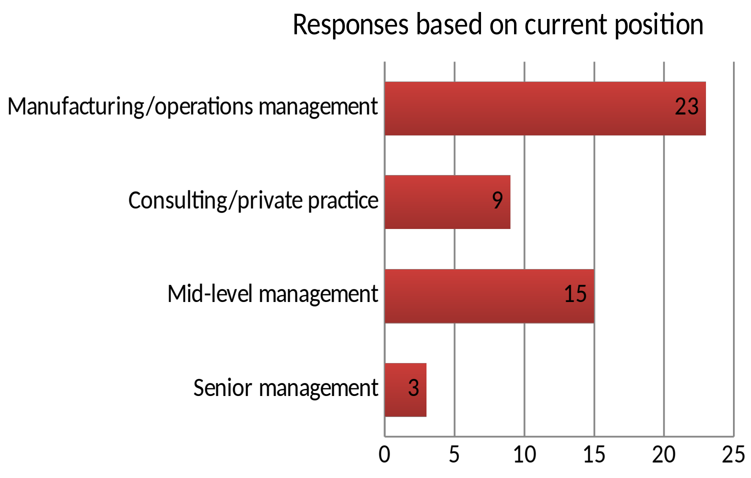

Figure 6.2: Position of Delphi participants

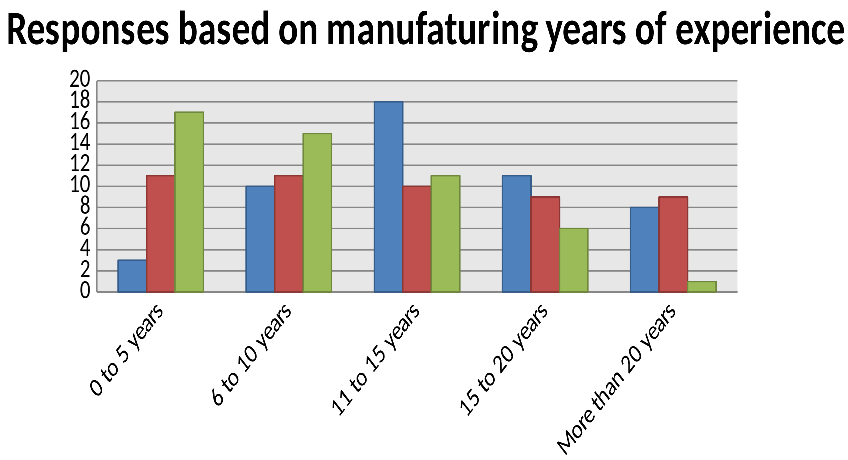

Figure 6.3: Expertise of participants

Table 6.1: Profile of validation respondents

Descriptive	Frequency	Percentage
Level of education		
High school	0	0
Associate degree	6	12
Bachelor's degree	8	16
Master's degree	10	20
Doctorate degree	26	52
Level in organization		
Senior management	3	6
Mid-level management	15	30
Consulting/private practice	9	18
Manufacturing/operations management	23	46
Years of experience (Lean)		
0 to 5	3	6
6 to 10	10	20
11 to 15	18	36
15 to 20	11	22
Over 20	8	16
Years of experience (agility)		
0 to 5	11	22
6 to 10	11	22
11 to 15	10	20
15 to 20	9	18
Over 20	9	18
Years of experience (green)		
0 to 5	17	34
6 to 10	15	30
11 to 15	11	22
15 to 20	6	12
Over 20	1	2

6.3.3 Statistical data analysis

The two main purposes to the analysis of Delphi study include the provision of feedback to respondents between rounds and the identification of when consensus has been reached (Hanafin, 2004). For the purpose of this study, a decision was made on the level of consensus reached using the standard deviation as proposed by Grobbelaar (2007) and shown in table 6.2 and the median. On a 7-point likert scale, the median value for agreement should be (mdn) ≥ 5.

Table 6.2: Decision criteria for level of consensus reached

Standard deviation	**Level of consensus**
0 ≤ X < 1	High level
1 ≤ X < 1.5	Fair level
1.5 ≤ X < 2	Low level
2 ≤ X 2	No consensus

Sampling adequacy was confirmed with the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity. The value of the Kaiser-Meyer-Olkin measure of sampling adequacy in this study is 0.619 which is considered acceptable since it is over the threshold of 0.6 (Ocampo et al., 2017). A significant Bartlett's test (p = 0) assessed that the correlation matrix was appropriate for factoring (Ocampo et al., 2017; Zhong et al., 2014).

In the first round of the Delphi, a total of 50 questionnaires were answered and returned and consensus was reached on most items. Questions 5 and 6 analysed with a focus on the level of consensus. An item by item analysis of the Delphi for both rounds is presented herein.

The market performance of a product determines production strategy.

In the first round, there is a high level of consensus on this item that how a product performs in terms of demand, sales and competitive abilities should influence how production in conducted by management. The standard deviation (SD) of 0.48 which falls within the range 0 ≤ X < 1 indicates a high level of consensus among the Delphi participants. The second round also showed high level of consensus among the respondents with SD = 0.46. Table 6.3 shows the result of the analysis for the first item on the Delphi.

Table 6.3: Consensus level on production strategy given market performance

	Round	1	2
Agreement	Agree	65%	71%
	Disagree	35%	29%
Importance	Median	1	1
	Range	1	1
	Mean	1.35	1.29
	Rank	1	2
	Standard deviation	0.481	0.46

The practicality of adopting management practices tailored to PLC stages

This item follows up on the first and asks whether it makes sense to adopt management practices tailored to PLC stages. To this the consensus level was recorded at SD = 0.46 after the first round. After the second round, the consensus level was recorded at SD = 0.48 which indicates a slightly less consensus rate than the first round. However, the consensus level of the second round at SD = 0.48 still falls well within the high consensus level range $0 \leq X < 1$, showing that the respondents agree that management practices should be tailored to PLC stages. Table 6.4 shows the result of the analysis for the first item on the Delphi.

Table 6.4: Consensus level on practicality of adopting management practices tailored to PLC stages

	Round	1	2
Agreement	Yes	70%	65%
	No	30%	35%
Importance	Median	1	1
	Range	1	1
	Mean	1.30	1.35
	Rank	2	1
	Standard deviation	0.463	0.48

Properties of PLC stages

Each stage of the product life cycle (PLC) has distinct characteristics. For example, the introduction stage of the PLC is characterised by low sales and few competitors; the growth stage is characterised by increasing sales and more competitors; the maturity stage is characterised by a peak in sales volume and predictable/stable level of competition; while the properties of the decline stage include fall in sales and number of competitors. This

Delphi question elicits the opinion of the expert participants on the judiciousness of considering all of these and more properties of the PLC stages in deciding on the production strategies to be adopted by management. The first Delphi round shows a consensus level given approximately by SD = 0.42 which falls within the high level of consensus range as indicated in the table. The second Delphi round also shows a high level of consensus though slightly less than the first round. The high consensus level of the second Delphi round is given by SD = 0.44. Hence the conclusion is that considering both the first and second rounds, the experts are in agree that it is sensible to consider the properties of the PLC stages when deciding on the production strategies to adopt. Table 6.5 shows the results.

Table 6.5: Consensus on considering properties of PLC stages

	Round	1	2
Agreement	Yes	78%	75%
	No	22%	25%
Importance	Median	1	1
	Range	1	1
	Mean	1.22	1.25
	Rank	3	1
	Standard deviation	0.419	0.44

Use of the Analytic Hierarchy Process

This Delphi item asks the experts' opinion on the use of the AHP as a tool in making the decision on what lean, agile and green practices to select and at what PLC stages. This item generated a few comments from the experts as one expert suggested the framework could be made more robust if it incorporated the use of Data Envelopment Analysis (DEA) as part of its structure for decision making. Another expert suggested the use of multi attribute utility analysis (MAUT) while one other expert said that it would be better to use the analytic network process (ANP). Table 6.6 shows the result of the first and second Delphi rounds on this item.

Table 6.6: Consensus on the use of AHP

	Round	1	2
Agreement	Yes	71%	62%
	No	27%	37%
Importance	Median	1	1
	Range	1	1
	Mean	1.27	1.37
	Rank	2	1
	Standard deviation	0.45	0.49

It shows that despite the various comments and suggestions, the experts agree that the use of the AHP for the decision problem described in this research and presented to them is justified as indicated by the high consensus levels of SD = 0.45 and SD = 0.49 in the first and second rounds respectively. Also, the use of AHP as part of the framework has been justified in CHAPTER FIVE.

Measuring competitiveness.

The experts were presented with six items for their opinion on which ones would be sufficient for measuring competitiveness in the FMCG sector. Measuring factors for competitiveness which showed improved consensus levels after the second Delphi round are cost which went from SD = 1.15 to SD = 0.99; waste with SD = 1.24 in the first round to SD = 1 in the second round; lead time which showed consensus level SD = 1.13 in the first round and an improved SD = 1.05 in the second round, and quality, with SD = 1.33 in the first round and 1.20 after the second round. Dependability showed a low consensus level with SD = 1.5 after the second round, the median value of 4 for dependability which is less than 5 is interpreted as no consensus, implying that the experts don't rate dependability sufficiently as a measure of competitiveness. The result of this is presented with table 3.1 in CHAPTER THREE.

Sufficiency of framework components

This item asks the experts after considering similar frameworks provided, to peruse the framework and provide their opinion ratings on a 7-point likert scale about the parts of the framework that they consider appropriate for achieving competitiveness. 1 on the likert scale represents very inappropriate while 7 represents very appropriate. Table 6.7 shows the results of the analysis for this item.

Table 6.7: Consensus level on components of the framework

	Step 1-5		Step 6&7		Step 8		Step 9		Step 10	
Round	1	2	1	2	1	2	1	2	1	2
Very inappropriate	0%	0%	0%	0%	16%	0%	0%	6%	0%	0%
Mostly inappropriate	0%	0%	6%	0%	22%	4%	0%	9%	0%	0%
Somewhat inappropriate	2%	6%	6%	0%	13%	3%	8%	14%	0%	0%
Neither appropriate nor inappropriate	16%	12%	14%	6%	36%	17%	19%	22%	14%	6%
Somewhat appropriate	28%	14%	51%	16%	8%	23%	16%	5%	16%	16%
Mostly appropriate	38%	22%	13%	19%	5%	9%	14%	4%	32%	13%
Very appropriate	16%	9%	10%	22%	0%	7%	43%	3%	38%	28%
Median	6	6	5	5	3	3	6	4	6	3
Range	5	4	5	5	5	5	4	6	3	6
Mean	5.51	5.33	4.86	4.89	3.13	3.19	5.65	5.54	5.94	6.08
Rank	3	3	4	4	5	5	2	2	1	1
Standard deviation	0.998	1.06	1.22	1.233	1.408	1.33	1.405	1.40	1.061	1.067

Steps 1 to 5 which describe the AHP received a consensus level very close to SD = 1 after the first round. Though the consensus level after the second round is SD = 1.06, the median for the first and second rounds of (mdn) = 6 is greater than 5, therefore, the experts are in agreement that the AHP is an appropriate component of the framework for achieving competitiveness. Steps 6 and 7 describe getting the current practices currently adopted in a company as well as corresponding figures regarding cost savings, lead time improvement and waste reduction. For steps 6 and 7, the consensus levels are given as SD = 1.22 and SD = 1.23 for the first and second rounds respectively, and a median value of 5 for both rounds could be interpreted as a fair level of consensus, meaning also that the experts see these steps as important components of the framework for achieving competitiveness. Step 8 identifies the practices of the company which match up with the ones that are already part of the AHP. The median values of 3 for both rounds is less than 5 which is interpreted as no agreement, however, the consensus level for this step at SD = 1.4 for the first round and SD = 1.33 for the second round are fair levels of consensus. Step 9 involves selecting the best ranked practices from the AHP according their cost reduction, lead time improvement and waste reduction capabilities per PLC stage and has received a fair level of consensus after the second round of the Delphi. Step 10 which involves observing if improvement is achieved with either a company's practices or the practices from the framework received a consensus level of approximately 1.07 which is interpreted as fair.

Updating the framework with a feedback channel

The result for this item of the Delphi though it shows consensus at SD = 0.5 after the first and second rounds, shows a 50-50 split in the responses of the experts considering the percentages with about half of the experts saying that a feedback channel is justified and the other half saying that it is not. Table 6.8 shows the result of the analysis for this item.

Table 6.8: Feedback channel for updating the framework

	Round	1	2
Agreement	Yes	51%	49%
	No	49%	51%
Importance	Median	1	2
	Range	1	1
	Mean	1.49	1.51
	Rank	2	1
	Standard deviation	0.504	0.50

This Delphi shows consensus on most of the items under study, implying that the experts believe that the framework and most of its components is fit for purpose.

6.4 Face Validity

As stated earlier, face validity (expert opinion) is the chosen methods for validating the developed decision support framework for the selection of appropriate lean, agile and green practices, mainly because no real-system data were handy. The objectives of expert opinion validation are to assess the feasibility of the model in terms of its adequacy and clarity, and to ensure that the model is reasonably robust, practicable and will be acceptable to users.

Three options for carrying out the validation were considered: (a) focus group (b) interviews and (c) surveys. The use of focus group or interviews was handicapped by the time and cost constraints of the research, leaving survey as the most appropriate option. Problems associated with surveys such as the restrictive nature of the questionnaire and lack of opportunity to clarify respondents' doubts were overcome by carefully designing the questionnaire and including with it a worked example on the application of the model to clarify any misunderstandings the experts may have. The following sections describe the procedure of the validation exercise, which includes development of validation questionnaire, selection of experts, administration of the questionnaire and the findings.

6.4.1 Development of the validation questionnaire

This stage of the validation process involves the development of a questionnaire indicating the areas where the views experts or comments are sought. The questionnaire was designed bearing in mind a number of criteria for validating a model including (Gass, 1983; Macal, 2005):

- Feasibility/Practicality: Is the framework understandable and usable with minimal practical difficulties?

- Utility/usefulness: Does the framework assist in the selection of appropriate LAG practices for the reduction of costs, lead time and environmental waste? Is it fit for purpose?

- Usability: Is the framework practicable in real life decision problems?

- Completeness: Does the framework include all important decision variables required in the selection of LAG practices?

The questionnaire also made provision for experts to make comments on the framework in general or on specific aspects of it.

6.4.2 Selection of experts and response

For the model to be of acceptable standard, it is important that the validation generates useful and relevant comments from relevant experts. This can only be achieved if the experts chosen to participate in the validation have the required expertise. Considering this, the experts were selected from the list of practitioners who took part in the previous questionnaire survey and the Delphi study based on the following criteria: relevant expertise, relevant experience, academic and professional qualifications. The use of previous survey respondents list as a sample frame has two main advantages. Firstly, most of the practitioners in this list were individuals in senior and mid-level positions from FMCG firms and academics with relevant expertise and experience in production management. Secondly, their prior involvement in the earlier surveys makes them familiar with this research, which will ensure good response rate. Prior to sending out the questionnaire, letters were sent to the experts requesting for their kind assistance in the validation exercise. Following this, a brief description of the model incorporating the worked example was sent out electronically to 29 selected experts. The mail also included the validation questionnaire and a cover letter, stating the purpose of the research, the validation process and what was expected of them.

6.4.3 Analysis of experts' response

Of the experts contacted, 11 responded to the survey. This compares positively with Akadiri (2011) who had 25 questionnaires sent out and 7 returned. This Table 6.9 shows the profile of these experts in terms of their organization, job designation, area of expertise, qualifications and years of experience. As can be seen, the experts are all actively involved in the lean, agile and/or green paradigms either in academia or in industry. They possess relevant qualifications and their combined experience is 100 years.

As earlier mentioned, the participants were asked in a structured, semi-closed questionnaire to comment on the model. In addition to offering check-box responses, some of the experts provided their own comments about the model. A summary of the responses to the various questions in the questionnaire are presented in Table 6.10.

Table 6.9: Profile of validation respondents

Respondent	**Organization**	**Designation**	**Qualification**	**Experience (years)**
1	University	Post-doctoral	PhD Operations Management	3
2	University	Senior lecturer	PhD Supply Chain Management	10
3	FMCG	Director of operations	B.Eng Manufacturing Engineering	14
4	FMCG	Director of operations	MSc. Engineering Management	12
5	FMCG	Director of operations	MSc. Lean Six Sigma	7
6	FMCG	Director of operations	Manufacturing Leadership Masters	8
7	FMCG	Director of operations	MBA Industrial Management	9
8	FMCG	Director of operations	B.Eng Manufacturing Engineering	10
9	FMCG	Operations manager	BA (Hons) Business Management	11
10	FMCG	Operations manager	MSc. Engineering Management	7
11	FMCG	Operations manager	MSc. Engineering Management	9

Table 6.10: Face validity responses from experts

Criteria	Responses from experts					
	1	2	3	4	5	6
The framework addresses problem of selecting appropriate LAG practices	Yes, but not reliably	Yes, but not reliably	Yes it does	Yes it does	Yes it does	Yes it does
Framework's capability in helping managers select appropriate LAG practices	Just capable	Just capable	Highly capable	Highly capable	Highly capable	Highly capable
Framework is clear, understandable and usable with little difficulties	Yes	Yes	Yes	Yes	Yes	Yes
Framework is practicable	It is practicable	It is practicable	It is practicable	It is practicable	Moderately practicable	It is practicable
AHP is suitable part of the framework	Very Suitable	Suitable	Suitable	Suitable	Not sure	Not sure
Suitability of AHP hierarchy-criteria, sub-criteria and alternatives	Very Suitable	Suitable	Suitable	Suitable	Not sure	Not sure
Cost, lead time and waste are suitable measure of competitiveness	Very Suitable	Suitable	Suitable	Suitable	Very Suitable	Very Suitable
Framework is suitably described	Comprehensiv e	Adequate	Comprehensiv e	Comprehensiv e	Adequate	Comprehensiv e

Criteria	Responses from experts				
	7	8	9	10	11
The framework addresses problem of selecting appropriate LAG practices	Yes it does	Yes it does	Yes it does	Yes it does	Yes it does
Framework's capability in helping managers select appropriate LAG practices	Just capable	Highly capable	Highly capable	Just capable	Highly capable
Framework is clear, understandable and usable with little difficulties	Yes	Yes	Yes	Yes	Yes
Framework is practicable	It is practicable	It is practicable	It is practicable	It is practicable	It is practicable
AHP is suitable part of the framework	Suitable	Very suitable	Very suitable	Not sure	Suitable
Suitability of AHP hierarchy-criteria, sub-criteria and alternatives	Very suitable	Suitable	Suitable	Not sure	Suitable
Cost, lead time and waste are suitable measure of competitiveness	Very Suitable	Suitable	Very Suitable	Very Suitable	Very Suitable
Framework is suitably described	Comprehensiv e	Comprehensiv e	Comprehensiv e	Adequate	Adequate

It is observable from table 6.10 that most of the experts agreed that the framework addresses the problem of selecting appropriate LAG practices as presented; this attests the utility of the framework and usefulness of the framework. Considering whether the framework if fit for purpose, that is, whether the framework actually helps in the selection of appropriate LAG practices, 4 of the experts responded that it is 'just capable' while 7 of them responded 'highly capable. Overall, the experts agree that the framework is capable of assisting managers in selecting the appropriate practices as presented in the framework. This further suggests that the framework would be regarded by expert respondents as a useful tool in making the decision on what practices to adopt and at what PLC stage to adopt them for meeting specific needs. Again, concerning its usability, 10 of the experts agree that the framework is practicable in real life decision problems while one expert responded 'moderately practicable'. This attests to the usability of the framework by practitioners.

In terms of the framework's feasibility, all the experts were unanimous in the opinion that the framework is understandable and usable with minimal practical problems. On the completeness of the framework, 3 experts responded 'not sure' to the suitability AHP in the framework, 5 responded 'suitable' while 3 responded very suitable; on the use of cost, lead time and waste, experts agree that they are suitable measures of competitiveness in the FMCG industry, though some provided comments on some other competitive priorities that could be considered. They include quality, return on investment, new product introduction, durability and profits. With the exception of 3 experts who responded 'not sure' the respondents answered positively on the suitability of the AHP hierarchy showing the alternatives, criteria and sub-criteria. Issues of concern raised relates to the possible subjectivity in determining the PLC stage, one expert mentioned that though the PLC is an important consideration, accuracy in that regard would require a high level of expertise and extensive experience. Another issue of concern is on the subjectivity of the AHP, though the respondent believes that years of experience and knowledge would make the AHP rankings more rigorous and objective. One of the experts suggested that writing a computer program for the framework could improve its quality and usage.

Overall, the opinions of the experts were in favour of the framework, suggesting that it is regarded as a valuable tool for selecting appropriate LAG practices at PLC stages. This represents a positive contribution to the body of knowledge and adoption of lean, agile and green in the FMCG industry. The framework can therefore be recommended to managers, subject to future modifications that can improve its acceptability and performance.

6.5 Case study

In CHAPTER 5, the conceptual framework was introduced and steps 1 to 5 of the framework discussed therein. This section presents the remaining steps 6 to 10 in detail. These steps represent how the framework could be used by businesses to identify appropriate LAG practices within product life cycle stages and how LAG measures are used to assess performance.

- Step 6: Get practices used by company
- Step 7: Analyse LAG measures
- Step 8: Identify matching practices and their corresponding weightings
- Step 9: Select top priority practices based on weights
- Step 10: Compare company's practices with proposed

To validate and demonstrate the applicability of these steps and hence the overall framework, a case study of a real fashion business was carried out. The fashion business which falls within the FMCG industry has been anonymized for ethical and confidential reasons. This section discusses steps 6 to 10 in detail (sub-sections 6.5.2 to 6.5.6) by applying it to a company. In essence, the validation of these steps of the framework is used as a means to explain and illustrate the steps.

6.5.1 The Company

This research refers to the participating company for this case study as "Fine K". Located in the United Kingdom, Fine K has been in existence for more than 230 years and prides itself as the finest knitwear making company. According to an international business news report in 2008, Fine K is one of a number of UK manufacturers who have been able to overcome the challenges presented by low-cost clothing manufacturers in India and China, where the bulk of the world's clothes are now made. Fine K had 450 employees according to the same report and in 2007 generated £13 million in sales. Fine K revealed that the company now generates up to £17 million.

This growth has been achieved through the application of lean, agile and green practices. For instance, bill of materials (BOM) has been reduced from 48% to 14%; Process waste has also been reduced through the application of LAG practices to 7; lead time has been reduced from 40 days to 20 days; new packaging machine has helped reduce the amount of material used in product packaging. Some of the other LAG practices adopted by the company which has helped save costs and improve its overall competitive outlook *are bottle-neck removal, process reengineering, self-directed work teams, cycle time reduction* and others as presented in table 6.11.

6.5.2 Required data and Step 6 and 8

As step 6 deals with gathering the LAG practices used in the company and step 8 deals with identifying the company's LAG practices that match with the practices from the framework, both steps 6 and 8 are presented together for convenience. Step 8 also deals with identifying the corresponding weightings of the practices in order to identify the practices with low weights so that they can be addressed in step 9. The data for this case study was collected by means of an interview. Questions were delivered with the aid of the questionnaire already developed and this helped elicit the required information from the operations director of Fine K.

The data required from the respondent are:

1. Lean, agile and green practices adopted
2. Cost performance-cost saving made if any
3. Lead time performance-how much time saved if any
4. Waste reduction-how much reduction in waste achieved (e.g. waste going to landfill)
5. PLC stage

Practices adopted at Fine K were identified during at this stage. Discussions also revealed operations at a previous FMCG company.

At Fine K, once a new design is completed it goes through a costing phase to determine what it would cost to produce the design in terms of materials, labour and other required resources in both monetary and material resources needed. The production planners work closely with the sales and marketing department in order to develop the production plan. The "dating" is where times and dates are determined for the process including when the products will be released to the market.

The following LAG practices shown in the table 6.11 below were also identified (as matching with some of those from this research) as the interview progressed.

Table 6.11: LAG practices from Case Study Company

IDENTIFIED PRACTICES	DESIGNATION IN FRAMEWORK	USE AT COMPANY
Cycle time reduction	L_2	Designed a process which helps reduce process wait.
Bottle-neck removal	L_5	Removal of process that slow down production.
Planning and scheduling	L_7	Capacity planning to meet requirements
Total quality control/durable products	L_8, G_7	Focus on quality rather than price. Company has a department that ensures good quality is maintained.
Quality circles (meetings)	L_9	Holds regular production meetings to improve productivity.
Continuous improvement	L_{10}	Strives to makes improvements in efficiency and quality.
Self-directed work teams	L_{13}	Trained employees capable of working on own initiative.
Research for new products	A_1	Employees can come up with a new design for consideration. Currently making new products.
Large/small batches	A_6	Company produces and delivers products in batches as needed.
Innovation culture	A_8	Encourages a culture of innovation among employees
Internal communication	A_9	Company has put system in place to eliminate having to look for employees I order to pass information. Every employee can now be easily located.
Quickly develop new products	A_{12}	Speed in new product development.
Quick decision making	A_{13}	Facilitated quick decision making by replacing paper system with computerised one. Information can now be provided to shareholders quickly.
Demand information capturing	A_{14}	The company makes use of market information in developing new products.
Site selection	G_1	An advantage of company's location is that it makes use of the natural springs there for production purposes.
Use of non-hazardous materials	G_4	Company has an employee who is dedicated to the review/inspection of materials coming in to be used for production to ensure that they are environmentally compliant
Outsourcing to 3PLs	G_6	Company employs the use of DHL for to and from delivery.
Smaller packaging/Use of less material	G_8, G_9	A new packaging machine was brought in which has helped reduce the amount of material used in packaging. Bill of materials has also been significantly reduced.
Recyclable materials	G_{11}	Packaging materials are recyclable.
Recycling programs	G_{12}	Materials are sold to third party for the purpose of recycling.

6.5.3 Step 7: Analyse LAG measures

In order to proceed with this step, this research requires information on how the company have performed in terms of making cost savings, reducing lead time and waste.

Some information on Fine K's cost savings and lead time information over two years was provided during the interview. In terms of cost savings the company has been able to make cost savings of £1 million over two years, averaging half a million pounds a year.

For lead time reduction, with process wait at 7%, the OD mentioned that a lead time target of 20 days was set and has been achieved. Prior to this, the lead time was 40 days.

The bill of materials (BOM) which was at 48% has been reduced to 14% which has helped reduce the waste generated by the machines to 14%. The BOM describes the component structure of a product. It provides a list of raw materials and may include sub-assemblies, parts and other materials as well as their quantities which are needed to produce an item.

With these data (LAG practices and performance outcomes), this research then needs to ascertain if the top ranked LAG practices from this research will result in better performance outcomes or not; this is achieved with the aid of a regression model developed in section presented herein.

6.5.3.1 Background to regression model

Regression analysis is a statistical modelling technique employed when the focus is on the relationship between a dependent variable (or multiple dependent variables) and one or more independent variables (or 'predictors'). The multiple linear regression here attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. The population regression line for p explanatory variables $x_1, x_2, ..., x_p$ is defined to be $\mu_y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p$. This line describes how the mean response μ_y changes with the explanatory variables. The observed values for y vary about their means μ_y and are assumed to have the same standard deviation σ. The fitted values $b_0, b_1, ..., b_p$ estimate the parameters $\beta_0, \beta_1, \ldots \beta_p$ of the population regression line. Formally, the model for multiple linear regression, given n observations, is: $y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ip} + \varepsilon$ for $i = 1, 2, ... n$……………………………………………………6.3

Since the observed values for y vary about their means μ_y, the multiple regression model includes a term for this variation. In words, the model is expressed as DATA = FIT +

RESIDUAL, where the "FIT" term represents the expression $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p$. The "RESIDUAL" term represents the deviations of the observed values *y* from their means μ_y, which are normally distributed with mean 0 and variance σ^2. The notation for the model deviations is ε. ε is conveniently thought of as a statistical error term; that is, a random variable that explains the failure of the model to fit the data exactly.

The relation 1 above can be translated as:,

Y = a + b1(X1) + b2(X2) + ... + bn(Xn)……………………………………………………………..6.4

a multiple regression model for predicting the outcome of Y given n observations (which also is a function of the observations) *X1, X2,…..Xn.* Where *a* is the constant representing the y-axis intercept of the regression line; *b1,b2,…..bn* are the partial regression coefficients representing the amount the dependent variable *Y* changes when the corresponding independent variable changes 1 unit and *n* is the number of independent variables. In applying multiple regression as a decision-making technique, the various attributes or criteria will be represented as independent variables and the dependent variable will represent the total score obtained by each alternative. Associated with multiple regression is *R2*, *coefficient of determination*, representing the percentage of variance in the dependent variable explained collectively by all of the independent variables. The higher it is, then the more accurate the model is able to predict. The difference between the actual values of *Y* and those predicted by the model is known as residuals.

6.5.3.2 Development of LAG regression model

To evaluate the effect of LAG practices on performance, the relationship between the measures studied (i.e. dependent variable – Yi) was established as an accumulation of a number of explanatory independent variables (i.e. lean, agile and green practices), where each of them had its own role and effect on the dependent variable.

Table 6.12: Model summary for integrated model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.861[a]	.740	-.590	.993	2.018

Predictors: LAG practices; Dependent Variable: What type of organisation do you work?

The table 6.12 above shows the multiple linear regression model summary and overall fit statistics. We find that the adjusted R^2 of our model is -0.590 with the R^2 = 0.740 that means that the linear regression explains 74% of the variance in the data. The Durbin-Watson d=

2.018, which is between two critical value of $1.5 < d < 2.5$ and therefore we can assume that there is no first order linear auto-correlation in our multiple linear regression data.

The Table 6.13 shown below summarizes the descriptive statistics and analysis results. As can be observed, many of the attribute are positive and significantly correlated with the criterion, indicating that those with higher scores on these variables tend to have higher share in the cost competitiveness.

Table 6.13: Descriptive statistics for LAG regression model

ITEM	Mean	Std. Deviation	N
What type of organisation do you work?	3.54	.788	50
Time based competition	2.92	1.122	50
Cycle time reduction	2.06	1.150	50
Set up time reduction	3.04	1.106	50
Cellular manufacturing	1.98	1.169	50
Bottle-neck removal	3.04	1.160	50
Focused factory	1.58	.928	50
Planning and scheduling	2.74	1.275	50
Total quality control	1.92	1.122	50
Quality circles	1.86	.904	50
Continuous improvement	3.00	1.125	50
Pull system/Kanban	3.70	.735	50
Preventive maintenance	2.90	.995	50
Self-directed work teams	1.96	.947	50
Research for new product	3.22	1.130	50
Rapid reconfiguration	2.26	.876	5

ITEM	Mean	Std. Deviation	N
			0
Virtual organisation	3.38	1.048	50
Strategic postponement	2.48	1.015	50
Demand flexibility	1.80	.782	50
Large/small batches	1.92	.966	50
Strategic outsourcing	1.82	.774	50
Innovation culture	1.88	.895	50
Internal communication	2.86	1.294	50
Supplier partnership	1.76	.822	50
Storage facilities	1.82	.850	50
Speed in NPD	1.92	.922	50
Quick decision	2.56	1.091	50
Information capture	2.60	1.278	50
Site selection	2.02	.892	50
Large doors/windows	2.52	1.092	50
Temperature control	3.62	.725	50
Non hazardous materials	2.66	1.042	50
Supplier survey	1.96	.781	50
Outsourcing to 3PLs	2.04	.856	50
Durable products	1.90	.678	50
Smaller packaging	2.10	.839	50

ITEM	Mean	Std. Deviation	N
Use of less material	3.02	1.204	50
Waste processing	1.86	.833	50
Recyclable materials	1.86	.857	50
Recycling programs	1.88	.872	50
Use of PLC analysis	2.58	1.071	50
Environmental lab	2.90	1.199	50

Table 6.14: ANOVA table for integrated model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.526	41	.549	.557	.894[a]
	Residual	7.894	8	.987		
	Total	30.420	49			

Predictors: LAG practices

Dependent Variable: What type of organisation do you work?

The table 6.14 is the F-test, the linear regression's F-test has the null hypothesis that there is no linear relationship between the variables (in other words R^2 =0). The F-test is highly significant, thus we can assume that there is a linear relationship between the variables in this model.

Table 6.15: F-test for integrated model

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	6.588	6.027		1.093	.306
Time based competition(L_1)	-.022	.214	-.031	-.101	.922
Cycle time reduction(L_2)	-.082	.318	-.120	-.258	.803
Set up time reduction(L_3)	-.136	.278	-.191	-.489	.638
Cellular manufacturing(L_4)	-.200	.291	-.297	-.687	.511
Bottle-neck removal(L_5)	.025	.219	.037	.114	.912
Focused factory(L6)	-.282	.544	-.332	-.518	.619
Planning and scheduling(L_7)	-.136	.491	-.219	-.276	.789
Total quality control(L_8)	-.209	.236	-.298	-.885	.402
Quality circles(L_9)	-.255	.375	-.293	-.681	.515
Continuous improvement(L_{10})	-.029	.304	-.042	-.096	.926
Pull system/Kanban(L_{11})	-.380	.574	-.355	-.662	.526
Preventive maintenance(L_{12})	-.019	.384	-.024	-.050	.962
Self-directed work teams(L_{13})	.086	.238	.103	.361	.727
Research for new product(A_1)	.169	.292	.242	.579	.579
Rapid reconfiguration(A_2)	.503	.384	.559	1.309	.227
Virtual organisation(A_3)	.060	.320	.080	.187	.856
Strategic postponement(A_4)	-.154	.323	-.199	-.478	.646
Demand flexibility(A_5)	.561	.404	.557	1.389	.202
Large/small batches(A_6)	-.097	.324	-.119	-.301	.771
Strategic outsourcing(A_7)	-.148	.385	-.146	-.386	.710
Innovation culture(A_8)	.096	.464	.109	.207	.841
Internal communication(A_9)	.527	.344	.866	1.531	.164
Supplier partnership(A_{10})	-.618	.578	-.645	-1.070	.316
Storage facilities(A_{11})	.418	.466	.451	.898	.396
Speed in NPD(A_{12})	-.200	.293	-.234	-.684	.513
Quick decision(A_{13})	-.166	.263	-.230	-.632	.545
Information capture(A_{14})	-.205	.246	-.333	-.836	.427
Site selection(G_1)	-.280	.336	-.317	-.834	.429
Large doors/windows(G_2)	-.654	.383	-.907	-1.705	.127
Temperature control(G_3)	-.487	.547	-.448	-.891	.399
Non hazardous materials(G_4)	.152	.446	.201	.340	.742
Supplier survey(G_5)	-.017	.521	-.017	-.033	.975
Outsourcing to 3PLs(G_6)	.007	.357	.007	.019	.985
Durable products(G_7)	.507	.462	.436	1.098	.304
Smaller packaging(G_8)	.177	.406	.188	.436	.674
Use of less material(G_9)	.250	.299	.382	.836	.427

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Waste processing(G_{10})	-.121	.507	-.128	-.238	.818
Recyclable materials(G_{11})	.086	.502	.094	.172	.867
Recycling programs(G_{12})	-.078	.317	-.086	-.245	.813
Use of PLC analysis(G_{13})	.234	.311	.318	.752	.473
Environmental lab(G_{14})	.011	.309	.017	.036	.972

Dependent Variable: What type of organisation do you work?

Looking at the p-values of the t-test for each predictor in table 6.15 (the t-values), it can be observed that many of the practices have some contribution to the model while some others do not. Once organization's competitiveness is taken into account, there is no longer a mean grade difference between the attributes. Now that a "working" model has been developed to predict organizational effectiveness, we might decide to apply it to several organizations with same practices and life cycle stage. So, we use the raw score model to compute our predicted scores.

Integrated Model (IM) = 6.588 – 0.022L1 – 0.082L2 – 0.136L3 – 0.200L4 + 0.025L5 -0.282L6 -0.136L7 – 0.209L8 – 0.255L9 – 0.029L10 – 0.380L11………………. – 0.078G12 + 0.234G13 + 0.011G14

Where L1, L2, L3,…, G14 are LAG practices that could be adopted by businesses.

6.5.4 Step 9: Select top priority practices based on weights

Using the integrated regression model developed in the previous section, step 9 of this framework selects the top ranked LAG practices according to their weightings in specific PLC stages. In the case study, the top ranked practices for the maturity stage of the PLC are selected.

At this stage, this research selects the top ranked LAG practices from the weightings obtained for maturity stage as that is the PLC stage identified from the interview at Fine K. Since 20 LAG practices were identified from the company, this research picks out the top 20 according the number of lean practices, agile practices and green practices the company has adopted out of a knowledge base comprising all the LAG practices identified for the FMCG industry. Fine K has adopted 7 lean, 7 agile and 6 green practices, hence this research will pick out the top 7 lean, top 7 agile and top 6 green practices for cost reduction, lead time reduction and waste reduction assuming that Fine has only has the capacity for that number of practices.

All the practices which were not part of the company’s practices have been highlighted in bold font in tables 6.16, 6.17 and 6.18 to show that they are new entrants as the proposed practices.

Table 6.16: Maturity stage top practices for cost reduction

Lean Practice	Weight	Agile Practice	Weight	Green Practice	Weight
L_2	2.35	**A_3**	2.47	G_1	3.36
L_3	2.80	**A_5**	2.24	**G_3**	2.92
L_4	2.41	A_8	2.24	G_4	3.21
L_5	2.59	A_9	2.35	G_{11}	2.63
L_6	3.55	**A_{10}**	2.47	G_{12}	2.05
L_{12}	4.79	**A_{11}**	2.71	**G_{13}**	3.21
L_{13}	2.82	A_{14}	2.35		

Table 6.17: Maturity stage top practices for lead time reduction

Lean Practice	Weight	Agile Practice	Weight	Green Practice	Weight
L_3	1.82	**A_5**	3.74	G_4	3.36
L_5	1.63	A_6	3.09	**G_7**	4.32
L_6	1.47	**A_7**	4.01	G_8	3.92
L_9	2.54	A_8	4.38	**G_{10}**	3.67
L_{11}	1.83	**A_{10}**	4.41	G_{11}	3.71
L_{12}	1.65	**A_{11}**	4.19	G_{12}	4.54
L_{13}	3.20	A_{14}	3.10		

Table 6.18: Maturity stage top practices for waste reduction

Lean Practice	Weight	Agile Practice	Weight	Green Practice	Weight
L_1	2.43	A_1	3.94	G_1	3.04
L_2	3.21	**A_2**	3.88	G_4	3.42
L_4	1.88	**A_4**	4.14	**G_7**	2.88
L_5	1.82	A_8	3.99	G_8	2.74
L_7	1.76	**A_{11}**	4.19	**G_{10}**	2.81
L_9	2.00	A_{12}	3.57	G_{12}	3.07
L_{11}	3.00	A_{13}	3.39		

6.5.5 Step 10: Compare Company's practices with proposed practices

In order to make the comparison between outcomes of the top weighted practices against the company's practices, the LAG regression model is applied to analyse the data in terms of cost, lead time and environmental waste

In order to apply the regression model, it is necessary to compute cost reduction, lead time reduction and waste reduction values achievable by the selected LAG practices in the maturity stage of the PLC. This needs to be carried out for the set of practices identified from the company and also for those proposed by the framework so that comparisons can be made.

6.5.5.1 Analysing Cost

For cost, this research adopts the general relation for calculating total cost given as:

Total cost = Fixed cost + Variable cost × number of units………………6.2.3

The equation 6.2.3 is represented as:

$\hat{Y} = a + bx$ …………………………..6.2.4

First, the values for a and b needs to be generated using the relation:

$a = \overline{Y} - b\overline{X}$ ………………………...6.2.5

$b = \frac{\sum XY - n\overline{X}\,\overline{Y}}{\sum X^2 - n\overline{X}^2}$ …………………….….6.2.6

In equations 6.2.5 and 6.2.6 $\overline{X}$ and $\overline{Y}$ are means of x and y values. The equations are used to calculate the coefficients a and b. Using the equations, values for the company's LAG practices were calculated as presented in table 6.19.

Table 6.19: Computation of cost with company's LAG practices

Identified Practices	X	Y	XY	X^2	$\hat{Y}$
Cycle Time Reduction-JIT(L_2)	2.35	13	30.55	5.5225	21
Bottle-Neck Removal (L_5)	2.59	15	38.85	6.7081	23
Planning And Scheduling (L_7)	2.31	10	23.10	5.3361	20
Total Quality Control (L_8)	2.32	4	9.28	5.3824	20
Quality Circles (L_9)	2.31	34	78.54	5.34	20
Continuous Improvement (L_{10})	1.72	23	39.56	2.9584	15
Self-Directed Work Teams (L_{13})	2.82	18	50.76	7.9524	25
Research for new products (A_1)	2	14	28	4	18
Large/small batches (A_6)	2	22	44	4	18
Innovation culture (A_8)	2.24	12	26.88	5.0176	20
Internal communication (A_9)	2.35	6	14.10	5.5225	21
Quickly develop new products (A_{12})	2.5	33	82.50	6.25	22
Quick decision making (A_{13})	2.41	32	77.12	5.8081	21
Demand information capturing (A_{14})	2.35	11	25.85	5.5225	21
Site selection (G_1)	3.36	34	114.24	11.2896	30
Use of non-hazardous materials (G_4)	3.21	44	141.24	10.3041	28
Outsourcing to 3PLs (G_6)	1.77	33	58.41	3.1329	16
Smaller packaging/Use of less material (G_8)	2.46	22	54.12	6.0516	22
Recyclable materials (G_{11})	2.63	23	60.49	6.9169	23
Recycling programs (G_{12})	2.85	25	71.25	8.1225	25
	$X=¿48$ $\sum ¿$	$\sum Y=$	$\sum XY=1($	$\sum X^2=12$	

$\bar{X}$ is the mean, calculated from the X column and $\bar{Y}$ is the mean from the Y column. N refers to the number of practices used.

N = 20, $\bar{X}$ = 2.43, $\bar{Y}$ =21.4

The approximated $\hat{Y}$ column in the above table 6.19 is derived plugging in the value of x into the regression equation 6.2.6 and to get the total fixed cost, we plug in the above $\hat{Y}$ values into the integrated model (IM).

Applying equation 6.2.6

$$b \quad ¿ \frac{1068.84-20(2.43)(21.4)}{121.382-20(2.43)^2}=8.77$$

Now applying equation 6.2.5

a = 21.4 - 8.77(2.43)

=0.08

Therefore $\hat{Y}$ = 0.09 + 8.77X…………6.2.7

The approximated $\hat{Y}$ column in table 6.19 is derived plugging in the value of x into the integrated model equation 6.2.7 and to get the total fixed cost, we plug in the above $\hat{Y}$ values into the integrated model:

6.588 – 0.082(21) + 0.025(23) - 0.136(20) -0.209(15) + 0.255(20) – 0.029(15) + 0.086 (25) +0.169(18) – 0.097(18) + 0.096(20) + 0.527(21) – 0.2 (22) – 0.166(21) – 0.205(21) – 0.280(30) + 0.152(28) + 0.007(16) +0.177(22) + 0.086(23) – 0.078(25)

= -1.817

Table 6.20: Computation of cost with proposed LAG practices

Identified Practices	**X**	**Y**	**XY**	**X²**	$\hat{Y}$
Cycle Time Reduction (L2)	2.35	13	30.55	5.5225	14
Set Up Time Reduction (L3)	2.80	16	44.8	7.84	20
Cellular Manufacturing (L4)	2.41	14	33.74	5.8081	15
Bottle Neck Removal (L5)	2.59	15	38.85	6.7081	17
Focused Factory (L6)	3.55	14	49.7	12.6025	29
Preventive Maintenance (L12)	4.79	41	196.39	22.9441	44
Self-Directed Work Teams (L13)	2.82	18	50.76	7.9524	20
Virtual organisation (A3)	2.47	10	24.7	6.1009	16
Demand Flexibility (A5)	2.24	17	38.08	5.0176	13
Innovation culture (A8)	2.24	12	26.88	5.0176	13
Internal communication (A9)	2.35	6	14.1	5.5225	14
Supplier Partnership (A10)	2.47	13	32.11	6.1009	16
Storage Facilities (A11)	2.71	19	51.49	7.3441	19
Demand information capturing (A14)	2	11	22	4	10
Site selection (G1)	3.36	34	114.24	11.2896	27
Temperature Control (G3)	2.92	14	40.88	8.5264	21
Non Hazardous Material (G4)	3.21	44	141.24	10.3041	25
Recyclable materials (G11)	2.63	23	60.49	6.9169	18
Recycling programs (G12)	2.85	25	71.25	8.1225	20
Use of PLC Analysis (G13)	3.21	34	109.14	10.3041	25
	$\sum X=5$	$\sum Y=$	$\sum XY=11$	$\sum X^2=1$	

$$\hat{Y}=a+bx$$

$$N=20, \overline{X}=2.8, \overline{Y}=19.7$$

$$b=\frac{\sum XY-n\overline{X}\,\overline{Y}}{\sum X^2-n\overline{X}^2}$$

$$¿\frac{1191.39-20(2.8)(19.7)}{163.95-20(2.8)^2}=12.33$$

$$a=\overline{Y}-b\overline{X}$$

=19.7-12.33(2.8) = -14.83

Therefore, $\hat{Y}=-14.83+12.33X$ ---------------------- 6.2.8

The approximated $\hat{Y}$ column in the above table 6.20 is derived by plugging in the value of x into the model 6.2.8 and to get the total fixed cost, we plug in the above $\hat{Y}$ values into the general model:

General Model (GM) = 6.588– 0.082L2 -0.136L3 – 0.200L4 + 0.025L5 -0.282L6 -0.019L12 + 0.086L13 + 0.060A3 +0.0561A5 + 0.096A8 + 0.527A9 -0.618A10 + 0.418A11 – 0.205A14 - 0.280G1 + 0.487G3 + 0.152G4 +0.086G11 -0.078G12 + 0.234G13

= 6.588– 0.082(14) -0.136(20) – 0.200(15) + 0.025(17) -0.282(29) -0.019(44) + 0.086(20) + 0.060(16) +0.056(13) + 0.096(13) + 0.527(14) – 0.618(16) + 0.418(19) – 0.205(10) - 0.280(27) + 0.487(21) + 0.152(25) + 0.086(18) - 0.078(20) +0.234(25)

= 11.474

Making the comparison between the cost values of the company's and proposed LAG practices

The regression output with the company's LAG practices showed lower value (-1.817) than the proposed LAG practices (11.474); the values represent the level of cost savings with the LAG practices used. Since the value from the company's LAG practices is lower than that from the proposed LAG practices, the conclusion is drawn that the proposed LAG practices would be better at reducing costs than the company's practices. The company's set of LAG practices and the newly proposed set of LAG practices show that 10 LAG practices have been introduced displacing 10 of the company's LAG practices as they are ranked lower for cost reduction in the maturity PLC stage. The proposed LAG practices include the following new entrants: *set-up time reduction, cellular manufacturing, focused factory, preventive maintenance, virtual organization, demand flexibility, supplier partnership, storage facilities, temperature control and use of PLC analysis*; the LAG practices giving way are: *planning and scheduling, total quality control, quality circles, continuous improvement, large/small batches, quickly develop new products, quick decision making, outsourcing to 3PLs and smaller packaging.*

This outcome shows that the proposed practices are largely consistent with what has been indicated in literature to contribute to cost reduction. *Preventive maintenance* programs help to reduce cost as production downtimes are reduced, resulting in fewer machine breakdowns. *Preventive maintenance* also helps reduce costs because routine repair works circumvent fewer large scale break-down of machines and parts. This research however does not propose a complete elimination of lower ranked LAG practices used by a company as some of them might be crucial to the day-to-day running of business operations for example *planning/scheduling and quality circles*. The suggestions are on what practices should receive more emphasis than others at a given PLC stage and which LAG practices should be introduced if a company is not already practicing them.

6.5.5.2 Analysing Lead time

For lead time reduction, this research uses statistical inference to make estimation of the mean days and standard deviation. The computation is made at 95% confidence level using the practice t distribution.

The confidence interval is calculated by: $\mathrm{CI} = t^* \left(\frac{s}{\sqrt{n}}\right)$

Table 6.21: Computation of lead time with company's LAG practices

Model	Mean	95% Confidence Interval for B		C.I value
		Lower Bound	Upper Bound	
Cycle time reduction	1.27	-.058	.284	0.342
Bottle-neck removal	1.63	-.128	.195	0.323
Planning and scheduling	1.27	-.305	-.030	0.275
Total quality control	1.40	-.136	.167	0.303
Quality circles	2.54	-.009	.399	0.408
Continuous improvement	1.10	.671	1.014	0.343
Self-directed work teams	3.20	-.153	.234	0.387
Research for new products	2.47	-.314	.082	0.396
Large/small batches	3.09	-.278	.160	0.438
Innovation culture	3.09	-.221	.239	0.46
Internal communication	3.01	-.225	.130	0.355
Speed in NPD	1.97	-.237	.198	0.435
Quick decision making	2.54	-.395	-.048	0.347
Information capture	3.10	-.271	.034	0.305
Site selection	2.94	-.273	.108	0.381
Non-hazardous materials	3.36	-.242	.134	0.376
Outsourcing to 3PLs	1.57	-.231	.178	0.409
Smaller packaging	3.92	-.255	.162	0.417
Recyclable materials	3.71	-.012	.483	0.497
Recycling programs	4.54	-.024	.397	0.421
95% confidence level				8.271

With this, the true mean can then be estimated using the relation:

$$\mu = \overline{X} \pm t^* \left(\frac{s}{\sqrt{n}}\right)$$

$\overline{x}$	mean time of our sample (2.67)
μ	true mean time of the entire practice
n	number of practice in the sample (20)
s	the standard deviation of the sample
t*	t statistics [confidence level(.05) and degrees of freedom n-1 (19)]

From table 6.21, the 95% confidence level is 8.271.

Plugging in the numbers, for the estimated mean of the total practice on this task we get:

μ = 2.67 + or – 8.271

Therefore at 95% confidence level the mean days are between -5.6 and 10.94. The lead time value has an upper bound of 11.

Table 6.22: Computation of lead time with proposed LAG practices

Model	Mean	95% Confidence Interval for B		C.I value
		Lower Bound	Upper Bound	
Set up time reduction	1.82	-0.434	0.128	0.562
Bottle-neck removal	1.63	-0.29	0.259	0.549
Focused factory	1.47	-0.177	0.469	0.646
Quality circles	2.54	-0.817	-0.121	0.696
Pull system/Kanban	1.83	-0.775	0.193	0.968
Preventive maintenance	1.65	-0.021	0.571	0.592
Self-directed work teams	3.20	-0.265	0.353	0.618
Demand flexibility	3.74	-0.225	0.692	0.917
Large/small batches	3.09	-0.55	0.253	0.803
Strategic outsourcing	4.01	-0.017	0.884	0.901
Innovation culture	4.38	-0.731	-0.009	0.722
Supplier partnership	4.41	-0.657	0.104	0.761
Storage facilities	4.19	-0.044	0.869	0.913
Information capture	3.10	-0.22	0.26	0.48
Non hazardous materials	3.36	0.019	0.654	0.635
Durable products	4.32	-0.281	0.685	0.966
Smaller packaging	3.92	-0.679	0.035	0.714
Waste processing	3.67	-0.314	0.535	0.849
Recyclable materials	3.71	-0.217	0.548	0.765
Recycling programs	4.54	-0.487	0.278	0.765
95% confidence level				14.822

From table 6.22, the 95% confidence level is 14.822.

$\overline{x}$ mean time of our sample (3.229)
μ true mean time of the entire practice
n number of practice in the sample (20)
s the standard deviation of the sample
t* t statistics [confidence level(.05) and degrees of freedom n-1 (19)]

μ = 3.229 + or – 14.822

Therefore at 95% confidence level the mean days are between -11.6 and 18.1. The lead time value has an upper bound of 18 for proposed LAG practices.

Making the comparison between the lead time values of the company's and proposed LAG practices

The results show that the proposed LAG practices are better at reducing lead time than the company's LAG practices at the maturity PLC stage. The proposed LAG practices have 10 entrants which are not in the company's set of LAG practices as they ranked higher than the company's current LAG practices for the maturity PLC stage. The practices are: *set-up time reduction, focused factory, pull system/kanban, preventive maintenance, demand flexibility, strategic outsourcing, supplier partnership, storage facilities, durable products and waste processing*; the LAG practices giving way are: *cycle time reduction, planning and scheduling, total quality control, continuous improvement, research for new products, internal communication, speed in new product development, quick decision making, site selection and outsourcing to third party logistics (3PLs)* companies.

However, some of the company's LAG practices which are lower ranked must not be completely eliminated as they contribute significantly to the daily running of the company- planning and scheduling and internal communication. Some innovation in the way those practices are adopted has to be introduced. While it is understandable why a practice like research for new products and speed in new product development has to give way (at the maturity PLC stage, a product is no longer new) some of the others may contribute to the reduction of lead time at the maturity stage if properly adopted, for *example quick decision making*. Hence the company will have to consider adopting the proposed LAG practices at the maturity PLC stage.

6.5.5.3 *Analysing Waste*

The equations 6.2.3 and 6.2.6 are used to solve for waste reduction

Table 6.23: Computation of waste with company's LAG practices (Waste)

Identified Practices	**X**	**Y**	**XY**	**X^2**	$\hat{Y}$
Cycle Time Reduction (L2)	3.21	13.5	43.335	10.3041	23
Bottle-Neck Removal (L5)	1.82	15.6	28.392	3.3124	21
Planning And Scheduling (L7)	1.76	10.04	18.304	3.0976	21
Total Quality Control (L8)	1.13	4.2	4.746	1.2769	20
Quality Circles (L9)	2	35.4	70.8	4	21
Continuous Improvement (L10)	1.12	24	26.88	1.2544	20
Self-Directed Work Teams (L13)	1	18.8	18.8	1	20
Research for new products (A1)	3.94	14.6	57.524	15.5236	24
Large/small batches (A6)	3.72	22.9	85.188	13.8384	24
Innovation culture (A8)	3.99	12.5	49.875	15.9201	24
Internal communication (A9)	3.30	6.2	20.46	10.89	23
Speed in NPD (A12)	3.57	34.4	122.808	12.7449	24
Quick decision making (A13)	3.39	33.3	112.887	11.4921	24
Demand information capturing (A14)	3.10	11.5	35.65	9.61	23
Site selection (G1)	2.83	35.4	100.182	8.0089	23
Use of non-hazardous materials (G4)	3.70	45.8	169.46	13.69	24
Outsourcing to 3PLs (G6)	1.95	34.4	67.08	3.8025	21
Smaller packaging/Use of less material (G8)	1.83	22.9	41.907	3.3489	21
Recyclable materials (G11)	1.88	24	45.12	3.5344	21
Recycling programs	1.81	26	47.06	3.2761	21
	$X = ¿51$ $\sum ¿$	$Y = ¿44$ $\sum ¿$	$\sum XY = 11$	$\sum X^2 = 14$	

N = 20, $\bar{X}$ = 2.55, $\bar{Y}$ =22.27

$$b = ¿\frac{1166.46 - 20(2.55)(22.27)}{149.93 - 20(2.55)^2} = 1.54$$

a = 22.27 – 1.54(2.55) = 18.34

Therefore, $\hat{Y}$ = 18.34 + 1.54X……………...6.2.9

The $\hat{Y}$ approximated column is derived using 6.2.9

To derive the value for waste for the company's practices, the approximated $\hat{Y}$ values in table 6.23 are fed into to integrated model:

Hence;

6.588 - 0.082(23) + 0.025(21) - 0.136(21) - 0.209(20) - 0.255(21) -0.029(20) +0.086(20)+ 0.169(24) - 0.097(24) - 0.097(24) + 0.096(24) + 0.527(23) - 0.2(24) - 0.166(24) - 0.205(23) - 0.28(23) + 0.152(24) + 0.007(21) + 0.177(21) + 0.086(21) - 0.078(21)

= -2.13

Table 6.24: Computation of waste with proposed LAG practices

Identified Practices	X	Y	XY	X^2	$\hat{Y}$
Time based competition (L1)	2.43	8.3	20.169	5.9049	20.8972
Cycle Time Reduction (L2)	3.21	13.5	43.335	10.3041	24.0484
Cellular Manufacturing (L4)	1.88	14.6	27.448	3.5344	18.6752
Bottle Neck Removal (L5)	1.82	15.6	28.392	3.3124	18.4328
Planning and scheduling (L7)	1.76	10.4	18.304	3.0976	18.1904
Quality circles (L9)	2.00	35.4	70.8	4	19.16
Pull system/Kanban (L11)	3.00	10.4	31.2	9	23.2
Research for new product (A1)	3.94	14.6	57.524	15.5236	26.9976
Rapid reconfiguration (A2)	3.88	33.3	129.204	15.0544	26.7552
Strategic postponement (A4)	4.14	42.7	176.778	17.1396	27.8056
Innovation culture (A8)	3.99	12.5	49.875	15.9201	27.1996
Storage Facilities (A11)	4.19	19.8	82.962	17.5561	28.0076
Speed in NPD (A12)	3.57	34.4	122.808	12.7449	25.5028
Quick decision (A13)	3.39	33.3	112.887	11.4921	24.7756
Site selection (G1)	2.83	35.4	100.182	8.0089	22.5132
Non Hazardous Material (G4)	3.70	45.8	169.46	13.69	26.028
Durable products (G7)	2.04	13.5	27.54	4.1616	19.3216
Smaller packaging (G8)	1.83	22.9	41.907	3.3489	18.4732
Waste processing (G10)	3.06	12.5	38.25	9.3636	23.4424
Recycling programs (G12)	1.81	26	47.06	3.2761	18.3924
	$\sum X=58.4$	$\sum Y=454.9$	$\sum XY=1$	$\sum X^2=1$	

$$N=20, \overline{X}=2.9, \overline{Y}=22.8$$

$$b=\frac{\sum XY - n\overline{X}\,\overline{Y}}{\sum X^2 - n\overline{X}^2}$$

$$¿\frac{1396.01-20(2.9)(22.8)}{186.43-20(2.9)^2}=4.04$$

Therefore, $a=\overline{Y}-b\overline{X}$

a = 22.8 - 4.04(2.9) = 11.08

Therefore, $\hat{Y}=11.08+4.04X$ ----------------- 6.2.10

The $\hat{Y}$ approximated column is derived using 6.2.10

To get the percentage waste reduction value, we plug in the $\hat{Y}$ values into our IM. i.e

General Model (GM) = 6.588-.022L1 – 0.082L2 – 0.200L4 + 0.025L5 -.136L7 -.255L9 -0.380L11 + 0.169A1 + 0.503A2 - 0.154A4 + 0.096A8 + 0.418A11 - 0.200A12 - 0.166A13 - 0.280G1 + 0.152G4 + 0.507G7 + 0.177G8 - 0.121G10 - 0.078G12

= 6.588 - 0.022(20.90) – 0.082(24.05) – 0.200(18.68) + 0.025(18.43) - 0.136(18.19) - 0.255(19.16) - 0.380(23.20) + 0.169(27.00) + 0.503(26.76) - 0.154(27.81) + 0.096(27.20) + 0.418(28.01) -.200(25.50) - 0.166(24.78) - 0.280(22.51) + 0.152(26.03) + 0.507(19.32) + 0.177(18.47) - 0.121(23. 44) -0.078(18.39)

= 9.997035

Making the comparison between the waste values of the company's and proposed LAG practices

The proposed LAG practices with a waste reduction value of approximately 10 are shown by the regression model to reduce more waste than the company's practices. The new set of LAG practices shows entrants *time based competition (Just in time), cellular manufacturing, pull system/kanban, strategic postponement, storage facilities, durable products and waste processing*. The LAG practices which have been replace in order of priority *are total quality control, continuous improvement, self-directed work teams, large/small batches, internal communication, demand information capturing, outsourcing to 3PLs and recyclable materials*.

Even though this research suggests adopting the proposed LAG practices, some of the practices which have gone down the pecking order such as internal communication must not be done away with as it is crucial to the daily operations of the company; continuous improvement is also essential in maintaining quality and must not be completely eliminated but should be adopted with utmost expertise.

6.6 Chapter Summary

This chapter demonstrated the applicability of the framework developed in CHAPTER 5. This study revealed that the participating company has adopted lean, agile and green practices to save costs, reduce lead time and wastes. Though this represents step 10 of the process view of the framework, it was used as illustrations to confirm and support the framework. With this step, the framework could also come to be updated and enriched with more reliable information.

Having carried out case study research and analysed the information received with the aid of the regression model, it is possible to conclude that Lean, Agile and Green practices can be integrated at specific PLC stages and that since the proposed LAG practices showed better performance outcomes, the framework is useful and applicable.

CHAPTER SEVEN

DISCUSSION

7.1 INTRODUCTION

This chapter discusses the overall findings of the research as presented in previous chapters. The focus of this chapter also includes a discussion on how the objectives have been met; contributions to theory; implications to practice and future research directions. It draws attention to the outcomes of the systematic literature review presented in CHAPTER TWO and the gap in knowledge clarified as a result. This chapter also discusses the outcomes of the methods which were used to validate the framework. The conclusion of the overall findings of the research is presented in CHAPTER EIGHT.

Section 7.2 of this chapter discusses the rationale for the research. Section 7.3 presents a discussion on how the aim and objectives of this research have been achieved. In section 7.4 discussions on the research findings are presented. These discussions include discussion on the literature review findings, discussion on the survey analysis and discussion on the framework developed in this research. The contribution of this research to the body of knowledge is presented in section 7.5. Section 7.6 presents implications of this research to practice. Limitations of this research and recommendations for future research are presented in sections 7.7 and 7.8 respectively.

7.2 Discussion on the rationale for the research

This research was born out of the desire to develop new knowledge on how to address issues of changing customer requirements, demand uncertainty, competition, environmental sustainability issues and concerns that arise as a result of changing priorities as a product proceeds through its different product life cycle stages. It is important to constantly adapt to consumer trends, and the product life cycle concept provides a platform to do that. The lean, agile and green paradigms have traditionally been applied in reducing non-value adding activities, creating customer focused value; being flexible and responsive to customer needs in a cost-effective and efficient manner reducing the impact of management decisions on the environment. However, a review of literature revealed that these paradigms have not been sufficiently applied in an integrated fashion that enables the selection of the most appropriate LAG practices for reducing costs, reducing non-value adding activities, being responsive and reducing environmental waste.

The fast moving consumer goods (FMCG) provides a unique opportunity to explore this area of research because the industry is a particularly fast paced industry that is constantly evolving. The FMCG sector also presents a critical challenge in efficiently serving increasing customer expectations (Farahani et al., 2013). This issue is even more critical considering that customer loyalty is often very low in this industry, and that a high competitiveness means that this has to be achieved at minimal cost (Farahani et al., 2013). Therefore addressing customer requirements implies focusing on what the customers care about, such as compressed lead times, low cost production that is passed on to the customer in terms of low cost products, improved quality, environmental sustainability and so on.

7.3 How aim and objectives have been achieved

The aim of this research as stated in CHAPTER ONE is to develop an integrated decision framework that supports decision making in selecting the appropriate combination of lean, agile and green practices in product life cycle stages for organizations to improve competitiveness and environmental sustainability. Following this stated aim, objectives were formulated in order to achieve the stated aim. For clarity, these objectives are repeated below:

1. Carrying out desk research to identify the lean, agility and green practices applied in industry.
2. Carrying out field research to:
    - o identify the lean, agile and green practices operated in industry;
    - o determine the life cycle stage of selected FMCGs;
    - o identify the manufacturing strategy (mix of lean, agility and green practices) adopted for the products given their life cycle stage;
    - o investigate the contribution of lean, green and agility practices to cost reduction, lead time reduction and waste generated at PLC stages.
3. To develop a decision support framework for selecting the right mix of lean, agile and green practices that reduce costs, lead time and waste at each stage of the PLC.
4. To verify and validate the LAG selection framework.

The first objective to identify the lean, agile and green practices operated in industry was achieved through a review of literature which looked at the literature on lean, agility and green discussing consumer packaged goods industry or products identifiable as consumer packaged goods. This led to the identification of a list of practices which were then used to develop the questionnaire used for the field research and meeting second objective of this research.

The second objective (field research) involve identifying the lean, agile, green practices operated in industry; determining the PLC stage of products; identifying mix of LAG practices adopted at PLC stages and investigating the contribution of the practices towards cost reduction, lead time contraction and environmental waste reduction. These were all achieved through questionnaire survey. In the questionnaire, experts were asked to identify the following: (i) the lean, agile and green practices adopted in their companies; (ii) the PLC stage at which those LAG practices were adopted by focusing on a product. In achieving (i) and (ii) the identification of the mix of lean, agile and green practices adopted at PLC stages would also be achieved. The questionnaire was also used to obtain information from the practitioners about the contribution of the LAG practices towards cost reduction, lead time contraction and environmental waste reduction. The experts rated the contribution on a likert scale which were then collated by PLC stages and analysed. Care was taken to approach experienced practitioners with sufficient knowledge and expertise in lean, agile and green within the FMCG industry so that the credibility of their responses and that of the research can be trusted.

Having considered the lean, agile and green practices; the product life cycle stages and the reduction of costs, lead time and environmental waste, integrating these into a single framework for achieving the aim of this research, can be observed to present a situation comprising multiple criteria to be considered as well as multiple alternatives. This was therefore treated as a multi-criteria decision problem; hence the use of analytic hierarchy process (AHP) which is one of the most widely used and trusted multi-criteria decision analysis tools. The development of the framework and its corresponding steps are presented in detail in CHAPTER FIVE and CHAPTER SIX demonstrating that the third objective has been achieved. This is decision support framework for selecting the appropriate mix of LAG practices that reduce costs, lead time and environmental waste.

The fourth objective which is the validation of the framework was achieved through Delphi method, face validity and case study. All methods of validation involved significant input from experts in management who are very knowledgeable about Lean, Agile and Green. This was a key aspect of the validation of the framework.

The Delphi method provides researchers a flexible and adaptable tool for gathering and analysing the required data. Expert selection and the time frames for conducting and completing a Delphi study are areas which have been carefully considered prior to initiating the study. As has been shown with the application of Delphi in this research, the Delphi method has and will continue to be an important data collection methodology with a wide variety of applications and uses for people who want to gather information from those who have to become knowledgeable about the topic of interest and can provide real-time and real-world knowledge. Face validity was also conducted with the aid of a questionnaire which was responded to by 11 industry experts which showed that the framework is practical, useable and feasible.

7.4 Research findings

This section discusses the outcomes of the literature review in CHAPTER TWO; the results of the data analysis in CHAPTER FOUR; the framework developed and presented in CHAPTER FIVE. Findings of the validation process are also discussed herein.

7.4.1 Discussion of the literature review

The literature review presented in CHAPTER TWO covered some background to Lean, Agility and Green paradigms. Following a Systematic Literature Review (SLR), the limitations of Lean, Agility and Green frameworks were highlighted, as well as the gap in knowledge, underpinning the need for this research. In addition, the literature review stressed the need and importance of combining Lean, Agility and Green. The combinations of Lean, Agile and Green, such as Lean and Green; Lean and Agility; Agility and Green and Lean, Agility and Green were also discussed in the literature review. This revealed that some of the works have included practices of the paradigms while some have not.

The concept of product life cycle in the context of this research was also presented in the literature review. It was revealed that ‘the life of products’ could be likened to biological life and would require different adaptable strategies to deal with the challenges/characteristics that each stage of life presents. The general importance of the PLC concept was also discussed, showing that PLC needs to be considered as a necessary factor in deciding on a befitting manufacturing strategy (Lean, Agile, Green) as failure to consider the PLC could lead to superfluous short-term investment on the one hand and high production cost on the other. Some studies, for example, Luna and Aguilar (2004) proposed adopting lean on products presenting long PLCs and the agility on products with short PLCs and high demand uncertainty, while Fisher (1997) offered some directions on implementing lean and agility based on product type-innovative and functional products.

In the literature, the impacts of lean, agility and green on measures such as cost, lead time and waste was presented and this helped in development of the research hypothesis which helped to clarify the need for this research. The discussion on the impacts of LAG and the tests of hypothesis showed that different LAG practices have different effects on performance measures, hence the need to develop a framework for selecting which practices were best for certain performance measures. For example, Sharma et al. (2015) discovered through multiple regression analysis of data from their research that set up time reduction was observed to be a significant positive predictor for lead time reduction while surprisingly, productive maintenance did not. The explanation given for the negative coefficient observed for *preventive maintenance* is that many of the firms that participated in the study fell short on *preventive maintenance*.

The review also focused on identifying lean, agile and green practices especially the ones implemented by FMCG operators and/or for FMCG products. It was important to identify LAG practices as this helped in the development of the questionnaire which was distributed and completed by the expert respondents. The questionnaire also helped to obtain information on which practices were better for achieving improved performance and at what PLC stage.

Since the research proposes to develop a framework for selecting appropriate LAG practice for achieving competitiveness, a systematic literature review (SLR) was carried out to facilitate a thorough review of existing frameworks that support the adoption of LAG either in singularity or in a combination, highlight the limitations of those frameworks and hence clarify the need for this research.

There was strong suggestion in the SLR that the adoption of lean and agility and green practices could yield benefits in meeting customer requirements, however, few studies have provided an integrated approach considering their simultaneous adoption despite their capabilities in achieving competitiveness. Also, product characteristics need to be matched with the appropriate management paradigm and practices because as products mature through their product life cycles, customer requirements may significantly change (Fisher, 1997). Therefore a company needs to possess the appropriate mix of strategies to compete at all stages of the product life cycle (Aitken et al., 2002). As a result, it was found that the integration of paradigms and product life cycles is lacking, hence the need for the framework developed in this research.

7.4.2 Discussion on survey analysis

The questionnaire survey was analysed using SPSS and Excel. Though, there is literature suggesting that the implementation of green could yield other benefits including cost reduction and lead time compression rather than just having environmental sustainability benefits, the finding from the survey that the green paradigm is adopted by the respondents to minimise cost and improve lead time was seen as an interesting outcome. However, this finding was largely consistent with the findings from analysis of the AHP. This shows that the respondents could have adopted green in their respective organisations for a protracted period of time, long enough to observe other benefits that accrue from adopting environmental sustainability practices, benefits which include the achievement of competitive advantage. Lake et al. (2015) stated that the conflict between environmental sustainability and competitiveness is a false dichotomy based on a narrow view of prosperity sources and static view of competition. Al Sheyadi. (2014) suggested that the availability of firm specific capabilities could enable firms to achieve a cost competitive advantage when it implements appropriate green practices and Madu et al. (2002) and Mollenkopf et al. (2010) believe that environmental consciousness is a strategic competitiveness issue. The finding that the green paradigm offers lead time and cost reduction benefits should therefore not come as a surprise.

The general hypothesis H_1 which states that competitiveness (cost reduction, lead time reduction and green waste reduction) is improved by a combination of appropriate LAG practices at PLC stages, was partitioned into a hierarchy of sub-hypotheses as shown in figure 7.1 to test the effectiveness of adopting LAG at the level of paradigm not down to known practices and also at the level of known practices for the purposes of achieving competitiveness and environmental waste reduction. The aim of the tests of hypotheses is to discover how practitioners view the effectiveness of the adoption of LAG at both paradigm and practices levels and at PLC stages. This helped to clarify the need for this research and buttress the importance of identifying LAG practices for achieving specific objectives. Sub-hypothesis SH_1 which is further partitioned into SH_1a, SH_1b, SH_1c, and SH_1d test the effectiveness of lean, agile and green paradigms at the four stages of the PLC. The results for these hypotheses tests show that the null hypotheses were all rejected except for the first test of SH_1a for the introduction stage which shows that firm competitiveness is positively associated with lean practices in the introduction stage. This result is interpreted to mean that without clarity and specificity on what lean, agile or green implementation implies in terms of what practices to adopt and when to adopt it, the implementation of LAG may not guarantee effectiveness in attaining competitive status. This is also shown with SH_3 which showed that the paradigm level adoption of LAG is ineffective for achieving environmental waste reduction.

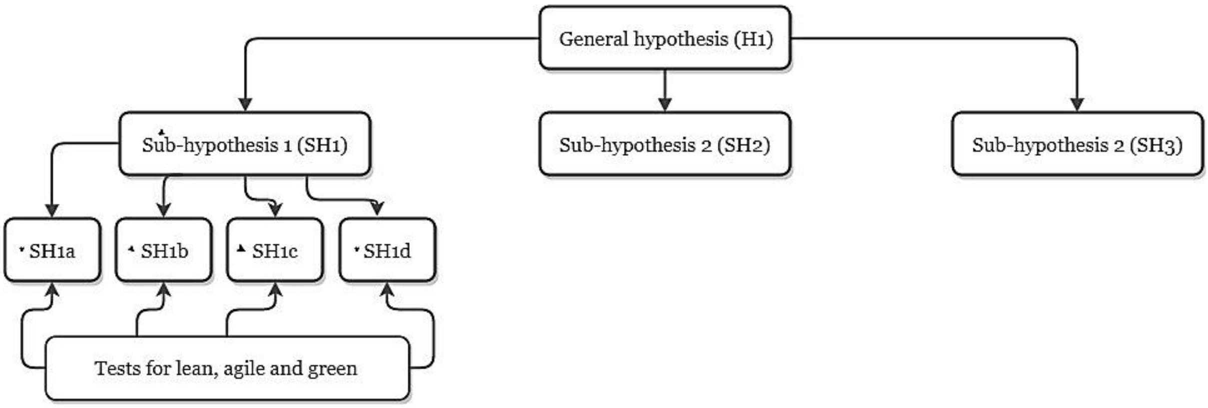

Figure 7.1 Hierarchy of hypotheses

Sub-hypothesis 2 (SH_2) on the other hand shows that effectiveness in achieving competitiveness is better achieved when one can pick out individual LAG practices. For example, a manager who is interested in implementing lean, agile and green for cost reduction would be better advised if he/she is made to understand that he/she can accomplish that by adopting the lean *practices total preventive maintenance, Kanban, bottleneck removal, virtual organisation, demand flexibility, out sourcing to 3Pls, use of less material* and so on. The outcome of SH_2 also showed that the set of practices for reducing cost is different form the set of practices for compressing lead time and for reducing environmental waste. These would also be different for each stage of the PLC.

This sub-hypotheses show that lean, agility and green are better adopted and their benefits better harnessed when there is clarity on which of their practices to adopt, rather than adoption of paradigms for the sake of it and without knowledge on what practices are more effective for achieving improvement on certain competitive measures. This is where the framework developed in this research comes in, providing knowledge on what practices are better for reducing cost, compressing lead time and reducing environmental waste and also proving direction on the PLC stages where LAG practices can provide optimal benefits.

7.4.3 Discussion on the framework validation

The validation process which involved the Delphi study, face validity and case study required knowledgeable participants. The Delphi helped to validate the steps of the process view of the framework as well as the methods used in developing the framework. It also helped to justify the use of cost, lead time and waste as measures of competitiveness.

Making time for group meetings and geographical distance are barriers for obtaining the needed knowledge. For this situation, the Delphi method can be adopted to solve the problem by sending questionnaires to experts. The approach of sending questionnaires also obtains the characteristics of anonymity so that experts can evaluate the first round questionnaires without being influenced by the group pressure. Similarly, utilising questionnaires in the second round encourages to shift their positions without losing face if they agree to the group opinion (Zolingen and Klaassen, 2003).

The Delphi study relied on the judgement of the selected experts to make determinations on the following aspects and more:

- The practicality of adopting management practices tailored to PLC stages
- Use of the Analytic Hierarchy Process
- Best measures of competitiveness
- Sufficiency of framework components

The judgement involved a two-round consultation about the importance of the factors gathered from literature review.

The main steps included in the Delphi study were expert selection, the first round consultation, the second round consultation and data interpretation. Based on the criteria of standard deviation falling within the range $0 \leq X < 1$ for high level of consensus and $1 \leq X < 1.5$ for fair level of consensus, all the factors met the criteria though, at different levels. Steps 8 and 9 of the framework came close to dropping into the low level of consensus range based on the set criteria. The present researcher argues that the factors examined by this Delphi study provide sufficient validation for the framework.

The researcher perceives the disadvantages of the Delphi method; for instance, some Delphi studies may face the problem of being time consuming or having high dropout rate. Time consumption caused by multi-rounds could be reduced by designing a proper communication mode. In the same fashion, reducing drop-out rate could be handled by well-prepared questionnaires. High drop-out rates are more likely in studies having long questionnaires; thus, a trade-off between the higher response rate and the shorter questionnaire needs to be made (Zolingen and Klaassen 2003). In addition, the questions should be easy to understand and answer. This was prevented by providing additional information describing the questionnaire and guiding respondents by close-ended questions which help with the understanding the topics of concern (Burns and Grove, 2008; Holsapple and Joshi, 2000; Scott, 2000).

Face validity, as is the Delphi method, relies on expert opinion. The objectives of expert opinion validation are to assess the feasibility of the framework in terms of its adequacy and clarity, and to ensure that the model is reasonably robust, practicable and will be acceptable to users. This face validity was achieved by means of questionnaire survey which was responded to by 11 experts with industry experience. The responses of the experts suggest that the framework is a valuable tool for selecting appropriate LAG practices at PLC stages. This also means that the framework is a positive contribution to the body of. The framework can therefore be recommended to managers, subject to future modifications that can improve its acceptability and performance.

Case study in this research helped to estimate the output that the framework in a real environment, given a set of input and conditions. This was achieved by applying the information received in an interview with the operations director of a reputable fashion business in the framework. The output realized with the fashion business' LAG practices were compared with the LAG practices proposed as a result of the framework; and the outcome suggests that the framework gives better and improved results in terms of cost, lead time and environmental waste.

7.5 Contribution to body of knowledge

The main results of this research are:

a) Lean, Agile and Green (LAG) practices adopted in the FMCG sector gathered both from a literature review and survey of professionals;

b) the impact of LAG practices on performance measures – cost, lead time and environmental waste at product life cycle (PLC) stages;

c) an AHP-based framework for selecting appropriate LAG practices based on their impact on performance measures (cost reduction, lead time compression and environmental waste reduction) at the four PLC stages;

d) validation of the framework to ensure that it is feasible, practical and useful.

This research therefore makes four main contributions to the body of knowledge. Firstly, this research highlights the LAG practices that are adopted in the FMCG industry through literature review and questionnaire survey. Also, the AHP-based model which was applied in devising a structured method for selecting appropriate LAG practices at each PLC stage in order to achieve competitiveness is useful and practical. It provides effective decision making compared to methods used at present which are based on intuition. For example, embarking on efforts to reduce costs without prioritising the impacts of the LAG practices on costs may result in adopting practices which are inefficient for the desired purposes and wastage of organisational resources. This becomes a more critical situation when companies face stiff competition, demand uncertainty, constantly changing customer requirements and global as well as local demands for environmentally sustainable practices in manufacturing.

The research also adds to the body of knowledge by providing guidance and direction for the PLC on the adoption LAG practices. This research incorporates the PLC within a decision support framework to aid the adoption of lean, agile and green practices. The framework provides companies with the opportunity to use information on product life cycle characteristics and impacts to inform operational strategies. This provides companies with direction on when is appropriate to adopt certain LAG practices considering the characteristics of that PLC stage. Unlike the existing works discussed in the literature review, this framework supports the adoption of lean thinking, agility and environmental sustainability throughout the entire product life cycle.

In developing the framework, this research also investigated the contributions of LAG practices towards cost reduction, lead time compression and environmental waste reduction at PLC stages. This informs better decision making and adds to theory in a unique way because from a set of practices that can be adopted at any particular PLC stage – introduction, growth, maturity, decline, a company can pick out the practices that reduce costs, compress lead time and/or reduce environmental wastes depending on what performance measure the company is interested in effecting. Existing methods discussing directions for the PLC have not integrated the three paradigms as presented in this research, they either discuss the lean and agile, lean or green paradigms and in most cases they have not mentioned what practices need to be adopted.

7.6 Implications to practice

In practical terms, this research makes a clear contribution to existing body of knowledge in that the proposed methodological framework has a generic dimension to serve as a guide for companies in the FMCG industry to systematically integrate and adopt Lean, Agile and Green considering product life cycle stages to better manage their processes and meet customer requirements in their organisations.

This research and the framework developed as a result is a welcome solution to the problem of misapplication of LAG practices. Adopting appropriate LAG practices impacts positively on organizational profitability. The outcome of this research means that organizations can informatively address customer requirements and operational matters.

The common theme of the challenges faced by practitioners in the adoption of Lean, Agility and Green is that of inadequate understanding or knowledge of what priorities the adoption of LAG practices should take. Hence, to achieve successful adoption of Lean, Agility and Green, a combination of factors must be facilitated concurrently; these include an early understanding of the practices and their operational activities and the impact of these within any organization in terms of addressing customer requirements and operational matters. This research helps to address that problem for practitioners.

7.7 Limitations of the research

This research followed a structured research process, with care taken at every stage. However, inevitably there were some limitations affecting the study. First, questionnaire survey was used gather information from people who have worked within the UK FMCG industry. Therefore, the research results may only be valid for the characteristics and circumstances of managers and production within the UK FMCG industry, as a result the framework developed in this research is industry specific and may not successfully extended to different industry sectors and in countries other than the UK.

It is appreciated that there are deficiencies with a survey procedure. For this research, the survey of the study was based on data collected from a sample of professionals in the FMCG industry obtained from mostly members of the institute of operations management (IOM), prior to the survey, a pilot study was undertaken. The participants for the survey were derived from random sampling. This sampling method does not include other stakeholders, who in one way or another may influence decision making within an enterprise. The sample size may need to be extended to include stakeholders involved with the business in order to minimise sampling error.

Also, the AHP-based framework is a potential limitation because the pairwise comparison seems to be an artificial way of comparing a set of items. However, care was taken to ensure that the respondents were experienced professionals whose judgements can be considered reliable. This helped to compensate for the seemingly artificial pairwise comparison and subjectivity.

The number of case studies investigated is important, for this research it is one case study. However, this research has gone an extra mile with the three-stage validation process involving Delphi, face validity and case study as presented CHAPTER SIX.

Another limitation is the adoption of standard deviation as a measure of consensus for the Delphi study may lead to negative criticism when compared to other statistical methods. However, the Delphi method is not an approach developed to challenge the quantitative statistical methods; it intends to deal with situations where precise statistical techniques of large population are not possible, thus experts' judgement are necessary. Moreover, an accurate measurement is difficult in the Delphi method for the purpose of long-term forecasting. This is due to no existing set standard.

It is also acknowledged that there was time, administrative and financial constraints. However, the importance of the study remains, but the limitations do not detract them, but provides scope for further research.

7.8 Recommendations for future research

The fact that the results are industry specific and may not be generalized to other industry sectors provides an opportunity for improvement. Other industry sectors may require different actions especially in the adoption of LAG practices as presented in the framework. This research may further be developed as the LAG system, in a hybrid industry context and in different countries.

Having considered the entirety of the research including the outcomes, findings and limitations, several opportunities for further research have been identified.

- Some companies do not possess the capabilities to adopt certain LAG practices due to human, material or infrastructural constraints. Hence the development of a capability roadmap to enable companies acquire the necessary capabilities for adopting LAG practices may be necessary.
- As the characteristics of the PLC stages regarding costs, profits and sales are widely referenced in academia and industry, research into what happens at the various PLC stages regarding lead time and waste may also be of importance.
- Discrete event simulation could be introduced to provide a different perspective into the understanding of the impact of LAG practices on a system.
- More case studies could be used to test the applicability of the conceptual framework and identify areas for improvement.
- Time series forecasting could be used to predict what the outcomes regarding cost, lead time and waste for a company will be for adopting LAG practices using historical data of practices and outcomes for each LAG practice.

7.9 Summary

This chapter discussed the development of this research and its outcomes. Discussion on the rationale for this research presented in this chapter is a brief analysis the need for this research. This chapter also outlined how the aim and objectives of this research has been achieved. The contributions made by this research to the body of knowledge are also presented in this chapter, indicating the contribution to theory.

This chapter also presented what this research means to practice, stating how the outcome of this research could assist practitioners in resolving some of the issues that they might have, especially of selecting the most appropriate LAG practices. This research also encourages practitioners to consider the product life cycle in adopting LAG practices, providing guidance on how to achieve that.

The limitations of this research and recommendations for future research are also presented in this chapter. They outline the constraints of this research and present future research directions recommendations as a result of the findings, outcomes and limitations of this research.

CHAPTER EIGHT

SUMMARY AND CONCLUSIONS

8.1 Introduction

In this chapter, a summary of the thesis is presented. It discusses the findings from the literature review and the main results of the research and outlines managerial implications. The recommendations made in this research provide suggestions for future research which has arisen as a result of the findings of this research.

8.2 Review of aim and objectives

This thesis has satisfied the aim and objectives specified in CHAPTER 1 and repeated here for convenience.

Aim: The aim of this research is to develop an integrated decision framework that supports decision making in selecting the appropriate combination of lean, agile and green practices for the stages of a product's life cycle to improve firm competitiveness and environmental performance.

Objectives: In order to achieve the overall aim of the research, the following objectives have been set for this research:

1. Carrying out desk research to identify the lean, agility and green practices applied in industry.
2. Carrying out field research to:
    - identify the lean, agile and green practices operated in industry;
    - determine the life cycle stage of selected FMCGs;
    - identify the manufacturing strategy (mix of lean, agility and green practices) adopted for the products given their life cycle stage;
    - investigate the contribution of lean, green and agility practices to cost reduction, lead time reduction and waste generated at PLC stages.
3. To develop a decision support framework for selecting the right mix of lean, agile and green practices that reduce costs, lead time and waste at each stage of the PLC.
4. To verify and validate the LAG selection framework.

In order to achieve objective 1, a literature review was carried out to identify the lean, agile and green practices adopted in the FMCG industry and to identify methods of determining the PLC stage of products.

The literature review on lean, agility and green as well as their various combinations especially in the manufacturing and management revealed that no single paradigm is sufficient. The literature review also revealed that:

- Competition and changing customer demands will continue unabated requiring innovative strategies to address them;

- Companies must take a series of interrelated manufacturing decisions and make choices which must be continually reviewed and sometimes changed as the company's products evolve and mature. Then the company must decide what manufacturing system to adopt in the production of their product(s) (Hayes and Wheelwright, 1979);

- Environmental concerns are adding complexity to the already daunting task of managing businesses but it has not been adequately explored in combination with lean and agility;

- The importance of the product life cycle concept and the need to consider it in decision making;

- The life cycle of products have not been adequately considered in the development of manufacturing strategies; lean, agile and green paradigms.

- There is no decision support tool that incorporates the lean, agile and green practices with their practices in the FMCG industry considering the PLC concept.

The literature review showed that paradigms and their variations were developed and adopted as a result of the limitations of the preceding ones as market unpredictability and dynamism became an ever present part of the business atmosphere. The literature review contributed to knowledge as it helped to identify LAG practices in the FMCG industry; possible ways to determine the PLC stage of a product and the impacts of LAG practices on cost, lead time and waste.

8.2.1 Impacts of lean, agility and green practices

The second objective was achieved through the means of questionnaire-survey and was then used to achieve the third objective which is to investigate the impact of LAG on the performance cost, lead time and waste.

The impact of LAG on performance measures was achieved through test of hypothesis. The hypothesis and arguments were developed with the aid of literature review on the impacts of LAG on performance measures. The overall outcome of the hypothesis test is that the adoption of lean, agile and green are not only necessary but should be adopted at the practices level as each of the practices would have different levels of impact depending on the performance measure and the PLC stage where they are considered.

8.2.2 Conceptual framework

Having established that there is need for appropriate LAG practices to be adopted at specific PLC stages, there is a need to develop a framework for doing that, hence achieving the fourth objective. The framework was developed to aid the selection of appropriate LAG practices given product life cycle stages; the framework consists of three parts as shown in figure 5.1 in CHAPTER FIVE which are the knowledge base, decision support module and the Analysis and comparison module. The three parts are then fully explained with the aid of figure 5.5 which is the process view of the framework comprising 10 steps which include data collection, AHP development, regression model development and comparison.

The elements in the framework can be used to guide future improvements. A very important advantage of this framework is that it provides weights for the LAG practices given PLC stages, i.e. given a PLC stage, the framework shows LAG practices which should work better at reducing cost, lead time and generated waste than others by assigning weights to each of them. Another advantage of this CF is that it has been tailored to improving the three performance measures individually or simultaneously depending on the need of a company.

8.2.3 Validation

The fourth objective of this research is to validate the developed framework. This was done through Delphi method, face validity and case study. The case study was achieved through an interview, the set of LAG practices adopted by the company were identified and analysed with the aid of the regression model developed in the CHAPTER FIVE. The outcome of the analysis with company's set of practices was then compared with the set of practices proposed by the framework. The results indicate that the framework is effective in selecting

LAG practices for cost reduction, lead time reduction and waste reduction as the values obtained showed the set of LAG practices proposed by this framework would better at improving the performance measures.

8.3 Research Conclusions

There are no secrets to success. It is the result of preparation, perfect selection, and learning. Selection of appropriate LAG practices suitable to manufacturing companies is the requirement of multi criteria decision making problem. The selection process depends on several qualitative factors. LAG practices implementation problems are characterised by inadequate data, destitute knowledge and spurious input parameters. There is always a scope of optimization on the obtained results as these values are non- reflective of the real life scenario. In real world, the selection process comes across many uncertain factors, ambiguous and vague parameters while operating the practices in companies.

AHP allows a set of complex issues, to be compared with the importance of each issue relative to its impact on the solution to the problem

This thesis has:

- Identified lean, agile and green practices adopted in the fast moving consumer goods industry
- Explored the impact of lean, agility and green on cost, lead time and waste
- found that the adoption of lean, agile and green is necessary
- found that lean, agile and green are necessary at practices level
- found that product life cycle should be considered in the adoption of lean, agile and green practices
- developed a framework for selecting the most appropriate lean, agile and green practices at product life cycle stages for reducing cost, lead time and waste hence improving competitiveness

It is therefore believed that this research makes several original contributions to knowledge because it not only considered the lean, agile and green paradigms at the practices level, it introduced the PLC concept into the decision making process; it is also a decision framework which helps in making informed management decisions.

A surprising observation of this research is that the data analysis revealed that green is the most important paradigm for achieving overall competitive advantage when competitive advantage is defined by cost reduction, lead time compression and waste reduction. However, the importance of the green initiative has been shown to be consistent with the long term advantages of green practices adoption especially regarding cost reduction indicated in literature. The results of the hypothesis test also show some green practices are positively correlated with the reduction of cost, lead time and waste.

This research also shows that the decline PLC stage is important for achieving the overall objective of realizing competitive advantage. This also is consistent with one of the characteristics of the decline stage of the PLC as production costs is known to reduce considerably, so also waste generated by the product as less of it is produced as a result of considerable drop in demand and sales.

Overall, this thesis makes a significant contribution towards the understanding of how the lean agile and green paradigms have been deployed in order to improve operations and competitiveness. Considerations to be lean, agile, green or any of their combinations are made as a result of the fluidity of customer requirements in the market place and the improvement targets that have been set by an organisation. As the lean paradigm is an approach geared towards continuous improvement through the elimination of non-value adding activities; the agile paradigm encourages product innovation and quick response to changes in the market; and the green paradigm is concerned with environmental protection and the minimization of energy use, this thesis proposes a more integrated approach which encourages the consideration of the PLC in attempts to achieve improved operations and competitive capabilities.

The framework developed in this research can assist managers and practitioners within the FMCG industry in planning, coordination and control of manufacturing processes through the adoption of LAG practices. This thesis provides organisations with a deeper understanding of the importance of incorporating the PLC in decision making and also the identification of specific LAG practices and what PLC stage to have them deployed. Managers who adopt this framework will make be better informed decisions considering important factors such as cost, lead time and environmental waste, and confidently apply practices that would achieve improved operational efficiency, improved environmental profile and improved competitiveness as a result.

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APPENDIX ONE
CONSENT LETTER FOR QUESTIONNAIRE SURVEY

College of Business

University of Derby

To whom it may concern

Dear sir/madam,

RESEARCH INTO DECISION MAKING ON THE SELECTION OF APPROPRIATE LEAN, AGILE AND GREEN PRACTICES IN THE CONTEXT OF PRODUCT LIFE CYCLE.

The aim of this research is to develop a decision support model for selecting appropriate lean, agility and green practices to implement based on the product life cycle concept. This questionnaire is designed with intent to elicit information from you regarding the lean, agile and green practices employed for any identified product in a given life cycle stage and your opinion on the impact of these practices.

There are no absolutely right or absolutely wrong answers on this, only your expert opinion. I assure you that all your responses/feedback will be handled with strictest confidence and used solely for academic purposes. A copy of the final thesis will be available in the university library but may not be readily available to the general public. Some provision is made herein for you expand on your responses where necessary.

I appreciate that this questionnaire will take some of your valuable time, but without your kind and expert input the research objectives for this work cannot be realised. Participation in this research is entirely voluntary and you may withdraw at any time should you not wish to continue. At this juncture, I thank you very much in anticipation on your kind and invaluable consideration and correspondence.

Please return the completed questionnaire by return email to the sender's email address (chinonsokenneth@hotmail.co.uk).

Chinonso Udokporo
Centre for Supply Chain Improvement

College of Business
Derby Business School
University of Derby, DE22 1GB.

APPENDIX TWO

Guidance notes on completing the questionnaire

On this guidance note, I have elected to focus on sections C D and E which represents the bulk of the research. Section D especially needs expanding on for better understanding of what the terms mean. It is important to understand that this questionnaire is not a test of knowledge for the respondents but a humble request for valuable information which would go a very long way in achieving the aims and objectives of this research.

Section C Awareness of Lean, Agility and Green

(5) Level of awareness of lean, agility and green

To this section, respondents are expected to indicate their knowledge of the three paradigms lean, agility and green by checking the appropriate box for each paradigm. This should reflect how much the respondent is knowledgeable about paradigms either by initiating and applying it in their company or by carrying out instructions from superiors.

(6) Reason(s) for adopting lean, agility and green

In the second part of this section, respondents are to indicate their reason(s) for adopting/implementing lean, agility and green. Multiple selections can be made here

Section D Product life cycle (PLC) and related actions

(7) Awareness of the product life cycle concept

Respondents are expected to indicate their knowledge of the product life cycle concept by checking the appropriate boxes. A brief description in provided below.

The life cycle here is taken to be the period during which the product is in the market and consists of 4 phases as explained below

Introduction stage: New product is first made available for general purchase in the market. Characterised by;

- High costs
- Low sales and
- Low profits

Growth stage: Product begins to experience rapid gains. The growth stage is characterised by economies of scale;

- Rising sales

- Increasing profits and
- Reduction in costs

Maturity stage: Market saturation begins to occur at this stage. Profits reach their peak and start to drop. Other characteristics include;

- Reduction in costs
- Intense competition
- Low sales

Decline stage: At this stage manufacturing costs are lower as the sales for the product drops further. The characteristics are outlined below.

- Low profits
- Low sales
- Low costs

(8) Identify the life cycle of a product within the company

In this section, respondents are expected to identify the life cycle stage of any of their products. In other words, pick a product and with your knowledge of the product life cycle (PLC) concept or as described in (7) above. The respondents' experience within the company and their products should also be brought to bear especially in this section.

Though responses for one product is acceptable, responses for more than one product will be appreciated. Hence I implore respondents to identify more than one product in different stages of their life cycles. For example, product A in the introduction stage, product B in the maturity stage and so on.

Section E Lean, agility and green practices for the identified products.

Responses for this section are based on the product(s) selected in D (8) above. Respondents are to select from the list of practices listed, which ones are associated with the production of the identified product(s) (omitting the ones that are not) and ranking the impact of the selected practices on cost, demand level and profits by checking the appropriate boxes.

An explanation of the listed practices is provided here for guidance.

Lean Practices	Explanation
Time based competition	Speed in developing new products and in responding to customer demands. Just in time (JIT)
Cycle time reduction	Strategy for lowering total process completion time
Set up time reduction	Lowering the time it takes to change from the last item of previous order to the first good item of the next order
Continuous flow production	Method of production without interruption
Cellular manufacturing	Work place design model that groups similar processes in the 'cells'
Bottle-neck removal	Removal of processes that slow down or stop production
Planning and scheduling	Optimal allocation of raw materials and production capacity to meet demand
Total quality control	Applying quality principles from design to delivery

Lean Practices	Explanation
Quality circles	Regular employee meetings on ways of solving problems and improving productivity

Lean Practices (continued)	Explanations
Continuous improvement	Making small incremental improvements to improve efficiency and quality
Pull system/kanban	Producing only to actual demand from customers/ resource control by replacing only what has been consumed.
Preventive maintenance	Avoidance of equipment failure through proper use and regular servicing (including replacement of worn parts)
Self-directed work teams	Employees capable of working with minimal managerial supervision.

Agile Practices

Agile Practices	Explanations
Research for new products	Research and development for new product development
Rapid reconfiguration	Quickly adapt production processes for the task at hand
Flexible production lines	Creation of flexible production lines
Flexible employees	Flexible employees operating work cells with greater responsibility and control
Virtual organisation	Formation of temporary alliances to share skills and manage competencies in order to respond better to opportunities. Not particularly requiring a physical facility
Strategic postponement	Delay of final production (assembly) or distribution of product until order is received.
Demand flexibility	Strategically prepared to respond to fluctuations in demand by Shifting production/distribution to some other time, preferably when orders have been received
Large/small batches production	Production in large or small batches as required
Strategic outsourcing	Outsourcing of some production processes to focus on core competencies
Innovation culture	Development of a culture of innovation and market orientation
Internal communication	Encouragement of internal communication
Supplier partnership	Strong partnership with core suppliers
Storage facilities	Location of storage facilities/warehouses near production areas
Quickly develop new products	Speed in new product development and time to market capacity. Including finding alternative use for product(s)
Quick decision making	Facilitation of quick decision making
Demand information capturing	Capture of demand information quickly

Green Practices

Green Practices	Explanations
Site selection	Selection of sites and warehouses away from general population
Installing large doors/windows	Installation of large doors and windows for proper lighting and ventilation
Temperature control	Installation of temperature control devices
Use of non-hazardous materials	Use of non-hazardous materials in production and packaging
Supplier survey	Survey of suppliers to support accurate environmental reporting
Outsourcing to 3PLs	Outsourcing operations/activities to third party logistics providers
Production of durable products	Development of durable and long lasting products
Smaller packaging	Use of smaller, thinner and lighter packaging
Use of less material	Production with less material
Waste processing	Processing of waste in the region where it is collected
Recycling programs	Introduction of/participation in recycling programs for products at end of life
Recyclable materials	Products made with/use of recyclable packaging or materials
Use of PLC analysis	Use of a comprehensive product life cycle analysis that measures the carbon footprint of products throughout their life
Environmental laboratory	An environmental testing lab built to examine products for harmful substances and working with suppliers on this

APPENDIX THREE

Section A. Background of respondent (optional)

Name of company
Position in the company
Number of years of work experience in the company years months
Address
Telephone Email

Section B. General Information

1. What type of organisation do you work for? (Please check the appropriate box)

Apparel and accessories	☐	Personal care	☐	Health and Medicine	☐
Food, beverage and Tobacco	☐	Fast moving consumer electronics	☐		

2. What is the size of the company? (Please check the appropriate box)

50-249	☐	250-500	☐	Over 500	☐

3. Please check the appropriate box for the age of your organisation

0-5 years	☐	5-10 years	☐	10-20 years	☐	20-30 years	☐	over 30 years	☐

4. Please give an indication of the annual turnover of the organisation (in British £)

£1m-£5m	☐	£5m-£25m	☐	£25m-£100m	☐	Over £100m	☐

Section C. Awareness of Lean, Agility and Green

5. Please indicate your level of awareness for the following concepts

	Expert	Very aware	Moderately aware	Slightly aware	Not aware
Lean	☐	☐	☐	☐	☐
Agility	☐	☐	☐	☐	☐
Green	☐	☐	☐	☐	☐

6. Please rate on a scale of 1-5 your reason for adopting the Lean, Agility and Green paradigms

Note: 1 = Very low, 2 = Low, 3 = Moderate, 4 = High, 5 = Very high

	Lean					Agile					Green				
	Lowest				Highest	Lowest				Highest	Lowest				Highest
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Minimise cost	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improve lead time	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improve operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improve environmental performance	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Coordinate processes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Increase market share	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Improve customer satisfaction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other (Please specify)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Section D. Product life cycle awareness and related actions

7. Please indicate your awareness of the product life cycle (PLC) concept

	Expert	**Very aware**	**Moderately aware**	**Slightly aware**	**Not aware**
PLC	☐	☐	☐	☐	☐

8. Given your experience (in the company(s) where you have worked), please list the products and indicate their life cycle stage. An example is provided.

	Life Cycle Stages			
Product	**(1)Introduction**	**(2)Growth**	**(3)Maturity**	**(4)Decline**
Example: blue label	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

How many products would you say are in the company's product line? Choose an item.

In the next section, a list of practices has been provided for the lean, agile and green practices respectively. {You may not have used a number of them in the production and delivery of products at specific life cycle stages.}

From each paradigm (lean, agile, green), please select the practices you have used from the list provided, indicate their life cycle stage by checking the boxes 1 to 4 (1= Introduction stage; 2 = Growth stage; 3 = Maturity stage; 4 = Decline) under the 'Life Cycle Stage' column. Then the importance of the practices so selected is to be ranked on a scale 1 to 5 where 1 = Not important at all and 5 = crucial.

Section E. Lean, Agility and Green practices employed for the specific Life Cycle stages and their importance

Please select from the list of practices provided the ones you have used, the product life cycle stage and rate the importance of that practice for the life cycle stage. Note: 1 = Not important at all, 2 = Slightly important, 3 = Moderately important, 4 = Very important, 5 = Extremely important

Lean

		Life Cycle Stage				Importance of Practices				
Lean Practices		Introduction	Growth	Maturity	Decline	**1**	**2**	**3**	**4**	**5**
☐	Time based competition (JIT)	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Cycle time reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Set up time reduction	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Cellular manufacturing	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Bottle-neck removal	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Focused factory	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Planning and scheduling	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Total quality control	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Quality circles	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Continuous improvement	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Pull system/Kanban	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Preventive maintenance	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Self-directed work teams	☐	☐	☐	☐	☐	☐	☐	☐	☐

Select from the list of practices provided the ones you have used, the product life cycle stage and rate the importance of that practice for the life cycle stage. Note: 1 = Not important at all, 2 = Slightly important, 3 = Moderately important, 4 = Very important, 5 = Extremely important

Agility

		Life Cycle Stage				Importance of Practices				
Agile Practices		Introduction	Growth	Maturity	Decline	**1**	**2**	**3**	**4**	**5**
☐	Research for new product	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Rapid reconfiguration	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Virtual organisation	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Strategic postponement	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Demand flexibility	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Large/small batches	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Strategic outsourcing	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Innovation culture	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Internal communication	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Supplier partnership	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Storage facilities	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Speed in NPD	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Quick decision	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Information capture	☐	☐	☐	☐	☐	☐	☐	☐	☐

Select from the list of practices provided the ones you have used, the product life cycle stage and rate the importance of that practice for the life cycle stage. Note: 1 = Not important at all, 2 = Slightly important, 3 = Moderately important, 4 = Very important, 5 = Extremely important

Green

		Life Cycle Stage				Importance of Practices				
Green Practices (continued)		Introduction	Growth	Maturity	Decline	**1**	**2**	**3**	**4**	**5**
☐	Site selection	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Large doors/windows	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Temperature control	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Non hazardous materials	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Supplier survey	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Outsourcing to 3PLs	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Durable products	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Smaller packaging	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Use of less material	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Waste processing	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Recyclable materials	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Recycling programs	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Use of PLC analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	Environmental lab	☐	☐	☐	☐	☐	☐	☐	☐	☐

Statements

Please indicate the extent to which you agree or disagree to the following statements

1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

	Strongly disagree				Strongly agree
The product life cycle concept should be considered in the development of lean, agile and green manufacturing/management strategies	☐	☐	☐	☐	☐
My company has adequate coordination for lean, agile and green practices in its manufacturing/management processes	☐	☐	☐	☐	☐
My company has considered the product life cycle in the adoption of lean, agile and green practices	☐	☐	☐	☐	☐

APPENDIX FOUR
Questionnaire for PhD Research

<u>The contribution of practices to cost reduction, cycle time improvement and waste reduction.</u>

The main aim of this questionnaire is to obtain a ratings feedback on the contribution that lean, agile and green manufacturing practices makes (if any) towards cost reduction, lead time improvement and waste reduction focusing on the product life cycle.

Please complete the questions and ratings to the best of your knowledge and ability. Your expert opinion is invaluable in this research and your responses will be treated and handled with the strictest confidence and used solely for academic purposes.

In section B which contains the main body of the research, there are three items to be rated namely: cost reduction, lead time improvement and environmental performance improvement measured by reduction in waste generated. It may be necessary to return to this section to make adjustments if need be.

SECTION A

Name (optional): Click here to enter text.
Name of Company: Click here to enter text.
Type of Business (*select from drop down list*): Choose an item.
Position held in the company: Click here to enter text.

In the following page, we would like to elicit your opinion in order to select amongst the alternatives. The pairwise comparison scale is used to express the importance of element over another

Explanation	**Numeric values**
If options A and B are equally important: Check box for ➡	1
If Option A is moderately more important than Option B: Check box for ➡	3
If Option A is strongly more important than Option B: Check box for ➡	5
If Option A is very strongly more important than Option B: Check box for ➡	7
If Option A is extremely more important than Option B: Check box for ➡	9
Use even numbers for intermediate judgements	2,4,6,8

Saaty comparison scale

Pairwise comparisons: Lean, agile and green

With respect to achieving overall competitive advantage (that is reducing cost, lead time and generated waste)

Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important), please indicate the relative importance of options **A** (left column) to options **B** (right column) by checking the box appropriate box.

	Extremely		Very Strongly		Strongly		Moderately		**Equally**		*Moderately*		*Strongly*		*Very Strongly*		*Extremely*	
A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**B**
Lean	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Agile
Agile	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lean
Green	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Lean
Agile	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Green

Product life cycle stage

With respect to achieving overall competitive advantage (that is reducing cost, lead time and generated waste)

Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important), please indicate the relative importance of options **A** (left column) to options **B** (right column) by checking the box appropriate box.

	Extremely		Very strongly		Strongly		Moderately		**Equal**		*Moderately*		*Strongly*		*Very Strongly*		*Extremely*	
A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**B**
Introduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Growth
Growth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Maturity
Maturity	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Introduction
Decline	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Growth
Maturity	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Decline
Introduction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Decline

SECTION B: Select practices and rate their input towards cost reduction, cycle time reduction and waste reduction by checking the appropriate boxes.

		Cost reduction							**Lead time reduction**							**Waste reduction**						
Agile practices		**0**	**1**	**2**	**3**	**4**	**5**	**NS**	**0**	**1**	**2**	**3**	**4**	**5**	**NS**	**0**	**1**	**2**	**3**	**4**	**5**	**NS**
Research for new products	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rapid reconfiguration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Virtual organisation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Strategic postponement	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Demand flexibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Large/small batches production	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Strategic outsourcing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Innovation culture	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Internal communication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Supplier partnership	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Storage facilities near production	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quickly develop new products	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quick decision making	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Demand information capturing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Note: 0 = No contribution at all, 1 = Very low contribution, 2 = Low contribution, 3 = Neutral, 4 = High contribution, 5 = Very high contribution, NS = Not sure

Note: 0 = No contribution at all, 1 = Very low contribution, 2 = Low contribution, 3 = Neutral, 4 = High contribution, 5 = Very high contribution, NS = Not sure

SECTION C

		Cost reduction							Lead time reduction							Waste reduction					
ractices		**0**	**1**	**2**	**3**	**4**	**5**	**NS**	**0**	**1**	**2**	**3**	**4**	**5**	**NS**	**0**	**1**	**2**	**3**	**4**	**5**
ction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
large doors/windows	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ture control	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
on-hazardous materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
survey	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
cing to 3PLs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
on of durable products	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
packaging	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ess material	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
rocessing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ecyclable materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g programs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
LC analysis	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
nental lab	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

From the table below, select the life cycle stage in which the selected practices were/are being applied by checking the appropriate box.

LIFE CYCLE STAGE	INTRODUCTION ☐	GROWTH ☐	MATURITY ☐	DECLINE ☐
EXPLANATION	*High costs* *Low sales and* *Low profits*	*Rising sales* *Increasing Profits and* *Reduction in costs*	*Reduction in costs* *Intense competition* *Low sales*	*Low profits* *Low sales* *Low costs*

Give example of product(s) in this life cycle stage: Click here to enter text.

What time period were the practices applied (Example 1999-2001): Click here to enter text.

Rate the overall performance of the company in terms of cost reduction, lead time reduction and waste reduction within the stipulated time period

Note: 1 = Very negative, 2 = Negative, 3 = Neutral, 4 = Positive, 5 = Very positive

Performance indicators	1	2	3	4	5	Not sure
Cost reduction/savings	☐	☐	☐	☐	☐	☐
Lead time improvement	☐	☐	☐	☐	☐	☐
Waste reduction	☐	☐	☐	☐	☐	☐

Statement

Indicate the extent to which you agree or disagree with the following statement

Note: 1 = Disagree strongly, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, 5 = Agree strongly

	1	2	3	4	5
The market performance of the product(s) affects production	☐	☐	☐	☐	☐

Indicate how much waste in tonnes went to landfill in the same period:

Waste going to land fill in tonnes	< 10,000 ☐	10,000-20,000 ☐	20,000-30,000 ☐	>30000 ☐

Indicate by checking the appropriate box below, how much of the waste generated in the same period is recycled:

Note: 0 – 20(%) =significantly less than half; 20 – 40(%) =Less than half; 40 – 60(%) = about half; 60 – 100(%) = most

Waste recycled (%)	0 – 20 ☐	20 - 40 ☐	40 - 60 ☐	60 - 100 ☐

What is your environmental performance target? Click here to enter text.

Rate how much recycling/re-using/reducing contributes to meeting the environmental performance target.

Note: 0 = No contribution at all, 1 = Very low contribution, 2 = Low contribution, 3 = Neutral, 4 = High contribution, 5 = Very high contribution

	0	1	2	3	4	5	Not sure
Recycling	☐	☐	☐	☐	☐	☐	☐
Reducing	☐	☐	☐	☐	☐	☐	☐
Re-using	☐	☐	☐	☐	☐	☐	☐

APPENDIX FIVE

INFORMED CONSENT FORM

Researcher's Name: Chinonso Udokporo

Name and Address of Department: Derby Business School, Kedleston Road, Derby, DE22 1 GB

Email: chinonsokenneth@hotmail.co.uk

Title of Research: An Integrated Decision Support Framework for the Adoption of Lean, Agile and Green (LAG) Practices in Product Life Cycle (PLC) Stages.

Aim of the Delphi study: To validate the proposed framework for adopting LAG practices in PLC stages for the improvement of competitiveness.

Procedure of the study:

The current validation effort will be conducted using Delphi technique. This research will consist of a pilot survey followed by two rounds of mailed questionnaire to validate the items and stages of the framework.

Participation in this study is voluntary and very much appreciated. Participants can withdraw from the study at any time. The date collected will be kept confidential. Personal information of the subjects will not be disclosed. Any data related to personal information will be destroyed as soon as the results have been obtained and the research concluded.

If you have any further enquiries regarding the consent agreement and/or the research, you may contact me on the email address provided.

Please tick the appropriate boxes below to indicate your consent or lack thereof in taking part in this study.

☐ Agree ☐ Disagree

Demographic Questions		
1. What is your age group?		
a) Under 25		
b) 25 to 34		
c) 25 to 44		
d) 45 to 54		
e) 55 to 64		
f) 65 and above		
2. What is your highest level of education?		
a) High school		
b) Associate degree		
c) Bachelor’s degree		
d) Master’s degree		
e) Doctorate		
Other (Please specify):		
3. Which of the following most closely describes your current position in your organization?		
a) Senior management		
b) Mid-level management		
c) Consulting/private practice		
d) Manufacturing/Operations management		
Other (Please specify):		
4. Please rate your level of expertise in the field of lean, agile and green manufacturing		
Lean manufacturing	Agile manufacturing	Green
☐Very low	☐ Very low	☐ Very low
☐ Low	☐ Low	☐ Low
☐ Median	☐ Median	☐ Median
☐ High	☐ High	☐ High
☐ Very high	☐ Very high	☐ Very high
5. How many years of lean manufacturing related work experience do you have?		
Lean	Agile	Green
☐0 to 5 years	☐0 to 5 years	☐0 to 5 years
☐6 to 10 years	☐6 to 10 years	☐6 to 10 years
☐11 to 15 years	☐11 to 15 years	☐11 to 15 years
☐15 to 20 years	☐15 to 20 years	☐15 to 20 years
☐More than 20 years	☐More than 20 years	☐More than 20 years
6. Please indicate your level of commitment to serve on the Delphi panel and complete all rounds		
a) Very low		
b) Low		
c) Medium		
d) High		
e) Very high		

APPENDIX SIX

DELPHI QUESTIONNAIRE

1. The market performance of a product in terms of demand, sales, profits and competition should determine how production is conducted by management.
   ☐ Agree
   ☐ Disagree
   Please elaborate on your answer

   Click here to enter text.

2. If the market performance of a product should determine how production is conducted by management, is it practical to adopt management practices tailored to the product life cycle stage of the product(s) being made?
   ☐ Yes
   ☐ No
   Please elaborate on your answer

   Click here to enter text.

3. When deciding on the management paradigms/production strategies/tools/practices to implement in production, is it sensible to consider the properties of each product life cycle stage?
   ☐ Yes
   ☐ No
   Please elaborate on your answer

   Click here to enter text.

4. In making the decision on what management paradigms/tools/practices to implement and on what product life cycle stage, is it justified to use the analytic hierarchy process (AHP) to achieve that?
   ☐ Yes
   ☐ No
   Please elaborate on your answer

   Click here to enter text.

The following figures represent frameworks to assist management in tool selection

Figure 1 – Management tool selection. Adapted from Anvari et al. (2013)

Content removed for copyright reasons

Figure 2-Management tool selection. Cabral et al. (2012)

Content removed for copyright reasons

Figure 3 - Management tool selection. Alaskari et al. (2016)

Content removed for copyright reasons

5.

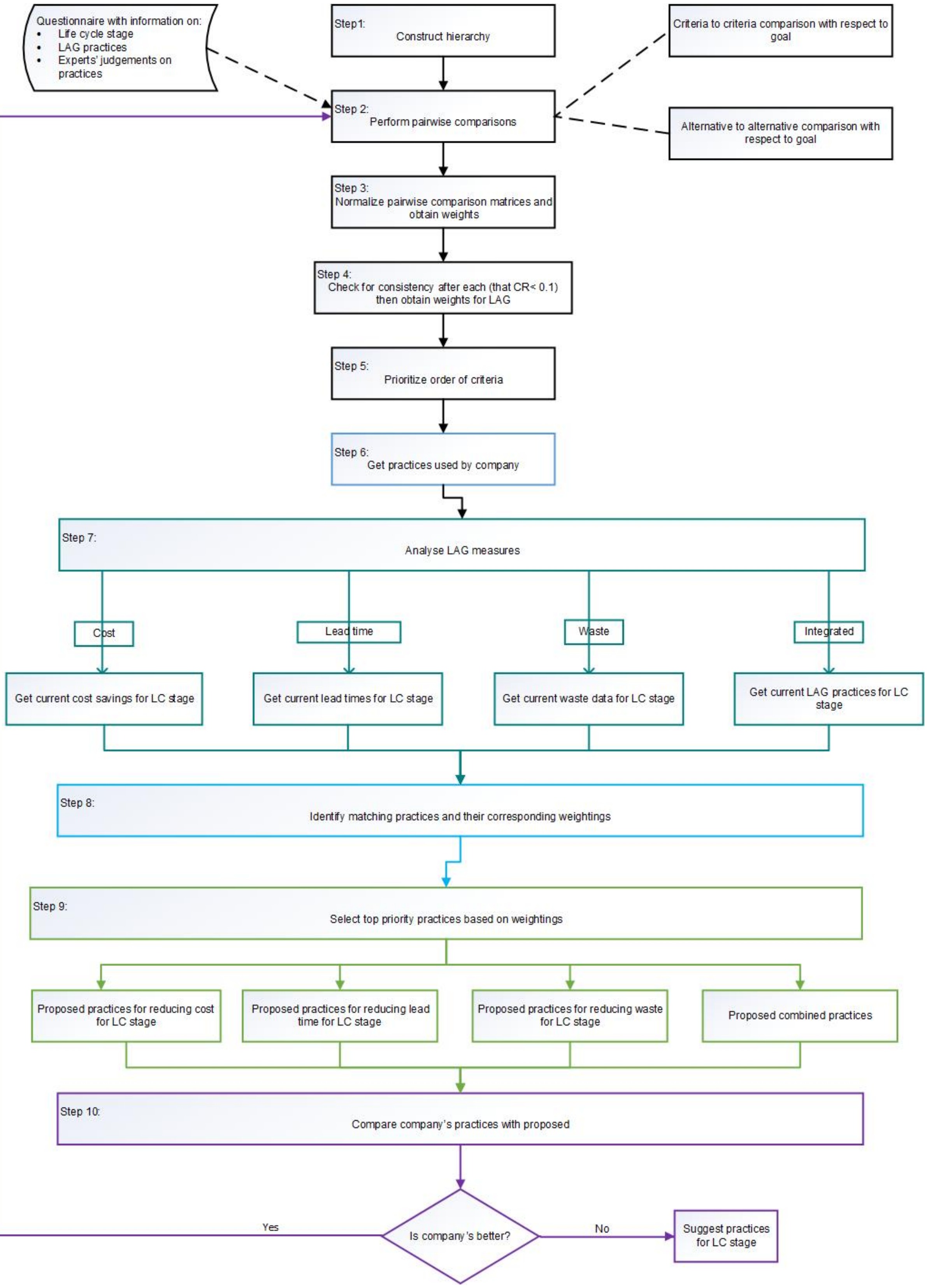
Considering the FMCG industry please rate the following by their adequacy in measuring competitiveness

Where 1 = Very inadequate, 2 = Mostly inadequate, 3 = Somewhat inadequate, 4 = Neither adequate nor inadequate, 5 = Somewhat adequate, 6 = Mostly adequate, 7=Very adequate

Performance measures	Components	1	2	3	4	5	6	7
Quality	High conformance to design specifications Customer perceived quality Cost of quality control Low defect rates	☐	☐	☐	☐	☐	☐	☐
Cost	High equipment or capacity utilization Low production/manufacturing cost High labour productivity Production efficiency	☐	☐	☐	☐	☐	☐	☐
Flexibility	High production flexibility to allow efficient new product introduction Rapid changes in current design Setup time/cost	☐	☐	☐	☐	☐	☐	☐
Lead time	Short changeover/ setup times Short production lead times Manufacturing lead time Short delivery times	☐	☐	☐	☐	☐	☐	☐
Dependability	Provision of product support resources Ease of maintaining product Availability of product Reliability of product	☐	☐	☐	☐	☐	☐	☐
Waste	Use of environmentally friendly production processes Providing the firm positive green image Using less materials in production/packaging Using less energy Recycling	☐	☐	☐	☐	☐	☐	☐

6. Is the following framework sufficient for assisting management in selecting the appropriate lean, agile and green practices for the product life cycle stages? Yes/No

Figure 6-Framework to select appropriate lean, agile and green practices for PLC stages



7. If the proposed framework is sufficient for its intended purposes, please indicate what steps are most appropriate to achieving competitiveness for a company.

Where 1 = Very inappropriate, 2 = Mostly inappropriate, 3 = Somewhat inappropriate, 4 = Neither appropriate nor inappropriate, 5 = Somewhat appropriate, 6 = Mostly appropriate, 7=Very inappropriate.

Steps 1 – 5 describe the analytic hierarchy process.

Steps 6 & 7 describe getting the current practices currently implemented in the company as well as corresponding figures regarding cost savings, lead time improvement and waste reduction.

Step 8 identifies the practices of the company which match up with the ones already part of the AHP

Step 9 involves selecting the best ranked practices from the AHP according their cost reduction, lead time improvement and waste reduction capabilities per PLC stage.

Step 10 involves seeing whether improvement is achieved either with the company's set of practices or with the practices selected from proposed framework and making a decision based on what set of practices offer the best solutions for improving competitiveness.

	Ratings						
Steps	1	2	3	4	5	6	7
1 - 5	☐	☐	☐	☐	☐	☐	☐
6 & 7	☐	☐	☐	☐	☐	☐	☐
8	☐	☐	☐	☐	☐	☐	☐
9	☐	☐	☐	☐	☐	☐	☐
10	☐	☐	☐	☐	☐	☐	☐

8. Is it justified to update the framework by adding a feedback channel?
   ☐ Yes
   ☐ No

9. Please provide your email address?
   Click here to enter text.

APPENDIX SEVEN

FACE VALIDITY QUESTIONNAIRE

College of Business

University of Derby

Dear Sir/Madam,

A QUESTIONNAIRE FOR VALIDATING A FRAMEWORK FOR THE ADOPTION OF LEAN, AGILE AND GREEN [RACTICES IN PRODUCT LIFE CYCLE STAGES.

The aim of this questionnaire is to gather and assess the opinion of experts on the framework attached herein. The framework is intended to assist companies in selecting the most appropriate lean, agile and green practices in production life cycle stages in order to improve competitiveness. This questionnaire is to validate the proposed framework regarding its significance to companies in the fast moving consumer goods industry (FMCG); workability in practice and adequacy in addressing the problem confronting managers on the appropriate practices to adopt for the right product life cycle stage.

The questionnaire comprises of three (3) sections. Section A seeks to collect you background information; sections B and C ask your opinion and/or comments on general and specific aspects of the framework. There are no absolutely right or wrong responses, only your expert opinion given to the best of your ability.

If you require any further information about the research, please contact me.

Chinonso Udokporo

University of Derby

College of Business, Law and Social Sciences

Kedleston Road

Derby

DE22 1GB

E-mail: chinonsokenneth@hotmail.co.uk

APPENDIX EIGHT

VALIDATION QUESTIONNAIRE

Section A: Background of respondent

Name of respondent (optional):…………………………………………………………..

Profession:………………………………………………………………………………….

Qualification:………………………………………………………………………………..

Current job title:…………………………………………………………………………….

Years of experience:……………………………………………………………………….

Section B: General impression on the framework (Please tick as appropriate)

1. Does the framework reliably address the problem of selecting appropriate practices for the achievement of competitiveness in the FMCG industry?
a) yes, it does
b) yes but not reliably
c) no, it does not make any difference
d) not sure of its significance
Comments:
2. Would you say that the framework is capable of assisting managers in the selection of appropriate practices to facilitate cost savings, lead time improvement and waste reduction?
a) yes, highly capable
b) yes, just capable
c) not capable
d) not sure of its capability
Comments:
3. Is the framework simple, clear, easily understandable and usable with minimal practical difficulties?
a) Yes
b) No
Comments (if No or otherwise):
4. What is your opinion on the practicability of the framework in real life decision problems?
a) It is practicable
b) It is moderately practicable
c) It is not practicable
Comments:
5. What is your opinion on the description of the framework and its layout?
a) comprehensive
b) adequate

c) poor
Comments:
6. Are there any other matters of importance which ought to be included or considered in the framework?
a) Yes
b) No
Specify (if yes):

Section C: Impression of the framework's techniques

7. What is your opinion on the use of the analytic hierarchy process (AHP) as part of the framework?
a) Very suitable
b) Suitable
c) Not suitable
d) Not sure
Comments:
8. What is your opinion on the use of cost, lead time and waste as measure of competitiveness?
a) Very suitable
b) Suitable
c) Not suitable
d) Not sure
Comments:
9. Are there any further methods/approaches/tools, which in your opinion are important to be considered as part of the framework considering cost, lead time and waste?
a) Yes
b) No
Specify (if yes):
10. What is your opinion on the set of criteria, sub-criteria and alternatives which make up the hierarchy?
a) Very suitable
b) Suitable
c) Not suitable
d) Not sure
Comments:
11. Are there any other important criteria that have not been considered in your opinion?
a) Yes
b) No
List criteria (if yes):
12. Please provide any general comments or suggestions for improvement (Continue on separate sheet if necessary

Thank you for your time

APPENDIX NINE
FREQUENCY TABLES FOR PILOT SURVEY

Table 5.0-**What type of organisation do you work?**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Health and beauty	2	14.3	15.4	15.4
	Pharmaceuticals and medicals	3	21.4	23.1	38.5
	Fashion	4	28.6	30.8	69.2
	Consumer electronics/accessories	4	28.6	30.8	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.1-**What is the size of the company?**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	50-249	7	50.0	50.0	50.0
	250-500	4	28.6	28.6	78.6
	Over 500	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.2-**Please check the appropriate box for the age of your organisation**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-5 years	1	7.1	7.1	7.1
	5-10 years	8	57.1	57.1	64.3
	10-20 years	3	21.4	21.4	85.7
	20-30 years	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.2-**Please give an indication of the annual turnover of the organisation (in British £)**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	£1m-£5m	4	28.6	30.8	30.8
	£5m-£25m	4	28.6	30.8	61.5
	£25m-£100m	4	28.6	30.8	92.3
	over £100m	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.3A-**Level of awareness: Lean**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	3	21.4	21.4	21.4
	Very aware	11	78.6	78.6	100.0
	Total	14	100.0	100.0	

Table 5.3B-**Level of awareness: Agility**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	1	7.1	7.1	7.1
	Very aware	11	78.6	78.6	85.7
	Moderately aware	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.3C-**Level of awareness: Green**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	7	50.0	50.0	50.0
	Very aware	6	42.9	42.9	92.9
	Moderately aware	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.4A-**Scale rating for Lean adoption: To minimise cost**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	9	64.3	64.3	64.3
	Low	1	7.1	7.1	71.4
	Neutral	2	14.3	14.3	85.7
	High	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.4B-**Scale rating for Lean adoption: To reduce lead time**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	1	7.1	7.7	7.7
	High	3	21.4	23.1	30.8
	Very high	9	64.3	69.2	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.4C-**Scale rating for Lean adoption: To improve operations**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	6	42.9	42.9	42.9
	Low	7	50.0	50.0	92.9
	Neutral	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.4D-**Scale rating for Lean adoption: To improve environmental performance**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very high	12	85.7	100.0	100.0
Missing	System	2	14.3		
Total		14	100.0		

Table 5.4E-**Scale rating for Lean adoption: To co-ordinate processes**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	6	42.9	42.9	42.9
	Low	4	28.6	28.6	71.4
	Neutral	2	14.3	14.3	85.7
	High	1	7.1	7.1	92.9
	Very high	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.4F-**Scale rating for Lean adoption: Increase market share**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	2	14.3	15.4	15.4
	Very high	11	78.6	84.6	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.4G-**Scale rating for Lean adoption: To improve customer satisfaction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	4	28.6	28.6	28.6
	High	7	50.0	50.0	78.6
	Very high	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.4H-**Scale rating for Lean adoption: Other**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	5	35.7	38.5	38.5
	High	7	50.0	53.8	92.3
	Very high	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.5 A-**Scale rating for Agile adoption: To minimise cost**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	1	7.1	7.7	7.7
	Very high	12	85.7	92.3	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.5B-**Scale rating for Agile adoption: To reduce lead time**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	5	35.7	35.7	35.7
	Very high	9	64.3	64.3	100.0
	Total	14	100.0	100.0	

Table 5.5C-**Scale rating for Agile adoption: To improve operations**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	3	21.4	25.0	25.0
	Very high	9	64.3	75.0	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.5D-**Scale rating for Agile adoption: To improve environmental performance**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	5	35.7	41.7	41.7
	Very high	7	50.0	58.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.5E-**Scale rating for Agile adoption: To co-ordinate processes**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	4	28.6	33.3	33.3
	Very high	8	57.1	66.7	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.5F-**Scale rating for Agile adoption: To increase market share**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	10	71.4	76.9	76.9
	Very high	3	21.4	23.1	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.5G-**Scale rating for Agile adoption: To improve customer satisfaction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	7	50.0	58.3	58.3
	High	5	35.7	41.7	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.5H-**Scale rating for Agile adoption: Other**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	4	28.6	30.8	30.8
	Low	5	35.7	38.5	69.2
	Neutral	3	21.4	23.1	92.3
	High	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.6A-**Scale rating for Green adoption: To minimise cost**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	5	35.7	38.5	38.5
	High	3	21.4	23.1	61.5
	Very high	5	35.7	38.5	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.6B-**Scale rating for Green adoption: To reduce lead time**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	2	14.3	14.3	14.3
	Low	2	14.3	14.3	28.6
	Neutral	6	42.9	42.9	71.4
	High	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 5.6C-**Scale rating for Green adoption: To improve operations**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	3	21.4	25.0	25.0
	Low	3	21.4	25.0	50.0
	Neutral	3	21.4	25.0	75.0
	High	1	7.1	8.3	83.3
	Very high	2	14.3	16.7	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.6D-**Scale rating for Green adoption: To improve environmental performance**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	2	14.3	14.3	14.3
	Neutral	6	42.9	42.9	57.1
	High	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 5.6E-**Scale rating for Green adoption: To co-ordinate processes**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	3	21.4	21.4	21.4
	High	6	42.9	42.9	64.3
	Very high	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table5.6F-**Scale rating for Green adoption: To increase market share**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	5	35.7	35.7	35.7
	High	8	57.1	57.1	92.9
	Very high	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table5.6G-**Scale rating for Green adoption: To improve customer satisfaction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	2	14.3	16.7	16.7
	Low	5	35.7	41.7	58.3
	Neutral	4	28.6	33.3	91.7
	High	1	7.1	8.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.6H-**Scale rating for Green adoption: Other**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	10	71.4	71.4	71.4
	Very high	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 5.7-**Please indicate your awareness of the product life cycle (PLC) concept**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	8	57.1	57.1	57.1
	Very aware	2	14.3	14.3	71.4
	Moderately aware	2	14.3	14.3	85.7
	Slightly aware	1	7.1	7.1	92.9
	Not aware	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

LEAN PRACTICES per Life Cycle Stage

Table 5.8A-**Time based competition**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	11	78.6	84.6	84.6
	Maturity	1	7.1	7.7	92.3
	Decline	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8B-**Reegineered process**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	9	64.3	64.3	64.3
	Maturity	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 5.8C-**Cycle time reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	5	35.7	35.7	35.7
	Maturity	8	57.1	57.1	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.8D-**Set up time reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	8	57.1	57.1	57.1
	Maturity	5	35.7	35.7	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.8E-**Continuous flow production**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	10	71.4	76.9	76.9
	Maturity	1	7.1	7.7	84.6
	Decline	2	14.3	15.4	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8F-**Cellular manufacturing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	4	28.6	28.6	28.6
	Maturity	8	57.1	57.1	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.8G-**Lot size reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	2	14.3	14.3	14.3
	Maturity	9	64.3	64.3	78.6
	Decline	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.8H-**Bottle-neck removal**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	4	28.6	28.6	28.6
	Maturity	7	50.0	50.0	78.6
	Decline	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table5.8I-**Focused factory**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	3	21.4	23.1	23.1
	Maturity	10	71.4	76.9	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8J-**Concurrent engineering**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	8	57.1	61.5	61.5
	Maturity	4	28.6	30.8	92.3
	Decline	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8K-**Group technology**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	1	7.1	7.7	7.7
	Growth	9	64.3	69.2	76.9
	Maturity	2	14.3	15.4	92.3
	Decline	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8L-**Planning and scheduling**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	23.1	23.1
	Growth	8	57.1	61.5	84.6
	Maturity	2	14.3	15.4	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8M-**Total quality control**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	5	35.7	35.7	35.7
	Growth	7	50.0	50.0	85.7
	Maturity	1	7.1	7.1	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.8N-**Quality circles**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	28.6	28.6
	Growth	9	64.3	64.3	92.9
	Maturity	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 5.8O-**Continuous improvement**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	2	14.3	16.7	16.7
	Growth	5	35.7	41.7	58.3
	Maturity	4	28.6	33.3	91.7
	Decline	1	7.1	8.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.8P-**Process capability analysis**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	30.8	30.8
	Growth	6	42.9	46.2	76.9
	Maturity	1	7.1	7.7	84.6
	Decline	2	14.3	15.4	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8Q-**Pull system/Kanban**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	30.8	30.8
	Growth	3	21.4	23.1	53.8
	Maturity	1	7.1	7.7	61.5
	Decline	5	35.7	38.5	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8R-**Uniform workload**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	27.3	27.3
	Growth	4	28.6	36.4	63.6
	Maturity	3	21.4	27.3	90.9
	Decline	1	7.1	9.1	100.0
	Total	11	78.6	100.0	
Missing	System	3	21.4		
Total		14	100.0		

Table 5.8S-**Maintenance optimisation**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	36.4	36.4
	Growth	3	21.4	27.3	63.6
	Maturity	3	21.4	27.3	90.9
	Decline	1	7.1	9.1	100.0
	Total	11	78.6	100.0	
Missing	System	3	21.4		
Total		14	100.0		

Table 5.8T-**Preventive maintenance**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	1	7.1	8.3	8.3
	Growth	4	28.6	33.3	41.7
	Maturity	4	28.6	33.3	75.0
	Decline	3	21.4	25.0	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 5.8U-**Multifunction employees**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	30.8	30.8
	Growth	5	35.7	38.5	69.2
	Maturity	3	21.4	23.1	92.3
	Decline	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 5.8V-**Self-directed work teams**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	4	28.6	28.6	71.4
	Maturity	1	7.1	7.1	78.6
	Decline	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

IMPORTANCE OF LEAN PRACTICES

Table 5.9A-**Time based competition**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	3	21.4	21.4	21.4
	Highly important	8	57.1	57.1	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.9B-**Reengineered process**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	6	42.9	42.9	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 5.9C-**Cycle time reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	3	21.4	21.4	21.4
	Less Important	2	14.3	14.3	35.7
	Highly important	6	42.9	42.9	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.9D-**Set up time reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	3	21.4	21.4	21.4
	Highly important	5	35.7	35.7	57.1
	Crucial	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 5.9E-**Continuous flow production**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less Important	4	28.6	28.6	28.6
	Very important	4	28.6	28.6	57.1
	Highly important	2	14.3	14.3	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 5.9F-**Cellular manufacturing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	3	21.4	21.4	21.4
	Highly important	3	21.4	21.4	42.9
	Crucial	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 5.9G-**Lot size reduction**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	2	14.3	14.3	14.3
	Highly important	5	35.7	35.7	50.0
	Crucial	7	50.0	50.0	100.0
	Total	14	100.0	100.0	

Table 5.9H-**Bottle-neck removal**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	5	35.7	35.7	35.7
	Highly important	6	42.9	42.9	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.9I-**Focused factory**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	8	57.1	57.1	57.1
	Highly important	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 5.9J-**Concurrent engineering**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	3	21.4	21.4	21.4
	Very important	9	64.3	64.3	85.7
	Highly important	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.9K-**Group technology**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	6	42.9	42.9	42.9
	Highly important	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 5.9L-**Planning and scheduling**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	14	100.0	100.0	100.0

Table 5.9M-**Quality circles**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	5	35.7	35.7	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 5.9N-**Continuous improvement**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	8	57.1	57.1	57.1
	Highly important	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 5.9O-**Process capability analysis**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	6	42.9	42.9	42.9
	Crucial	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 5.9P-**Pull system/Kanban**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	2	14.3	14.3	14.3
	Less important	3	21.4	21.4	35.7
	Very important	2	14.3	14.3	50.0
	Highly important	1	7.1	7.1	57.1
	Crucial	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 5.9Q-**Uniform workload**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	8	57.1	57.1	57.1
	Very important	2	14.3	14.3	71.4
	Highly important	1	7.1	7.1	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table5.9R-**Maintenance optimisation**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	4	28.6	28.6	28.6
	Very important	6	42.9	42.9	71.4
	Highly important	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 5.9S-**Preventive maintenance**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	4	28.6	28.6	28.6
	Less important	8	57.1	57.1	85.7
	Very important	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 5.9T-**Multifunction employees**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	5	35.7	35.7	35.7
	Less important	6	42.9	42.9	78.6
	Very important	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 5.9U-**Self-directed work teams**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	1	7.1	7.1	7.1
	Very important	1	7.1	7.1	14.3
	Highly important	10	71.4	71.4	85.7
	Crucial	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

AGILE PRACTICES

Table 6.0A-**Research & Development for NPD**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	36.4	36.4
	Growth	5	35.7	45.5	81.8
	Decline	2	14.3	18.2	100.0
	Total	11	78.6	100.0	
Missing	System	3	21.4		
Total		14	100.0		

Table 6.0B-**Rapid reconfiguration**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	7	50.0	50.0	50.0
	Growth	4	28.6	28.6	78.6
	Maturity	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.0C-**Mix/model flexibility**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	46.2	46.2
	Growth	6	42.9	46.2	92.3
	Maturity	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 6.0D-**Flexible production line**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	23.1	23.1
	Growth	7	50.0	53.8	76.9
	Maturity	1	7.1	7.7	84.6
	Decline	2	14.3	15.4	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 6.0E-**Flexible employees**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	5	35.7	35.7	35.7
	Growth	5	35.7	35.7	71.4
	Maturity	1	7.1	7.1	78.6
	Decline	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.0F-**Virtual organisation**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	25.0	25.0
	Growth	8	57.1	66.7	91.7
	Decline	1	7.1	8.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 6.0G-**Strategic postponement**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	46.2	46.2
	Growth	7	50.0	53.8	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 6.0H-**Temporary alliances**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	2	14.3	16.7	16.7
	Growth	9	64.3	75.0	91.7
	Maturity	1	7.1	8.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table6.0I-**Demand flexibility**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	10	71.4	71.4	71.4
	Growth	3	21.4	21.4	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.0J-**Large/small batches**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	9	64.3	69.2	69.2
	Growth	2	14.3	15.4	84.6
	Maturity	1	7.1	7.7	92.3
	Decline	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 6.0K-**Strategic outsourcing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	9	64.3	90.0	90.0
	Growth	1	7.1	10.0	100.0
	Total	10	71.4	100.0	
Missing	System	4	28.6		
Total		14	100.0		

Table 6.0L-**Innovation culture**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	10	71.4	83.3	83.3
	Growth	1	7.1	8.3	91.7
	Decline	1	7.1	8.3	100.0
	Total	12	85.7	100.0	
Missing	System	2	14.3		
Total		14	100.0		

Table 6.0M-**Process management**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	11	78.6	84.6	84.6
	Growth	1	7.1	7.7	92.3
	Maturity	1	7.1	7.7	100.0
	Total	13	92.9	100.0	
Missing	System	1	7.1		
Total		14	100.0		

Table 6.0N-**Internal communication**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	9	64.3	64.3	64.3
	Growth	2	14.3	14.3	78.6
	Maturity	1	7.1	7.1	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.0O-**Supplier partnership**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	2	14.3	14.3	14.3
	Growth	9	64.3	64.3	78.6
	Maturity	2	14.3	14.3	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.0P-**Partnership agreements**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	9	64.3	64.3	64.3
	Growth	3	21.4	21.4	85.7
	Maturity	1	7.1	7.1	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.0Q-**Storage facilities**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 6.0R-**Speed in NPD**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	10	71.4	71.4	71.4
	Growth	2	14.3	14.3	85.7
	Maturity	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.0S-**Quick decision**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	12	85.7	85.7	85.7
	Maturity	1	7.1	7.1	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.0T-**Information capture**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	11	78.6	78.6	100.0
	Total	14	100.0	100.0	

IMPORTANCE OF AGILE PRACTICES

Table 6.1A-**R & D for NPD**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	4	28.6	28.6	28.6
	Less important	5	35.7	35.7	64.3
	Very important	3	21.4	21.4	85.7
	Highly important	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.1 B-**Rapid reconfiguration**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	5	35.7	35.7	35.7
	Highly important	4	28.6	28.6	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.1C-**Mix/model flexibility**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	2	14.3	14.3	14.3
	Less important	2	14.3	14.3	28.6
	Very important	6	42.9	42.9	71.4
	Highly important	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.1D-**Flexible production line**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	3	21.4	21.4	21.4
	Less important	3	21.4	21.4	42.9
	Very important	3	21.4	21.4	64.3
	Highly important	2	14.3	14.3	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table6.1E-**Flexible employees**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	2	14.3	14.3	14.3
	Very important	6	42.9	42.9	57.1
	Highly important	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table6.1F-**Virtual organisation**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	3	21.4	21.4	21.4
	Highly important	6	42.9	42.9	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.1G-**Strategic postponement**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	5	35.7	35.7	35.7
	Highly important	8	57.1	57.1	92.9
	Crucial	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.1H-**Temporary alliances**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	3	21.4	21.4	21.4
	Less important	6	42.9	42.9	64.3
	Very important	4	28.6	28.6	92.9
	Highly important	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.1I-**Demand flexibility**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	10	71.4	71.4	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.1J-**Large/small batches**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	1	7.1	7.1	7.1
	Highly important	7	50.0	50.0	57.1
	Crucial	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 6.1K-**Strategic outsourcing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	1	7.1	7.1	7.1
	Highly important	10	71.4	71.4	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table6.1L-**Innovation culture**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	6	42.9	42.9	42.9
	Highly Important	4	28.6	28.6	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table6.1M-**Process management**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	8	57.1	57.1	57.1
	Highly important	3	21.4	21.4	78.6
	Crucial	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table6.1N-**Internal communication**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	10	71.4	71.4	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.1O**Supplier partnership**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	10	71.4	71.4	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.1P-**Information sharing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	4	28.6	28.6	28.6
	Less important	6	42.9	42.9	71.4
	Very important	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.1Q-**Partnership agreements**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	6	42.9	42.9	42.9
	Crucial	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 6.1R-**Storage facilities**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	5	35.7	35.7	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.1S-**Speed in NPD**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Crucial	14	100.0	100.0	100.0

Table6.1T-**Quick decision**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	1	7.1	7.1	7.1
	Highly important	6	42.9	42.9	50.0
	Crucial	7	50.0	50.0	100.0
	Total	14	100.0	100.0	

Table 6.1U-**Information capture**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	4	28.6	28.6	28.6
	Less important	5	35.7	35.7	64.3
	Very important	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

GREEN PRACTICES

Table 6.2A-**Site selection**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	28.6	28.6
	Growth	5	35.7	35.7	64.3
	Maturity	4	28.6	28.6	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2B-**Large doors/windows**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	11	78.6	78.6	100.0
	Total	14	100.0	100.0	

Table 6.2C-**Temperature control**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	1	7.1	7.1	7.1
	Growth	11	78.6	78.6	85.7
	Maturity	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2D-**Low energy lighting**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	7	50.0	50.0	50.0
	Growth	6	42.9	42.9	92.9
	Maturity	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2E-**Weather monitoring**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	9	64.3	64.3	64.3
	Growth	1	7.1	7.1	71.4
	Maturity	2	14.3	14.3	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2F-**Water reuse**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	5	35.7	35.7	35.7
	Growth	4	28.6	28.6	64.3
	Maturity	3	21.4	21.4	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2G-**Non-hazardous materials**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	7	50.0	50.0	92.9
	Maturity	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2H-**Supplier survey**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	5	35.7	35.7	35.7
	Growth	2	14.3	14.3	50.0
	Maturity	7	50.0	50.0	100.0
	Total	14	100.0	100.0	

Table 6.2I-**Outsourcing to 3PLs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	7	50.0	50.0	50.0
	Growth	4	28.6	28.6	78.6
	Maturity	2	14.3	14.3	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2J-**Supplier monitoring**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	8	57.1	57.1	57.1
	Growth	4	28.6	28.6	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2K-**Durable products**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	1	7.1	7.1	28.6
	Maturity	6	42.9	42.9	71.4
	Decline	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.2L-**Energy production**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	3	21.4	21.4	42.9
	Maturity	5	35.7	35.7	78.6
	Decline	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.2M-**Renewable energy**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	5	35.7	35.7	78.6
	Maturity	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.2N-**Use of alternative fuels**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	7	50.0	50.0	71.4
	Maturity	2	14.3	14.3	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2O-**Smaller packaging**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	4	28.6	28.6	71.4
	Maturity	3	21.4	21.4	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2P-**Use of less material**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	6	42.9	42.9	42.9
	Growth	5	35.7	35.7	78.6
	Maturity	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.2Q-**Waste processing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	1	7.1	7.1	7.1
	Growth	13	92.9	92.9	100.0
	Total	14	100.0	100.0	

Table 6.2R-**Product take-back**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	7	50.0	50.0	50.0
	Growth	5	35.7	35.7	85.7
	Maturity	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2S-**Recyclable materials**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Maturity	9	64.3	64.3	64.3
	Decline	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.2T-**Recycling programs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	28.6	28.6
	Growth	5	35.7	35.7	64.3
	Maturity	3	21.4	21.4	85.7
	Decline	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.2U-**Reusability**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	2	14.3	14.3	14.3
	Growth	4	28.6	28.6	42.9
	Maturity	4	28.6	28.6	71.4
	Decline	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.2V-**Use of PLC analysis**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	2	14.3	14.3	14.3
	Growth	2	14.3	14.3	28.6
	Maturity	6	42.9	42.9	71.4
	Decline	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.2W-**Environmental lab**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	4	28.6	28.6	28.6
	Growth	6	42.9	42.9	71.4
	Maturity	3	21.4	21.4	92.9
	Decline	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.2X-**Supporting green efforts**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Growth	2	14.3	14.3	14.3
	Maturity	6	42.9	42.9	57.1
	Decline	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 6.2Y-**Employee training**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	3	21.4	21.4	21.4
	Growth	2	14.3	14.3	35.7
	Maturity	3	21.4	21.4	57.1
	Decline	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

IMPORTANCE OF GREEN PRACTICES

Table 6.3A-**Site selection**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	9	64.3	64.3	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.3B-**Large doors/windows**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	2	14.3	14.3	14.3
	Very important	3	21.4	21.4	35.7
	Highly important	8	57.1	57.1	92.9
	Crucial	1	7.1	7.1	100.0
	Total	14	100.0	100.0	

Table 6.3C-**Temperature control**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	8	57.1	57.1	85.7
	Crucial	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.3D-**Low energy lighting**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	9	64.3	64.3	64.3
	Less important	2	14.3	14.3	78.6
	Very important	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.3E-**Weather monitoring**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	3	21.4	21.4	21.4
	Crucial	11	78.6	78.6	100.0
	Total	14	100.0	100.0	

Table 6.3F-**Water reuse**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	1	7.1	7.1	7.1
	Less important	2	14.3	14.3	21.4
	Very important	3	21.4	21.4	42.9
	Highly important	4	28.6	28.6	71.4
	Crucial	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.3G-**Non-hazardous materials**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	2	14.3	14.3	14.3
	Highly important	4	28.6	28.6	42.9
	Crucial	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 6.3H-**Supplier survey**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	12	85.7	85.7	85.7
	Crucial	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.3I-**Outsourcing to 3PLs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	8	57.1	57.1	57.1
	Crucial	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 6.3J-**Supplier monitoring**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	3	21.4	21.4	21.4
	Less important	6	42.9	42.9	64.3
	Very important	3	21.4	21.4	85.7
	Highly important	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.3K-**Durable products**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	2	14.3	14.3	14.3
	Highly important	7	50.0	50.0	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.3L-**Energy production**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	2	14.3	14.3	14.3
	Highly important	7	50.0	50.0	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.3M-**Renewable energy**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	4	28.6	28.6	28.6
	Very important	6	42.9	42.9	71.4
	Highly important	4	28.6	28.6	100.0
	Total	14	100.0	100.0	

Table 6.3N-**Use of alternative fuels**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	4	28.6	28.6	28.6
	Very important	7	50.0	50.0	78.6
	Highly important	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.3O-**Smaller packaging**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	1	7.1	7.1	7.1
	Less important	7	50.0	50.0	57.1
	very important	4	28.6	28.6	85.7
	Highly important	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

Table 6.3P-**Use of less material**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	4	28.6	28.6	28.6
	Very important	10	71.4	71.4	100.0
	Total	14	100.0	100.0	

Table 6.3Q-**Waste processing**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	10	71.4	71.4	100.0
	Total	14	100.0	100.0	

Table 6.3R-**Product take-back**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	4	28.6	28.6	28.6
	Less important	5	35.7	35.7	64.3
	Very important	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.3S-**Recyclable materials**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very important	4	28.6	28.6	28.6
	Highly important	5	35.7	35.7	64.3
	Crucial	5	35.7	35.7	100.0
	Total	14	100.0	100.0	

Table 6.3T-**Recycling programs**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	6	42.9	42.9	42.9
	Crucial	8	57.1	57.1	100.0
	Total	14	100.0	100.0	

Table 6.3U-**Reusability**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	14	100.0	100.0	100.0

Table 6.3V-**Use of PLC analysis**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Highly important	4	28.6	28.6	28.6
	Crucial	10	71.4	71.4	100.0
	Total	14	100.0	100.0	

Table 6.3W-**Environmental lab**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less important	3	21.4	21.4	21.4
	Very important	3	21.4	21.4	42.9
	Highly important	2	14.3	14.3	57.1
	Crucial	6	42.9	42.9	100.0
	Total	14	100.0	100.0	

Table 6.3X-**Supporting green efforts**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	11	78.6	78.6	78.6
	Less important	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.3Y-**Employee training**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	8	57.1	57.1	57.1
	Less important	3	21.4	21.4	78.6
	Very important	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.4-**This company has adequate coordination for lean, agile and green practices in its manufacturing/management processes**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	4	28.6	28.6	28.6
	Disagree	1	7.1	7.1	35.7
	Neither agree or disagree	6	42.9	42.9	78.6
	Agree	3	21.4	21.4	100.0
	Total	14	100.0	100.0	

Table 6.5-**This company has considered the product life cycle in the adoption of lean, agile and green practices**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	2	14.3	14.3	14.3
	Disagree	3	21.4	21.4	35.7
	Neither agree or disagree	3	21.4	21.4	57.1
	Agree	4	28.6	28.6	85.7
	Strongly agree	2	14.3	14.3	100.0
	Total	14	100.0	100.0	

APPENDIX TEN
FREQUENCY TABLES FOR MAIN SURVEY

Level of awareness; Lean

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	52	54.2	54.2	54.2
	Very aware	37	38.5	38.5	92.7
	Moderately aware	2	2.1	2.1	94.8
	Slightly aware	5	5.2	5.2	100.0
	Total	96	100.0	100.0	

Level of awareness; Agility

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	4	4.2	4.2	4.2
	Very aware	19	19.8	19.8	24.0
	Moderately aware	33	34.4	34.4	58.3
	Slightly aware	20	20.8	20.8	79.2
	Not aware	20	20.8	20.8	100.0
	Total	96	100.0	100.0	

Level of awareness; Green

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	5	5.2	5.4	5.4
	Very aware	8	8.3	8.6	14.0
	Moderately aware	47	49.0	50.5	64.5
	Slightly aware	20	20.8	21.5	86.0
	Not aware	13	13.5	14.0	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Scale rating for Lean adoption; Minimise cost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	51	53.1	53.7	53.7
	Low	29	30.2	30.5	84.2
	Neutral	4	4.2	4.2	88.4
	High	7	7.3	7.4	95.8
	Very high	4	4.2	4.2	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Scale rating for Lean adoption: Reduce lead time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	8	8.3	8.5	8.5
	Low	31	32.3	33.0	41.5
	Neutral	20	20.8	21.3	62.8
	High	23	24.0	24.5	87.2
	Very high	12	12.5	12.8	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Lean adoption; Improve operations

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	67	69.8	69.8	69.8
	Low	23	24.0	24.0	93.8
	Neutral	2	2.1	2.1	95.8
	High	3	3.1	3.1	99.0
	Very high	1	1.0	1.0	100.0
	Total	96	100.0	100.0	

Scale rating for Lean adoption: Improve environmental performance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	49	51.0	51.0	51.0
	Low	35	36.5	36.5	87.5
	Neutral	3	3.1	3.1	90.6
	High	9	9.4	9.4	100.0
	Total	96	100.0	100.0	

Scale rating for Lean adoption: Coordinate processes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	8	8.3	8.3	8.3
	Low	23	24.0	24.0	32.3
	Neutral	36	37.5	37.5	69.8
	High	11	11.5	11.5	81.2
	Very high	18	18.8	18.8	100.0
	Total	96	100.0	100.0	

Scale rating for Lean adoption; Increase market share

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	10	10.4	10.6	10.6
	Low	19	19.8	20.2	30.9
	Neutral	33	34.4	35.1	66.0
	High	11	11.5	11.7	77.7
	Very high	21	21.9	22.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Lean adoption; Improve customer satisfaction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	58	60.4	61.1	61.1
	Low	27	28.1	28.4	89.5
	Neutral	4	4.2	4.2	93.7
	High	4	4.2	4.2	97.9
	Very high	2	2.1	2.1	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Scale rating for Lean adoption: Others

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	6	6.2	6.4	6.4
	Low	33	34.4	35.1	41.5
	Neutral	22	22.9	23.4	64.9
	High	28	29.2	29.8	94.7
	Very high	5	5.2	5.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Agile adoption: Minimise cost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	76	79.2	79.2	79.2
	Low	11	11.5	11.5	90.6
	Neutral	3	3.1	3.1	93.8
	High	4	4.2	4.2	97.9
	Very high	2	2.1	2.1	100.0
	Total	96	100.0	100.0	

Scale rating for Agile adoption: Reduce lead time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	42	43.8	43.8	43.8
	Low	34	35.4	35.4	79.2
	Neutral	2	2.1	2.1	81.2
	High	9	9.4	9.4	90.6
	Very high	9	9.4	9.4	100.0
	Total	96	100.0	100.0	

Scale rating for Agile adoption: Improve operations

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	3	3.1	3.2	3.2
	Low	18	18.8	19.1	22.3
	Neutral	28	29.2	29.8	52.1
	High	20	20.8	21.3	73.4
	Very high	25	26.0	26.6	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Agile adoption: Improve environmental performance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	5	5.2	5.4	5.4
	Low	7	7.3	7.6	13.0
	Neutral	40	41.7	43.5	56.5
	High	21	21.9	22.8	79.3
	Very high	19	19.8	20.7	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Scale rating for Agile adoption: Coordinate processes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	42	43.8	45.2	45.2
	Low	26	27.1	28.0	73.1
	Neutral	4	4.2	4.3	77.4
	High	9	9.4	9.7	87.1
	Very high	12	12.5	12.9	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Scale rating for Agile adoption: Increase market share

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	8	8.3	8.6	8.6
	Low	25	26.0	26.9	35.5
	Neutral	18	18.8	19.4	54.8
	High	29	30.2	31.2	86.0
	Very high	13	13.5	14.0	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Scale rating for Agile adoption; Improve customer satisfaction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	56	58.3	59.6	59.6
	Low	21	21.9	22.3	81.9
	Neutral	8	8.3	8.5	90.4
	High	8	8.3	8.5	98.9
	Very high	1	1.0	1.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Agile adoption; Others

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	45	46.9	47.4	47.4
	Low	35	36.5	36.8	84.2
	Neutral	6	6.2	6.3	90.5
	High	9	9.4	9.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Scale rating for Green adoption: Minimise cost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	1	1.0	1.1	1.1
	Low	16	16.7	16.8	17.9
	Neutral	36	37.5	37.9	55.8
	High	19	19.8	20.0	75.8
	Very high	23	24.0	24.2	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Scale rating for Green adoption: Reduce lead time

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	5	5.2	5.3	5.3
	Low	12	12.5	12.8	18.1
	Neutral	38	39.6	40.4	58.5
	High	18	18.8	19.1	77.7
	Very high	21	21.9	22.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Green adoption: Improve operations

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	54	56.2	57.4	57.4
	Low	22	22.9	23.4	80.9
	Neutral	6	6.2	6.4	87.2
	High	6	6.2	6.4	93.6
	Very high	6	6.2	6.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Green adoption: Improve environmental performance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	3	3.1	3.2	3.2
	Low	32	33.3	33.7	36.8
	Neutral	23	24.0	24.2	61.1
	High	28	29.2	29.5	90.5
	Very high	9	9.4	9.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Scale rating for Green adoption: Coordinate processes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	71	74.0	74.0	74.0
	Low	6	6.2	6.2	80.2
	Neutral	4	4.2	4.2	84.4
	High	9	9.4	9.4	93.8
	Very high	6	6.2	6.2	100.0
	Total	96	100.0	100.0	

Scale rating for Green adoption: Increase market share

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	8	8.3	8.5	8.5
	Low	17	17.7	18.1	26.6
	Neutral	34	35.4	36.2	62.8
	High	17	17.7	18.1	80.9
	Very high	18	18.8	19.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Scale rating for Green adoption: Improve customer satisfaction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	53	55.2	57.0	57.0
	Low	28	29.2	30.1	87.1
	Neutral	8	8.3	8.6	95.7
	High	3	3.1	3.2	98.9
	Very high	1	1.0	1.1	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Scale rating for Green adoption; Others

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very low	5	5.2	5.3	5.3
	Low	29	30.2	30.5	35.8
	Neutral	20	20.8	21.1	56.8
	High	33	34.4	34.7	91.6
	Very high	8	8.3	8.4	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

PLC Level of Awareness

Please indicate your awareness of the product life cycle (PLC) concept

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Expert	72	75.0	75.0	75.0
	Very aware	12	12.5	12.5	87.5
	Moderately aware	5	5.2	5.2	92.7
	Slightly aware	4	4.2	4.2	96.9
	Not aware	3	3.1	3.1	100.0
	Total	96	100.0	100.0	

Lean practices per PLC stage

Time based competition (JIT)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	12	12.5	12.8	12.8
	Growth	29	30.2	30.9	43.6
	Maturity	8	8.3	8.5	52.1
	Decline	45	46.9	47.9	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Cycle time reduction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	42	43.8	45.2	45.2
	Growth	25	26.0	26.9	72.0
	Maturity	13	13.5	14.0	86.0
	Decline	13	13.5	14.0	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Set up time reduction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	11	11.5	11.7	11.7
	Growth	25	26.0	26.6	38.3
	Maturity	16	16.7	17.0	55.3
	Decline	42	43.8	44.7	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Cellular manufacturing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	43	44.8	45.7	45.7
	Growth	24	25.0	25.5	71.3
	Maturity	14	14.6	14.9	86.2
	Decline	13	13.5	13.8	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Bottle-neck removal

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	14	14.6	15.6	15.6
	Growth	25	26.0	27.8	43.3
	Maturity	15	15.6	16.7	60.0
	Decline	36	37.5	40.0	100.0
	Total	90	93.8	100.0	
Missing	System	6	6.2		
Total		96	100.0		

Focused factory

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	44	45.8	50.6	50.6
	Growth	20	20.8	23.0	73.6
	Maturity	14	14.6	16.1	89.7
	Decline	9	9.4	10.3	100.0
	Total	87	90.6	100.0	
Missing	System	9	9.4		
Total		96	100.0		

Planning and scheduling

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	18	18.8	18.8	18.8
	Growth	26	27.1	27.1	45.8
	Maturity	10	10.4	10.4	56.2
	Decline	42	43.8	43.8	100.0
	Total	96	100.0	100.0	

Total quality control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	48	50.0	53.9	53.9
	Growth	21	21.9	23.6	77.5
	Maturity	4	4.2	4.5	82.0
	Decline	16	16.7	18.0	100.0
	Total	89	92.7	100.0	
Missing	System	7	7.3		
Total		96	100.0		

Quality circles

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	40	41.7	41.7	41.7
	Growth	21	21.9	21.9	63.5
	Maturity	34	35.4	35.4	99.0
	Decline	1	1.0	1.0	100.0
	Total	96	100.0	100.0	

Continuous improvement

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	13	13.5	13.8	13.8
	Growth	17	17.7	18.1	31.9
	Maturity	23	24.0	22.4	54.3
	Decline	43	44.8	45.7	100.0
	Total	96	100.0	100.0	
Total		96	100.0		

Pull system/Kanban

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.1	1.1
	Introduction	4	4.2	4.2	5.3
	Growth	6	6.2	6.3	11.6
	Maturity	10	10.4	10.5	22.1
	Decline	74	77.1	77.9	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Preventive maintenance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	14	14.6	15.1	15.1
	Growth	10	10.4	10.8	25.8
	Maturity	41	42.7	44.1	69.9
	Decline	28	29.2	30.1	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Self-directed work teams

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	38	39.6	39.6	39.6
	Growth	35	36.5	36.5	76.0
	Maturity	18	18.8	18.8	94.8
	Decline	5	5.2	5.2	100.0
	Total	96	100.0	100.0	

Importance of Lean practices

Time based competition (JIT)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	25	26.0	26.0	26.0
	Less important	22	22.9	22.9	49.0
	Very important	34	35.4	35.4	84.4
	Highly important	8	8.3	8.3	92.7
	Crucial	7	7.3	7.3	100.0
	Total	96	100.0	100.0	

Cycle time reduction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	13	13.5	13.5	13.5
	Less Important	13	13.5	13.5	27.1
	Very important	17	17.7	17.7	44.8
	Highly important	46	47.9	47.9	92.7
	Crucial	7	7.3	7.3	100.0
	Total	96	100.0	100.0	

Set up time reduction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.0	1.0
	Less important	3	3.1	3.1	4.2
	Very important	10	10.4	10.4	14.6
	Highly important	72	75.0	75.0	89.6
	Crucial	10	10.4	10.4	100.0
	Total	96	100.0	100.0	

Cellular manufacturing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	13	13.5	13.5	13.5
	Less important	7	7.3	7.3	20.8
	Very important	39	40.6	40.6	61.5
	Highly important	27	28.1	28.1	89.6
	Crucial	10	10.4	10.4	100.0
	Total	96	100.0	100.0	

Bottle-neck removal

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	32	33.3	33.3	33.3
	Less important	31	32.3	32.3	65.6
	Very important	20	20.8	20.8	86.5
	Highly important	4	4.2	4.2	90.6
	Crucial	9	9.4	9.4	100.0
	Total	96	100.0	100.0	

Focused factory

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	26	27.1	27.1	27.1
	Less important	23	24.0	24.0	51.0
	Very important	36	37.5	37.5	88.5
	Highly important	5	5.2	5.2	93.8
	Crucial	6	6.2	6.2	100.0
	Total	96	100.0	100.0	

Planning and scheduling

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	23	24.0	24.2	24.2
	Less important	48	50.0	50.5	74.7
	Very important	17	17.7	17.9	92.6
	Crucial	7	7.3	7.4	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Total quality control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	29	30.2	30.5	30.5
	Less important	30	31.2	31.6	62.1
	Very important	18	18.8	18.9	81.1
	Highly important	9	9.4	9.5	90.5
	Crucial	9	9.4	9.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Quality circles

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	18	18.8	18.9	18.9
	Less important	13	13.5	13.7	32.6
	Very important	14	14.6	14.7	47.4
	Highly important	40	41.7	42.1	89.5
	Crucial	10	10.4	10.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Continuous improvement

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	31	32.3	32.6	32.6
	Less important	22	22.9	23.2	55.8
	Very important	28	29.2	29.5	85.3
	Highly important	7	7.3	7.4	92.6
	Crucial	7	7.3	7.4	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Pull system/Kanban

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	34	35.4	35.8	35.8
	Less important	31	32.3	32.6	68.4
	Very important	17	17.7	17.9	86.3
	Highly important	3	3.1	3.2	89.5
	Crucial	10	10.4	10.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Preventive maintenance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	34	35.4	35.8	35.8
	Less important	20	20.8	21.1	56.8
	Very important	32	33.3	33.7	90.5
	Highly important	3	3.1	3.2	93.7
	Crucial	6	6.2	6.3	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Self-directed work teams

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	24	25.0	25.0	25.0
	Less important	17	17.7	17.7	42.7
	Very important	37	38.5	38.5	81.2
	Highly important	9	9.4	9.4	90.6
	Crucial	9	9.4	9.4	100.0
	Total	96	100.0	100.0	

Agile practices per PLC stage

Research for new product

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	14	14.6	14.7	14.7
	Growth	13	13.5	13.7	28.4
	Maturity	14	14.6	14.7	43.2
	Decline	54	56.2	56.8	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Rapid reconfiguration

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	31	32.3	33.0	33.0
	Growth	25	26.0	26.6	59.6
	Maturity	32	33.3	34.0	93.6
	Decline	6	6.2	6.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Virtual organisation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	10	10.4	10.9	10.9
	Growth	12	12.5	13.0	23.9
	Maturity	10	10.4	10.9	34.8
	Decline	60	62.5	65.2	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Strategic postponement

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	24	25.0	25.8	25.8
	Growth	16	16.7	17.2	43.0
	Maturity	41	42.7	44.1	87.1
	Decline	12	12.5	12.9	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Demand flexibility

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	36	37.5	38.3	38.3
	Growth	37	38.5	39.4	77.7
	Maturity	17	17.7	18.1	95.7
	Decline	4	4.2	4.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Large/small batches

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	44	45.8	46.3	46.3
	Growth	25	26.0	26.3	72.6
	Maturity	22	22.9	23.2	95.8
	Decline	3	3.1	3.2	98.9
	5	1	1.0	1.1	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Strategic outsourcing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	36	37.5	39.1	39.1
	Growth	42	43.8	45.7	84.8
	Maturity	12	12.5	13.0	97.8
	Decline	2	2.1	2.2	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Innovation culture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	43	44.8	45.7	45.7
	Growth	31	32.3	33.0	78.7
	Maturity	12	12.5	12.8	91.5
	Decline	7	7.3	7.4	98.9
	5	1	1.0	1.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Internal communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	20	20.8	21.1	21.1
	Growth	17	17.7	17.9	38.9
	Maturity	6	6.2	6.3	45.3
	Decline	51	53.1	53.7	98.9
	5	1	1.0	1.1	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Supplier partnership

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	40	41.7	43.0	43.0
	Growth	36	37.5	38.7	81.7
	Maturity	13	13.5	14.0	95.7
	Decline	4	4.2	4.3	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Storage facilities

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	41	42.7	43.6	43.6
	Growth	34	35.4	36.2	79.8
	Maturity	19	19.8	20.2	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Speed in NPD

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	45	46.9	47.4	47.4
	Growth	16	16.7	16.8	64.2
	Maturity	33	34.4	34.7	98.9
	Decline	1	1.0	1.1	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Quick decision

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	20	20.8	20.8	20.8
	Growth	23	24.0	24.0	44.8
	Maturity	32	33.3	33.3	78.1
	Decline	21	21.9	21.9	100.0
	Total	96	100.0	100.0	

Information capture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	25	26.0	26.6	26.6
	Growth	20	20.8	21.3	47.9
	Maturity	11	11.5	11.7	59.6
	Decline	38	39.6	40.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Importance of agile practices

Research for new product

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	35	36.5	36.5	36.5
	Less important	30	31.2	31.2	67.7
	Very important	14	14.6	14.6	82.3
	Highly important	12	12.5	12.5	94.8
	Crucial	5	5.2	5.2	100.0
	Total	96	100.0	100.0	

Rapid reconfiguration

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	31	32.3	32.6	32.6
	Less important	23	24.0	24.2	56.8
	Very important	17	17.7	17.9	74.7
	Highly important	13	13.5	13.7	88.4
	Crucial	11	11.5	11.6	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Virtual organisation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	17	17.7	17.7	17.7
	Less important	20	20.8	20.8	38.5
	Very important	24	25.0	25.0	63.5
	Highly important	20	20.8	20.8	84.4
	Crucial	15	15.6	15.6	100.0
	Total	96	100.0	100.0	

Strategic postponement

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	22	22.9	23.2	23.2
	Less important	27	28.1	28.4	51.6
	Very important	29	30.2	30.5	82.1
	Highly important	13	13.5	13.7	95.8
	Crucial	4	4.2	4.2	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Demand flexibility

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	18	18.8	19.4	19.4
	Less important	23	24.0	24.7	44.1
	very important	20	20.8	21.5	65.6
	Highly important	24	25.0	25.8	91.4
	Crucial	8	8.3	8.6	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Large/small batches

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	6	6.2	6.3	6.3
	Less important	12	12.5	12.6	18.9
	Very important	17	17.7	17.9	36.8
	Highly important	27	28.1	28.4	65.3
	Crucial	33	34.4	34.7	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Strategic outsourcing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	29	30.2	30.2	30.2
	Less important	20	20.8	20.8	51.0
	Very important	22	22.9	22.9	74.0
	Highly important	15	15.6	15.6	89.6
	Crucial	10	10.4	10.4	100.0
	Total	96	100.0	100.0	

Innovation culture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	24	25.0	25.3	25.3
	Less imporatant	27	28.1	28.4	53.7
	Very important	24	25.0	25.3	78.9
	Highly Important	13	13.5	13.7	92.6
	Crucial	7	7.3	7.4	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Internal communication

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	19	19.8	20.2	20.2
	Less important	34	35.4	36.2	56.4
	Very important	21	21.9	22.3	78.7
	Highly important	14	14.6	14.9	93.6
	Crucial	6	6.2	6.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Supplier partnership

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	34	35.4	37.0	37.0
	Less important	25	26.0	27.2	64.1
	Very important	19	19.8	20.7	84.8
	Highly important	6	6.2	6.5	91.3
	Crucial	8	8.3	8.7	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Storage facilities

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	30	31.2	31.6	31.6
	Less important	25	26.0	26.3	57.9
	Very important	18	18.8	18.9	76.8
	Highly important	12	12.5	12.6	89.5
	Crucial	10	10.4	10.5	100.0
	Total	95	99.0	100.0	
Missing	System	1	1.0		
Total		96	100.0		

Speed in NPD

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	18	18.8	18.8	18.8
	Less important	15	15.6	15.6	34.4
	Very important	23	24.0	24.0	58.3
	Highly important	9	9.4	9.4	67.7
	Crucial	31	32.3	32.3	100.0
	Total	96	100.0	100.0	

Quick decision

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	14	14.6	14.9	14.9
	Less important	30	31.2	31.9	46.8
	Very important	22	22.9	23.4	70.2
	Highly important	14	14.6	14.9	85.1
	Crucial	14	14.6	14.9	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Information capture

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	21	21.9	22.8	22.8
	Less important	27	28.1	29.3	52.2
	Very important	27	28.1	29.3	81.5
	Highly important	8	8.3	8.7	90.2
	Crucial	9	9.4	9.8	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Green practices per PLC stage

Site selection

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	34	35.4	37.0	37.0
	Growth	18	18.8	19.6	56.5
	Maturity	34	35.4	37.0	93.5
	Decline	5	5.2	5.4	98.9
	10	1	1.0	1.1	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Large doors/windows

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	22	22.9	23.9	23.9
	Growth	27	28.1	29.3	53.3
	Maturity	21	21.9	22.8	76.1
	Decline	22	22.9	23.9	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Temperature control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.1	1.1
	Introduction	2	2.1	2.2	3.2
	Growth	14	14.6	15.1	18.3
	Maturity	14	14.6	15.1	33.3
	Decline	61	63.5	65.6	98.9
	5	1	1.0	1.1	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Non hazardous materials

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.1	1.1
	Introduction	17	17.7	18.5	19.6
	Growth	13	13.5	14.1	33.7
	Maturity	44	45.8	47.8	81.5
	Decline	17	17.7	18.5	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Supplier survey

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	28	29.2	30.4	30.4
	Growth	33	34.4	35.9	66.3
	Maturity	29	30.2	31.5	97.8
	Decline	2	2.1	2.2	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Outsourcing to 3PLs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	30	31.2	31.9	31.9
	Growth	28	29.2	29.8	61.7
	Maturity	33	34.4	35.1	96.8
	Decline	2	2.1	2.1	98.9
	5	1	1.0	1.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Durable products

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	27	28.1	28.7	28.7
	Growth	49	51.0	52.1	80.9
	Maturity	13	13.5	13.8	94.7
	Decline	5	5.2	5.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Smaller packaging

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	29	30.2	30.9	30.9
	Growth	35	36.5	37.2	68.1
	Maturity	22	22.9	23.4	91.5
	Decline	7	7.3	7.4	98.9
	5	1	1.0	1.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Use of less material

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	17	17.7	18.5	18.5
	Growth	21	21.9	22.8	41.3
	Maturity	11	11.5	12.0	53.3
	Decline	42	43.8	45.7	98.9
	5	1	1.0	1.1	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Waste processing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	33	34.4	36.7	36.7
	Growth	41	42.7	45.6	82.2
	Maturity	12	12.5	13.3	95.6
	Decline	4	4.2	4.4	100.0
	Total	90	93.8	100.0	
Missing	System	6	6.2		
Total		96	100.0		

Use of less material

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	17	17.7	18.5	18.5
	Growth	21	21.9	22.8	41.3
	Maturity	11	11.5	12.0	53.3
	Decline	42	43.8	45.7	98.9
	5	1	1.0	1.1	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Recyclable materials

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	30	31.2	33.0	33.0
	Growth	32	33.3	35.2	68.1
	Maturity	23	24.0	25.3	93.4
	Decline	6	6.2	6.6	100.0
	Total	91	94.8	100.0	
Missing	System	5	5.2		
Total		96	100.0		

Recycling programs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	38	39.6	40.9	40.9
	Growth	25	26.0	26.9	67.7
	Maturity	25	26.0	26.9	94.6
	Decline	5	5.2	5.4	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Use of PLC analysis

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	19	19.8	20.2	20.2
	Growth	21	21.9	22.3	42.6
	Maturity	34	35.4	36.2	78.7
	Decline	20	20.8	21.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Environmental lab

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Introduction	22	22.9	23.7	23.7
	Growth	18	18.8	19.4	43.0
	Maturity	17	17.7	18.3	61.3
	Decline	36	37.5	38.7	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Importance of green practices

Site selection

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	26	27.1	28.3	28.3
	Less important	11	11.5	12.0	40.2
	Very important	27	28.1	29.3	69.6
	Highly important	11	11.5	12.0	81.5
	Crucial	16	16.7	17.4	98.9
	10	1	1.0	1.1	100.0
	Total	92	95.8	100.0	
Missing	System	4	4.2		
Total		96	100.0		

Large doors/windows

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	18	18.8	19.4	19.4
	Less important	18	18.8	19.4	38.7
	Very important	24	25.0	25.8	64.5
	Highly important	30	31.2	32.3	96.8
	Crucial	3	3.1	3.2	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Temperature control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.1	1.1
	Not important at all	1	1.0	1.1	2.1
	Less important	1	1.0	1.1	3.2
	Very important	31	32.3	33.0	36.2
	Highly important	46	47.9	48.9	85.1
	Crucial	14	14.6	14.9	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Non hazardous materials

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	1.0	1.1	1.1
	Not important at all	9	9.4	9.6	10.6
	Less important	5	5.2	5.3	16.0
	Very important	42	43.8	44.7	60.6
	Highly important	20	20.8	21.3	81.9
	Crucial	17	17.7	18.1	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Supplier survey

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	19	19.8	20.4	20.4
	Less important	27	28.1	29.0	49.5
	Very important	18	18.8	19.4	68.8
	Highly important	13	13.5	14.0	82.8
	Crucial	16	16.7	17.2	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Outsourcing to 3PLs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	21	21.9	22.3	22.3
	Less important	16	16.7	17.0	39.4
	Very important	27	28.1	28.7	68.1
	Highly important	9	9.4	9.6	77.7
	Crucial	21	21.9	22.3	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Durable products

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	21	21.9	22.3	22.3
	Less important	34	35.4	36.2	58.5
	Very important	6	6.2	6.4	64.9
	Highly important	7	7.3	7.4	72.3
	Crucial	26	27.1	27.7	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Smaller packaging

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	22	22.9	23.4	23.4
	Less important	35	36.5	37.2	60.6
	very important	22	22.9	23.4	84.0
	Highly important	8	8.3	8.5	92.6
	Crucial	7	7.3	7.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Use of less material

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	11	11.5	11.8	11.8
	Less important	18	18.8	19.4	31.2
	Very important	17	17.7	18.3	49.5
	Highly important	31	32.3	33.3	82.8
	Crucial	16	16.7	17.2	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Waste processing

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	17	17.7	18.7	18.7
	Less important	18	18.8	19.8	38.5
	Very important	14	14.6	15.4	53.8
	Highly important	13	13.5	14.3	68.1
	Crucial	29	30.2	31.9	100.0
	Total	91	94.8	100.0	
Missing	System	5	5.2		
Total		96	100.0		

Recyclable materials

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	21	21.9	23.1	23.1
	Less important	23	24.0	25.3	48.4
	Very important	17	17.7	18.7	67.0
	Highly important	12	12.5	13.2	80.2
	Crucial	18	18.8	19.8	100.0
	Total	91	94.8	100.0	
Missing	System	5	5.2		
Total		96	100.0		

Recycling programs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	33	34.4	35.5	35.5
	Less important	20	20.8	21.5	57.0
	Very important	22	22.9	23.7	80.6
	Highly important	9	9.4	9.7	90.3
	Crucial	9	9.4	9.7	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

Use of PLC analysis

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	12	12.5	12.8	12.8
	Less important	15	15.6	16.0	28.7
	Very important	24	25.0	25.5	54.3
	Highly important	20	20.8	21.3	75.5
	Crucial	23	24.0	24.5	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

Environmental lab

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not important at all	8	8.3	8.5	8.5
	Less important	4	4.2	4.3	12.8
	Very important	11	11.5	11.7	24.5
	Highly important	27	28.1	28.7	53.2
	Crucial	44	45.8	46.8	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

The product life cycle concept should be considered in the development of lean, agile and green manufacturing/management strategies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	17	17.7	17.7	17.7
	Disagree	20	20.8	20.8	38.5
	Neither agree or disagree	27	28.1	28.1	66.7
	Agree	15	15.6	15.6	82.3
	Strongly agree	17	17.7	17.7	100.0
	Total	96	100.0	100.0	

My company has adequate coordination for lean, agile and green practices in its manufacturing/management processes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	22	22.9	23.4	23.4
	Disagree	30	31.2	31.9	55.3
	Neither agree or disagree	25	26.0	26.6	81.9
	Agree	11	11.5	11.7	93.6
	Strongly agree	6	6.2	6.4	100.0
	Total	94	97.9	100.0	
Missing	System	2	2.1		
Total		96	100.0		

My company has considered the product life cycle in the adoption of lean, agile and green practices

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly disagree	17	17.7	18.3	18.3
	Disagree	26	27.1	28.0	46.2
	Neither agree or disagree	27	28.1	29.0	75.3
	Agree	12	12.5	12.9	88.2
	Strongly agree	11	11.5	11.8	100.0
	Total	93	96.9	100.0	
Missing	System	3	3.1		
Total		96	100.0		

APPENDIX ELEVEN

TESTS OF HYPOTHESES

TESTING HYPOTHESIS ON A SINGLE POPULATION PROPORTION

To test hypothesis on a single population proportion

$$H_0 : P = P_0$$
$$H_1 : P < P_0$$

On a single population, where P is the hypothesised value of P_0, the test statistic is

$$Z_0 \approx N(0,1)$$

$$Z_0 = \frac{\hat{P} - P_0}{\sqrt{v\hat{a}r(\hat{P})}}$$

We estimate P by

$$\hat{P}_{sh} = \frac{n'}{n}$$

Where n' = respondents who use motor vehicles

$n =$ total number of respondents

$\hat{p} =$ proportion of those who use motor vehicles

$q = 1 - p =$ proportion of those who do not use motor vehicles

$$\hat{V}(\hat{p}) = (1-f)\frac{\hat{p}\hat{q}}{n-1}$$

$$f = \frac{n}{N}$$

Where $N =$ population size, and $n =$ sample size.

Cost Reduction (Lean practices)

Table 7.0-**Descriptive Statistics**

	Mean	Std. Deviation	N
Scale rating for Lean adoption: Minimise cost	1.69	1.037	64
LEAN PRACTICES: Time based competition	2.91	1.109	64
Cycle time reduction	2.02	1.148	64
Set up time reduction	2.97	1.112	64
Cellular manufacturing	1.98	1.134	64
Bottle-neck removal	2.98	1.161	64
Focused factory	1.78	1.046	64
Planning and scheduling	2.67	1.248	64
Total quality control	1.95	1.147	64
Quality circles	1.91	.904	64
Continuous improvement	3.05	1.075	64
Pull system/Kanban	3.66	.761	64
Preventive maintenance	2.89	.994	64
Self-directed work teams	1.92	.914	64

Table 7.1- **Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.496[a]	.246	.050	1.011

a. Predictors: (Constant), Self-directed work teams, Pull system/Kanban, Quality circles, Total quality control, Bottle-neck removal, LEAN PRACTICES: Time based competition, Cycle time reduction, Set up time reduction, Planning and scheduling, Focused factory, Continuous improvement, Cellular manufacturing, Preventive maintenance

b. Dependent Variable: Scale rating for Lean adoption: Cost reduction

Table 7.2-**ANOVA**

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.649	13	1.281	1.253	.272[a]
	Residual	51.101	50	1.022		
	Total	67.750	63			

a. Predictors: (Constant), Self-directed work teams, Pull system/Kanban, Quality circles, Total quality control, Bottle-neck removal, LEAN PRACTICES: Time based competition, Cycle time reduction, Set up time reduction, Planning and scheduling, Focused factory, Continuous improvement, Cellular manufacturing, Preventive maintenance

b. Dependent Variable: Scale rating for Lean adoption: Cost reduction

Cost Reduction (Agile practices)

Table 7.3-**Descriptive Statistics**

	Mean	Std. Deviation	N
Scale rating for Agile adoption; Minimise cost	1.38	.874	81
AGILE PRACTICES; Research for new product	3.22	1.084	81
Rapid reconfiguration	2.20	.967	81
Virtual organisation	3.37	1.066	81
Strategic postponement	2.53	1.013	81
Demand flexibility	1.89	.822	81
Large/small batches	1.83	.905	81
Strategic outsourcing	1.77	.746	81
Innovation culture	1.88	.927	81
Internal communication	3.04	1.229	81
Supplier partnership	1.74	.833	81
Storage facilities	1.77	.810	81
Speed in NPD	1.96	.941	81
Quick decision	2.59	1.081	81
Information capture	2.77	1.287	81

Table 7.4-**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.381[a]	.145	-.036	.890

a. Predictors: (Constant), Information capture, Demand flexibility, Quick decision, Supplier partnership, Rapid reconfiguration, AGILE PRACTICES; Research for new product, Innovation culture, Strategic postponement, Virtual organisation, Speed in NPD, Storage facilities, Strategic outsourcing, Internal communication, Large/small batches

b. Dependent Variable: Scale rating for Agile adoption: Cost reduction

Table 7.5-**ANOVA**

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	8.888	14	.635	.802	.664
	Residual	52.248	66	.792		
	Total	61.136	80			

a. Predictors: (Constant), Information capture, Demand flexibility, Quick decision, Supplier partnership, Rapid reconfiguration, AGILE PRACTICES; Research for new product, Innovation culture, Strategic postponement, Virtual organisation, Speed in NPD, Storage facilities, Strategic outsourcing, Internal communication, Large/small batches

b. Dependent Variable: Scale rating for Agile adoption: Cost reduction.

Cost Reduction (Green practices)

Table 7.6-**Descriptive Statistics**

	Mean	Std. Deviation	N
Scale rating for Green adoption; Minimise cost	3.48	1.082	86
GREEN PRACTICES; Site selection	2.19	1.306	86
Large doors/windows	2.49	1.103	86
Temperature control	3.47	.916	86
Non hazardous materials	2.66	.989	86
Supplier survey	2.03	.818	86
Outsourcing to 3PLs	2.12	.873	86
Durable products	1.95	.781	86
Smaller packaging	2.12	.926	86
Use of less material	2.90	1.188	86
Waste processing	1.85	.833	86
Recyclable materials	2.05	.932	86
Recycling programs	2.01	.964	86
Use of PLC analysis	2.59	1.022	86
Environmental lab	2.77	1.205	86

Table 7.7-**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.377[a]	.142	-.027	1.096

a. Predictors: (Constant), Environmental lab, GREEN PRACTICES; Site selection, Use of PLC analysis, Outsourcing to 3PLs, Smaller packaging, Durable products, Use of less material, Supplier survey, Recycling programs, Non-hazardous materials, Large doors/windows, Waste processing, Recyclable materials, Temperature control

b. Dependent Variable: Scale rating for Green adoption: Cost reduction

Table 7.8-**ANOVA**

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	14.115	14	1.008	.839	.626[a]
	Residual	85.339	71	1.202		
	Total	99.453	85			

a. Predictors: (Constant), Environmental lab, GREEN PRACTICES; Site selection, Use of PLC analysis, Outsourcing to 3PLs, Smaller packaging, Durable products, Use of less material, Supplier survey, Recycling programs, Non-hazardous materials, Large doors/windows, Waste processing, Recyclable materials, Temperature control

b. Dependent Variable: Scale rating for Green adoption: Cost reduction

Lead time reduction (Lean practices)

Table 8.0-**Descriptive Statistics**

	Mean	Std. Deviation	N
Scale rating for Lean adoption: Lead time reduction	1.38	.804	65
Time based competition	2.89	1.106	65
Cycle time reduction	2.02	1.139	65
Set up time reduction	2.97	1.104	65
Cellular manufacturing	2.00	1.132	65
Bottle-neck removal	2.98	1.152	65
Focused factory	1.78	1.038	65
Planning and scheduling	2.66	1.241	65
Total quality control	1.95	1.138	65
Quality circles	1.91	.897	65
Continuous improvement	3.03	1.075	65
Pull system/Kanban	3.65	.759	65
Preventive maintenance	2.91	.996	65
Self-directed work teams	1.94	.916	65

Table 8.1-**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.332[a]	.110	-.116	.850

a. Predictors: (Constant), Self-directed work teams, Pull system/Kanban, Quality circles, Total quality control, Bottle-neck removal, LEAN PRACTICES>Life Cycle Stage; Time based competition, Cycle time reduction, Set up time reduction, Planning and scheduling, Focused factory, Continuous improvement, Cellular manufacturing, Preventive maintenance

b. Dependent Variable: Scale rating for Lean adoption: Lead time reduction

Table 8.2-**ANOVA**

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	4.566	13	.351	.486	.922[a]
	Residual	36.819	51	.722		
	Total	41.385	64			

a. Predictors: (Constant), Self-directed work teams, Pull system/Kanban, Quality circles, Total quality control, Bottle-neck removal, LEAN PRACTICES>Life Cycle Stage; Time based competition, Cycle time reduction, Set up time reduction, Planning and scheduling, Focused factory, Continuous improvement, Cellular manufacturing, Preventive maintenance

b. Dependent Variable: Scale rating for Lean adoption: Lead time reduction

Lead time Reduction (Agile Practices)

Table 8.3-**Descriptive Statistics**

	Mean	Std. Deviation	N
Scale rating for Agile adoption; Improve operations	3.42	1.156	80
AGILE PRACTICES; Research for new product	3.22	1.091	80
Rapid reconfiguration	2.20	.973	80
Virtual organisation	3.39	1.061	80
Strategic postponement	2.51	1.006	80
Demand flexibility	1.90	.821	80
Large/small batches	1.84	.906	80
Strategic outsourcing	1.76	.750	80
Innovation culture	1.89	.928	80
Internal communication	3.06	1.215	80
Supplier partnership	1.75	.834	80
Storage facilities	1.78	.811	80
Speed in NPD	1.98	.941	80
Quick decision	2.60	1.086	80
Information capture	2.79	1.280	80

Table 8.4-**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.502[a]	.252	.091	1.102

a. Predictors: (Constant), Information capture, Demand flexibility, Supplier partnership, Quick decision, Rapid reconfiguration, AGILE PRACTICES; Research for new product, Innovation culture, Strategic postponement, Virtual organisation, Speed in NPD, Storage facilities, Internal communication, Large/small batches, Strategic outsourcing

b. Dependent Variable: Scale rating for Agile adoption: Lead time reduction

Table 8.5-**ANOVA**

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	26.588	14	1.899	1.563	.114[a]
	Residual	78.962	65	1.215		
	Total	105.550	79			

a. Predictors: (Constant), Information capture, Demand flexibility, Supplier partnership, Quick decision, Rapid reconfiguration, AGILE PRACTICES; Research for new product, Innovation culture, Strategic postponement, Virtual organisation, Speed in NPD, Storage facilities, Internal communication, Large/small batches, Strategic outsourcing

b. Dependent Variable: Scale rating for Agile adoption: Lead time reduction

APPENDIX TWELVE

WEIGHTS FOR PRACTICES

Introduction stage

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
LEAN				
Time based competition	1.12	3.01	1.65	1.93
Cycle time reduction	1.16	2.01	3.20	2.12
Set up time reduction	2.18	3.12	3.23	2.84
Cellular manufacturing	3.10	2.19	1.68	2.32
Bottle-neck removal	2.84	2.40	2.94	2.72
Focused factory	2.52	1.87	1.41	1.93
Planning and scheduling	2.62	2.37	1.95	2.31
Total quality control	2.77	3.78	3.36	3.30
Quality circles	1.91	3.33	1.89	2.38
Continuous improvement	2.60	1.11	4.27	2.66
Pull system/Kanban	2.30	4.65	4.32	3.76
Preventive maintenance	2.28	2.22	3.92	2.81
Self-directed work teams	2.77	3.55	3.31	3.21
AGILE				
Research for new product	3.71	1.88	1.72	2.44
Rapid reconfiguration	2.40	1.81	1.64	1.95
Virtual organisation	3.26	2.01	4.79	3.35
Strategic postponement	1.13	2.48	2.82	2.14
Demand flexibility	4.01	3.03	3.19	3.41
Large/small batches	2.13	2.07	1.17	1.79
Strategic outsourcing	2.79	2.35	1.29	2.14
Innovation culture	3.70	2.80	1.51	2.67
Internal communication	2.75	2.41	1.28	2.15
Supplier partnership	1.95	2.59	1.64	2.06
Storage facilities	2.04	3.55	1.47	2.35
Speed in NPD	1.83	2.31	1.17	1.77
Quick decision	2.02	2.32	2.76	2.37
Information capture	3.06	2.31	0.91	2.10
GREEN				
Site selection	4.06	3.25	1.78	3.03
Large doors/windows	1.34	2.34	1.21	1.63

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
Temperature control	1.09	1.53	2.33	1.65
Non hazardous materials	1.00	1.13	1.04	1.06
Supplier survey	1.00	1.47	1.04	1.17
Outsourcing to 3PLs	4.19	1.50	3.38	3.02
Durable products	2.66	2.28	3.38	2.77
Smaller packaging	1.31	1.03	2.52	1.62
Use of less material	1.94	1.84	1.08	1.62
Waste processing	1.03	1.47	1.18	1.23
Recyclable materials	1.09	3.31	1.50	1.97
Recycling programs	4.25	1.46	1.51	2.41
Use of PLC analysis	1.00	2.32	2.33	1.88
Environmental lab	3.19	1.74	1.02	1.98

Growth Stage

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
LEAN				
Time based competition	1.50	0.44	2.66	1.53
Cycle time reduction	2.85	0.12	2.09	1.69
Set up time reduction	3.05	2.42	2.71	2.73
Cellular manufacturing	0.62	1.44	3.62	1.89
Bottle-neck removal	1.97	0.42	1.11	1.17
Focused factory	0.99	0.74	0.42	0.72
Planning and scheduling	2.46	0.34	2.41	1.74
Total quality control	4.41	0.42	1.46	2.10
Quality circles	0.42	1.18	2.46	1.35
Continuous improvement	2.42	0.42	1.35	1.40
Pull system/Kanban	0.42	1.98	2.66	1.69
Preventive maintenance	3.65	0.42	2.06	2.04
Self-directed work teams	0.44	2.10	4.31	2.28
AGILE				
Research for new product	4.78	2.22	1.55	2.85
Rapid reconfiguration	2.99	1.44	2.05	2.16
Virtual organisation	1.20	1.66	3.47	2.11
Strategic postponement	1.51	2.22	2.72	2.15
Demand flexibility	1.02	1.68	1.51	1.40

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
Large/small batches	1.02	2.94	3.12	2.36
Strategic outsourcing	1.23	1.41	1.10	1.25
Innovation culture	4.26	1.95	1.19	2.47
Internal communication	2.60	3.36	2.25	2.74
Supplier partnership	1.29	1.89	2.02	1.73
Storage facilities	1.19	1.90	2.98	2.02
Speed in NPD	1.02	1.88	1.29	1.40
Quick decision	1.15	2.03	1.44	1.54
Information capture	4.39	3.79	2.54	3.57
GREEN				
Site selection	3.36	2.94	2.83	3.04
Large doors/windows	1.24	1.41	2.13	1.59
Temperature control	2.92	1.95	2.79	2.55
Non hazardous materials	3.21	3.36	3.70	3.42
Supplier survey	2.43	1.89	2.75	2.36
Outsourcing to 3PLs	1.77	1.57	1.95	1.76
Durable products	2.28	4.32	2.04	2.88
Smaller packaging	2.46	3.92	1.83	2.74
Use of less material	1.24	3.27	2.02	2.18
Waste processing	1.71	3.67	3.06	2.81
Recyclable materials	2.63	3.71	1.88	2.74
Recycling programs	2.85	4.54	1.81	3.07
Use of PLC analysis	3.21	2.26	2.01	2.49
Environmental lab	1.25	1.13	2.48	1.62

Decline stage

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
LEAN				
Time based competition	2.91	0.43	1.31	1.55
Cycle time reduction	1.19	2.03	2.00	1.74
Set up time reduction	1.50	4.02	2.23	2.58
Cellular manufacturing	2.45	2.66	3.00	2.70
Bottle-neck removal	1.71	1.38	2.12	1.74
Focused factory	1.17	2.24	4.05	2.49
Planning and scheduling	1.29	2.01	3.31	2.20
Total quality control	1.51	1.10	4.20	2.27
Quality circles	1.28	1.43	1.18	1.30
Continuous improvement	1.64	2.59	1.32	1.85
Pull system/Kanban	1.47	1.17	1.76	1.47
Preventive maintenance	1.17	3.56	1.38	2.04
Self-directed work teams	2.50	2.51	3.16	2.72
AGILE				

Practices	Cost reduction	Lead time reduction	Waste reduction	Combined
Research for new product	1.20	1.41	0.91	1.17
Rapid reconfiguration	2.03	1.47	1.19	1.56
Virtual organisation	1.50	1.10	1.50	1.37
Strategic postponement	1.43	1.19	2.45	1.69
Demand flexibility	1.31	4.84	1.71	2.62
Large/small batches	1.18	1.96	1.17	1.44
Strategic outsourcing	4.27	1.45	1.29	2.34
Innovation culture	1.97	1.95	1.51	1.81
Internal communication	3.67	1.63	1.28	2.19
Supplier partnership	3.60	3.27	1.64	2.84
Storage facilities	1.51	0.91	1.47	1.30
Speed in NPD	1.03	1.20	1.17	1.13
Quick decision	1.30	0.99	2.76	1.68
Information capture	1.20	1.41	0.91	1.17
GREEN				
Site selection	3.20	1.48	1.78	2.15
Large doors/windows	2.74	1.32	1.21	1.76
Temperature control	1.65	1.02	2.33	1.67
Non hazardous materials	2.39	1.57	1.04	1.67
Supplier survey	2.24	1.52	1.04	1.60
Outsourcing to 3PLs	1.50	1.49	3.38	2.12
Durable products	1.11	1.92	3.38	2.14
Smaller packaging	1.02	1.87	2.52	1.80
Use of less material	1.25	1.66	1.08	1.33
Waste processing	1.24	1.36	1.18	1.26
Recyclable materials	1.29	1.79	1.50	1.53
Recycling programs	1.21	0.30	1.51	1.01
Use of PLC analysis	1.29	1.34	2.33	1.65
Environmental lab	1.20	1.23	1.02	1.15